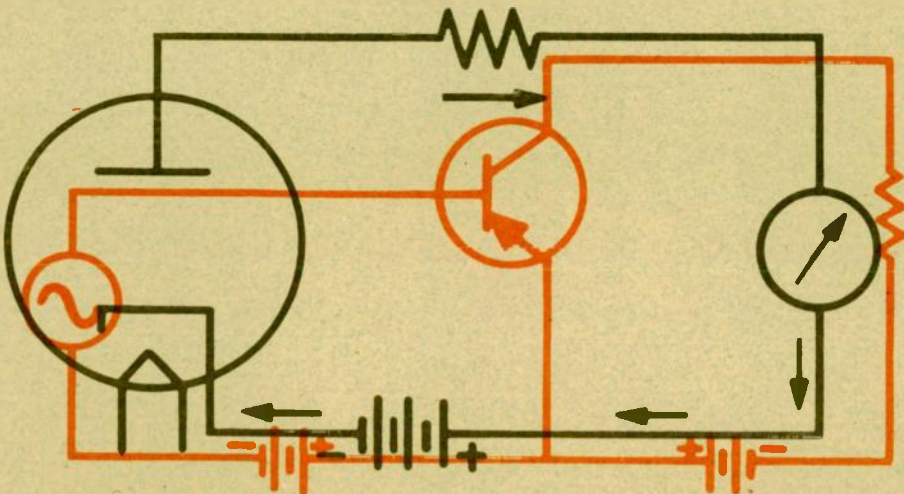
LESSON NO. 25

AF AND RF INDUCTORS



RADIO and TELEVISION SERVICE and REPAIR

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52-025

AF AND RF INDUCTORS

INTRODUCTION

In addition to tubes and transistors, all electronic devices contain combinations of three components. These components are resistors, capacitors, and inductors. This lesson will cover the construction of inductors and the action of inductors in circuits.

Inductors used in high frequency circuits are called radio frequency (RF) inductors, RF coils, or RF chokes. Inductors used in low frequency circuits are called audio frequency (AF) inductors, AF coils, or AF chokes. When an inductor has a relatively small amount of AC current passing through it, it is called a choke. This choke, however, may have a large AC voltage placed across it.

REVIEW

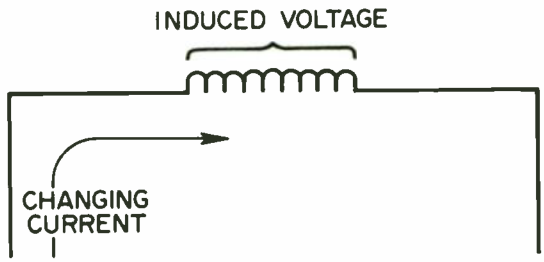
Inductance

An inductor has the property of inductance. The unit of measure of inductance is the *henry*. At times, inductors of less than one henry are used in electronic circuits. A 15 mh coil has an inductance of 15 millihenrys (0.015 henry). A 60 μh coil has an inductance of 60 microhenry (0.00006 henry).

A magnetic field is present around a conductor whenever current flows through the conductor. When the current changes, the magnetic field also changes. This change in the magnetic field causes a voltage to be induced in the conductor. An inductor has a large inductance if an amount of changing current induces a large voltage. If a current change of 2 amps per second induces 10 volts, the inductance equals 5 henrys (divide *induced voltage by the current change*). An inductor having 30 volts induced with a current change of 2 amps per second has an inductance of 15 henrys (Fig. 1). If only 0.2 of a volt is induced by a current change of 2 amps per second, the inductance will equal 0.1 henry (Fig. 1).

Reactance

Reactance is different from inductance. The *reactance* of a coil is measured in *ohms*. It is used in sinewave AC current and voltage calculations. Figure 2 gives the formula for inductive reactance. When f is 10 hertz and L is 5 henrys, the inductive reactance equals 314 ohms. When f is 60 hertz and L is 5 henrys, the reactance equals 1884 ohms.



CURRENT CHANGE	INDUCED VOLTAGE	INDUCTANCE
2 AMPS/SEC.	10 VOLTS	5 HENRYS
2 AMPS/SEC.	30 VOLTS	15 HENRYS
2 AMPS/SEC.	6 VOLTS	3 HENRYS
2 AMPS/SEC.	0.2 VOLTS	0.1 HENRY OR 100 MILLIHENRYS

Figure 1 - Basic electrical behavior of an inductor.

AC Action

For sinewave AC, the voltage equals the current times the inductive reactance (Fig. 3). When the AC current is 6 amps and the reactance is 20 ohms, the AC voltage is 120 volts. When the AC current is 0.5 amps and the reactance is 2,000 ohms, the AC voltage equals 1,000 volts.

RF CHOKE COILS

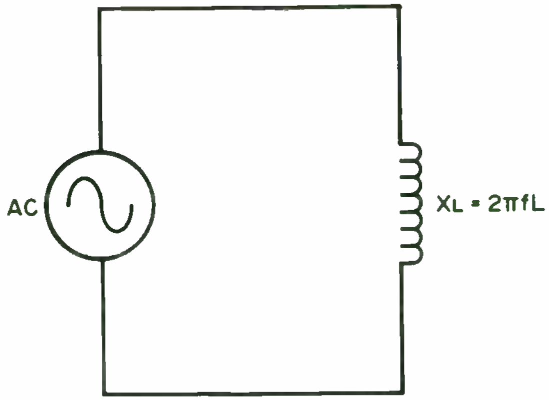
Frequencies above 20,000 hertz are radio frequencies. This section presents several applications of RF coils. A knowledge of reactance is helpful in understanding the behavior of AC circuits.

Resistance, Capacity, and Inductance in AC and DC Circuits

Most electronic circuits are series, parallel, or a combination of series and parallel connections. In a parallel circuit, the voltage is the same across *each* branch of the parallel circuit. If one of the parallel branches has minimum AC current, a circuit component having a large resistance should be used. This large resistance can be obtained by using a resistor, a capacitor, or an inductor. The DC behavior of these three components, however, is not the same. A resistor has the same value in ohms for both DC and AC. An inductor has less resistance for DC than for AC. Therefore, the action for AC, as well as for DC, must be considered when a part is selected.

Pulsating DC Current

Pulsating DC may be considered to be AC plus DC (Fig. 4). The pure DC is 7 amps and the pure AC is 2 amps peak-to-peak. Now, suppose that one



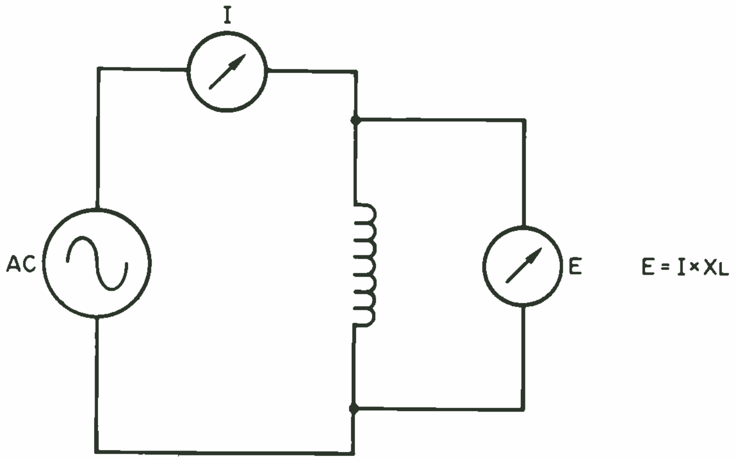
FREQUENCY	L	INDUCTIVE REACTANCE
10 HERTZ	5 HENRYS	2 x π x f x L= 2 x 3.14 x 10 x 5= 314 OHMS
10 HERTZ	10 HENRYS	2 x π x f x L= 2 x 3.14 x 10 x 10= 628 OHMS
60 HERTZ	5 HENRYS	2 x π x f x L= 2 x 3.14 x 60 x 5= 1884 OHMS

Figure 2 - Inductive reactance.

of the branches (Fig. 4) requires only the AC portion of the pulsating DC. The AC load block (Fig. 5) represents that branch. Capacitor C, called a coupling capacitor, does not permit any DC current in this branch. Its reactance compared to the impedance of the AC load, however, is small. AC current is not needed in the first branch. Therefore, the inductor, L, is used to keep the AC current out of this branch. Because the resistance of the coil is low for DC, DC readily flows in this part of the circuit. DC, with very little AC, is present in the first branch; AC, but no DC, is present in the branch containing the AC load.

Parallel Circuit Example (RFC)

With a load impedance of 50 ohms (Fig. 6), the coupling capacitor has a reactance of 5 ohms. Capacitor C, called a blocking capacitor, blocks the DC from the AC load. When the capacitor's reactance is lower than the impedance of the AC load, there is relatively small AC voltage across it. The AC power (volts and amps) should be concentrated only in the AC load. This makes the circuit more



AC CURRENT	INDUCTIVE REACTANCE	AC VOLTAGE
6 AMPS	20 OHMS	120 VOLTS
6 AMPS	100 OHMS	600 VOLTS
0.5 AMPS	2,000 OHMS	1,000 VOLTS

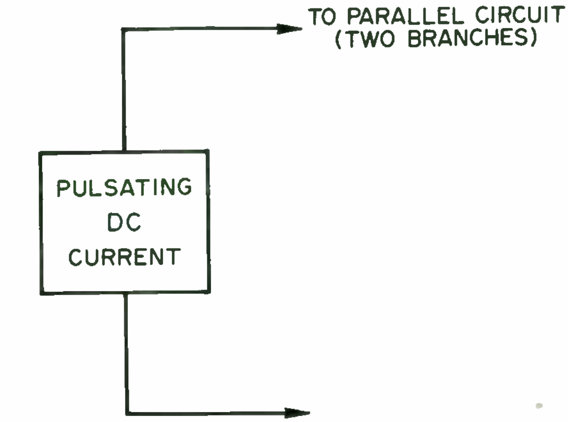
Figure 3 - AC voltage and current in an inductor.

efficient. The reactance of the RFC is much higher than the impedance of the other branch. Since the reactance of the RFC in this example is 20 times the impedance of the AC load, one-twentieth of the total AC current flows through the RFC. The pure DC (Fig. 6) is 80 milliamperes. The pure AC is 40 milliamperes, peak-to-peak. The RFC has 2 milliamperes peak-to-peak of AC current flowing through it. In addition, the entire 80 milliamperes of DC current flows through the RFC. The other branch has 38 milliamperes peak-to-peak of AC current and *no* DC current.

The battery is the source of the DC current. The block at the left of Figure 6 causes the DC current to pulsate. To keep AC current out of the branch containing the battery, the RFC passes the DC and opposes the AC.

Imagine yourself at point A of Figure 6. The AC current present at this point is split into two parts by either the impedance or the reactances of the two branches. The RFC has a higher reactance than the impedance of the AC load. Most of the AC current passes into the branch containing the AC load. Thus, the RFC acts as an open circuit for the AC.

If the AC load has an impedance of 2,000 ohms, an RFC with a reactance greater than 2,000 should be selected.



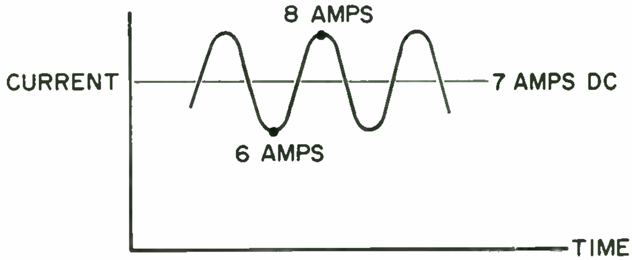
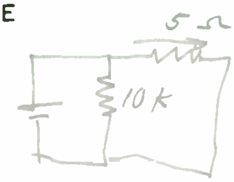


Figure 4 - A source of pulsating DC current.



$X_L = 2\pi f L$

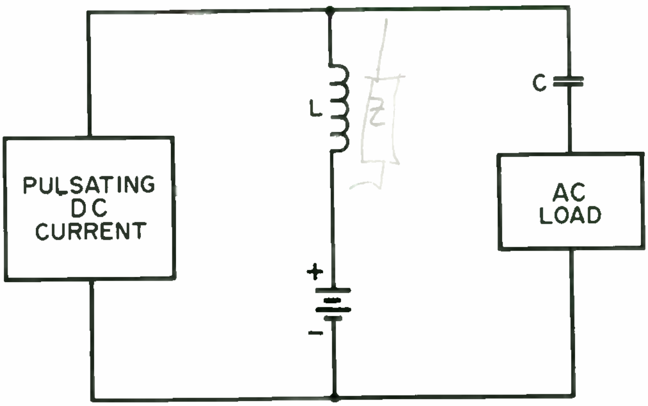


Figure 5 - The use of L to minimize AC current in a branch of a parallel circuit.

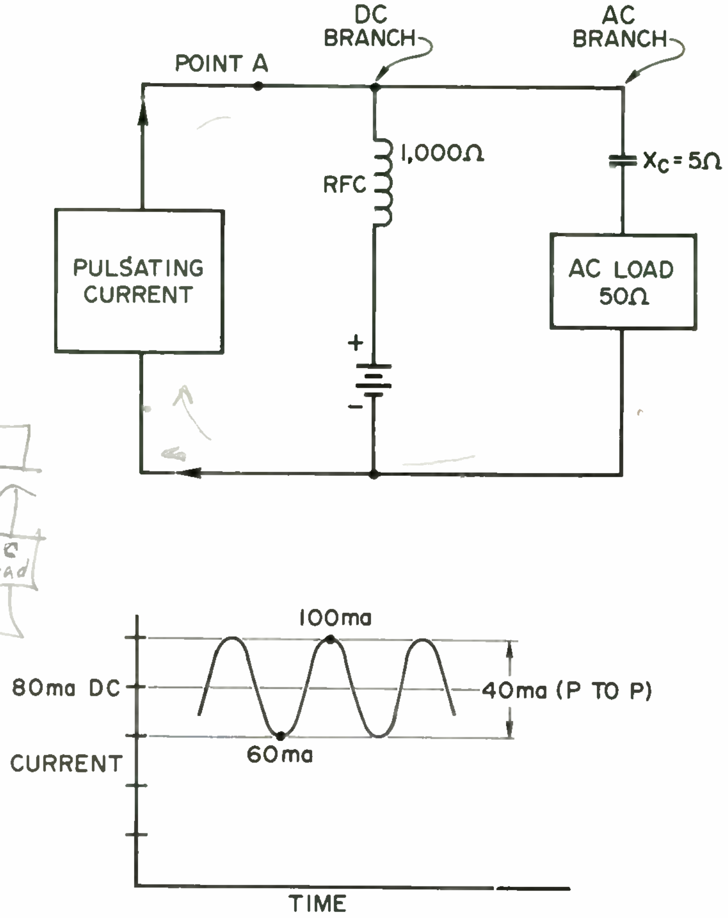


Figure 6 - Example of the use of a radio frequency choke.

A reactance of 20,000, 25,000 or 50,000 ohms would operate satisfactorily.

Parallel Tube Filament Operation

Another example of RF chokes would be their use in the filament circuits of high frequency electronic equipment such as FM and TV receivers.

Figure 7 illustrates two tubes with parallel filaments. If there were 10 or 20 tubes in a receiver, most of the tube filaments would be connected in parallel.

In the interconnections between tube signal paths, a grid usually receives a voltage from the plate circuit of the preceding tube. This should be the *only* source of AC signal voltage. When the tube filaments are connected in parallel, however, there may be some AC current leakage. In this case, the cause of this leakage is the capacity that exists between the filament and cathode of the tube. An additional interconnection, the RFC

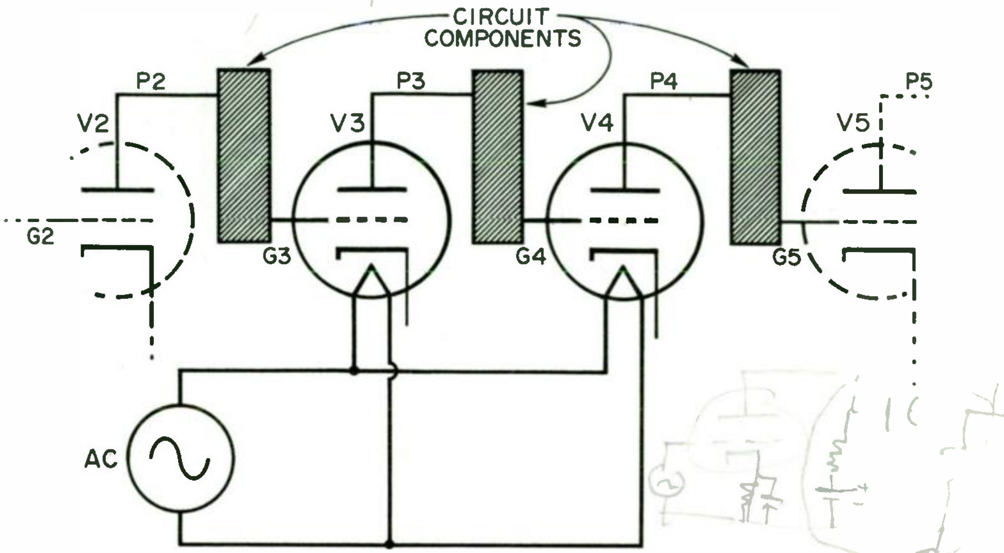


Figure 7 - A single source of AC to heat many filaments.

prevents the undesirable leakage of AC currents.

A capacitor is two conductors separated by a dielectric. There is unintentional capacity due to the construction of the tubes. Both the cathode and the filament are metallic. They are separated by insulating material.

In Figure 7, the plate of V2 is connected to the grid of V3 through circuit components. The plate of V3 is connected to the grid of V4 in the same way. The plate of V4 is also connected to the grid of V5 with circuit components. These connections produce the desired tube action. Any additional influences on tube action are undesirable because they cause improper operation of the electronic equipment.

The capacity between filament and cathode is usually quite small. Its effect can be ignored when the tube circuits are operating at low frequencies. When the tube circuits are operating at higher frequencies, however, the capacitive reactance of the cathode-to-filament decreases and appreciable current flows from the grid circuit to the filament. When this condition exists, the voltage at G4 influences the voltage at G3, and, likewise, the voltage at G3 influences the voltage at G4. Under this condition, the tubes act as if they were connected in parallel because of the common connection at the source of filament voltage.

RF chokes can be used as additional reactances in series with the cathode-to-filament capacity of the tube. Figure 8 shows the new circuit with the addition of the inductors. These chokes eliminate the coupling between the grid circuits.

When filament chokes are used, the values are smaller than 1 henry. At times, the filament lead is used to

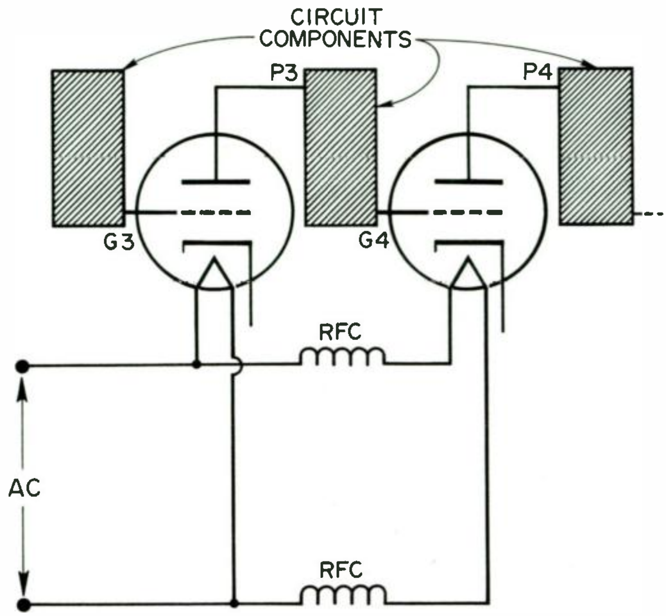


Figure 8 - RF chokes minimize coupling between tube circuits via a common filament source.

form the inductor. In this case, approximately three to six turns are wound from the filament wiring itself. The diameter is approximately ½ inch or less. The inductance could be 5 or 10 microhenrys.

AF CHOKE COILS

Frequencies below 20,000 hertz are audio frequencies. Inductors for audio use are larger in value than 1 henry. They are also larger and much heavier than inductors selected for use in RF circuits. The increase in weight is due to the iron core and to the large amount of wire used. Figure 9 shows the most common types of AF inductors. The general appearance is similar to AF transformers. Transformers, however, have at least 4 leads. Inductors have only 2 leads.

Pulsating DC Voltage

A source of pulsating DC voltage exists in Figure 10A. The voltage is varying continuously. For certain applications and uses, the variations are undesirable. Suggested circuitry additions to solve the problem are shown in Figure 10B.

The pulsations at the source of the voltage vary from 280 to 320 volts (Fig. 11). This is equivalent to 300 volts pure DC and 40 volts peak-to-peak AC. The reactance of L is 1,000 ohms and the reactance of C is 100 ohms. Most of the AC voltage is across the inductor. One-ninth of the 40 volt peak-to-peak AC voltage appears across the capacitor. Thus, the AC voltage at the capacitor is 4.4 volts peak-to-peak. The pulsating voltage at

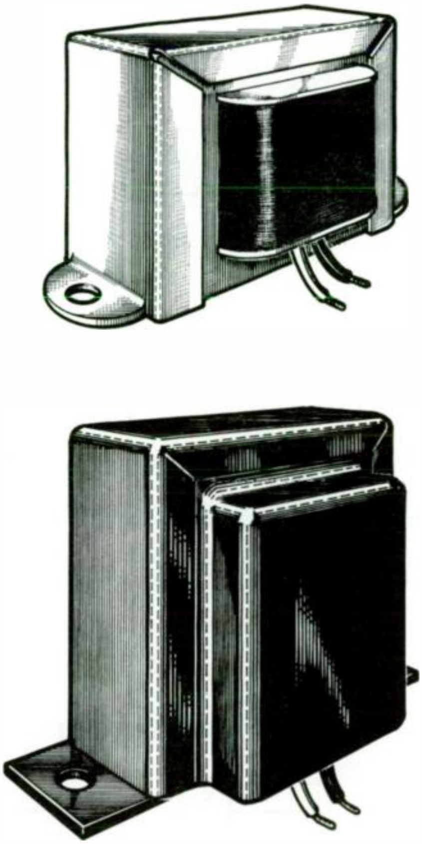


Figure 9 - Typical AF inductors.

terminals A and B varies from 297.8 to 302.2 volts (Fig. 12).

If the capacitor had a reactance of 10 ohms, one-hundredth of the pure AC, or 0.4 volts, would appear at the output terminals A and B, assuming that the original inductor is still in the circuit. The pulsating voltage at terminals A and B would vary from 299.8 to 300.2 volts (Fig. 12).

Reduction of Voltage Pulsations — One Section

There are several additional examples that can be verified (Fig. 13). In the first example, the AC at the input is 100 volts peak-to-peak. From the values of the reactances, we can determine that one-nineteenth of the input AC is 5.26 volts, and is calculated to appear at the output terminals. (The capacitor reactance is one-nineteenth of the total reactance.) The DC output voltage is varying from 397.37 (400 volts minus 2.63) to 402.63 volts.

In the next example (Fig. 13) the input is unchanged. It has 100 volts peak-to-peak of AC. From the relative values of the reactances, the output AC can be calculated to be one two-hundredth of the input AC. Thus, the AC at the output terminals is 0.5

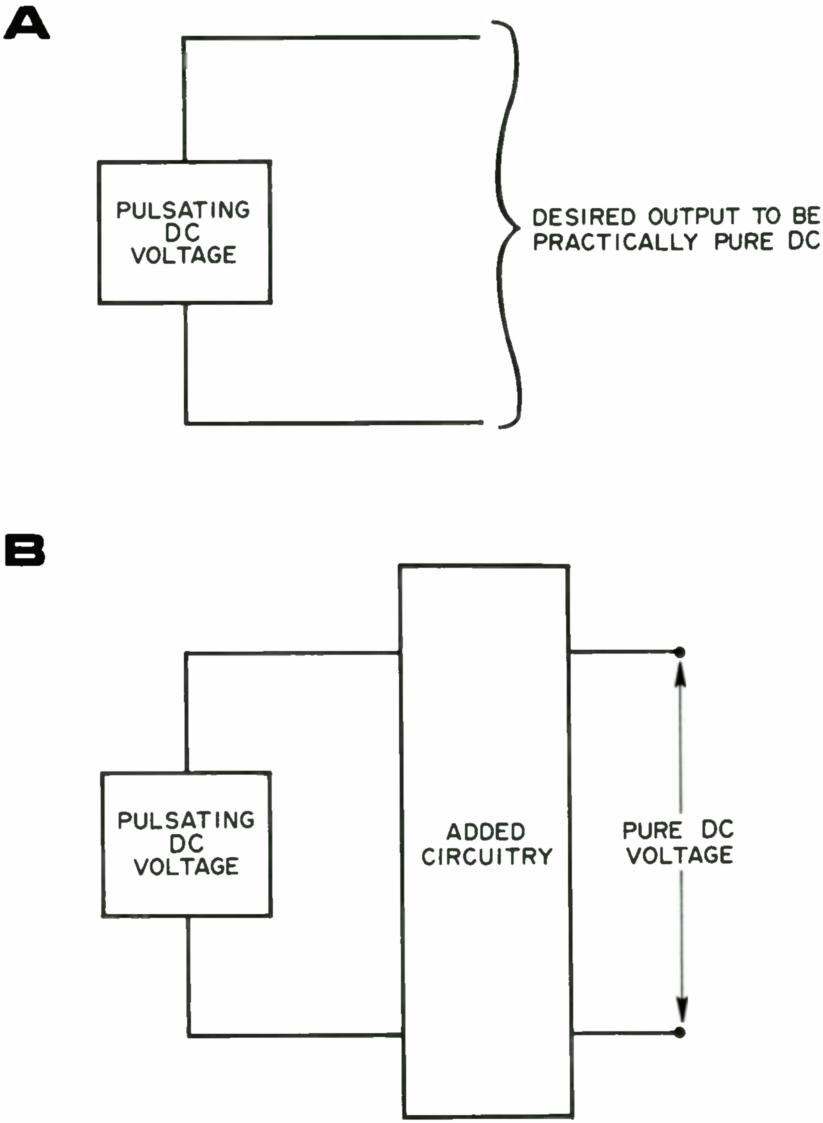
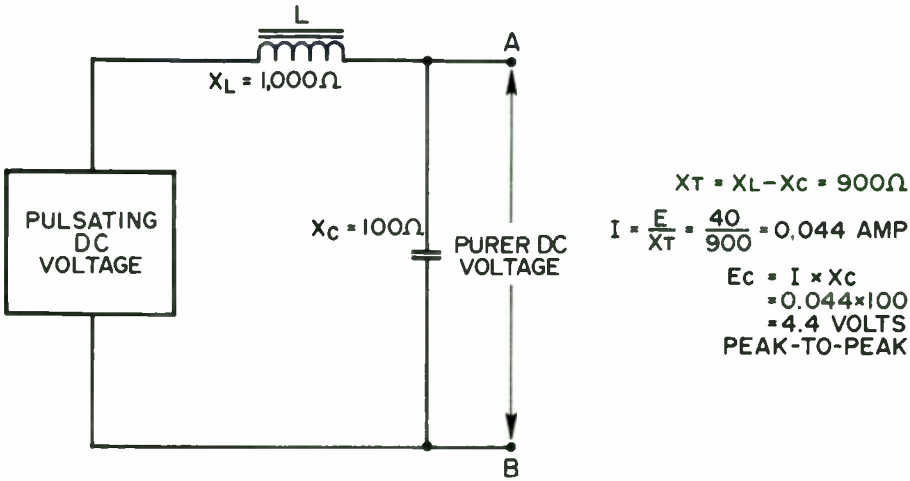


Figure 10 - Modifying a circuit to obtain a pure DC voltage.



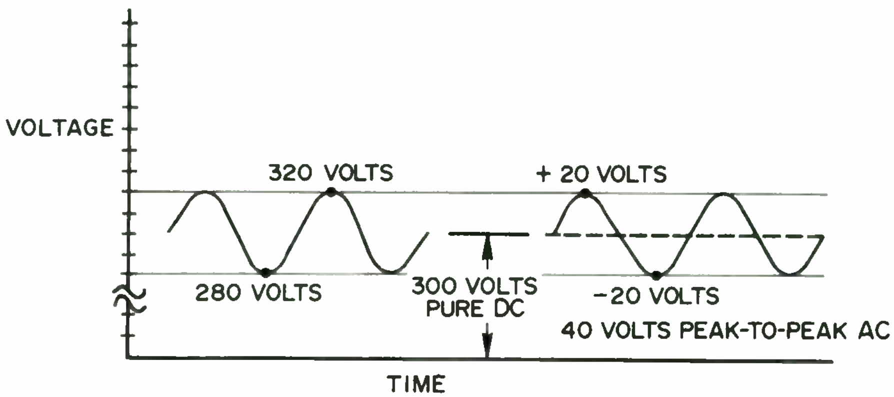


Figure 11 - The use of an inductor to minimize voltage pulsations.

volts peak-to-peak and the DC output voltage varies from 399.75 to 400.25 volts.

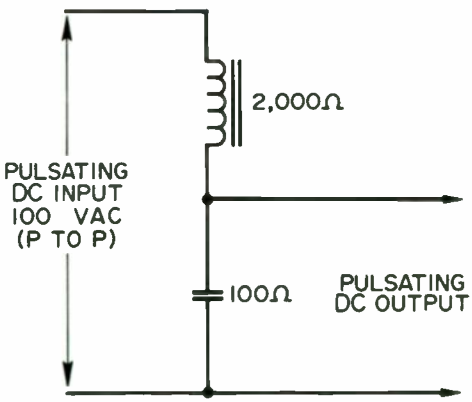
Reduction of Voltage Pulsations — Two Section

Often, instead of using one coil and one capacitor to obtain the desired reduction of voltage pulsations, two or three coils and capacitors are used. Figure 14 shows how two coils and two capacitors are connected. The pulsations at points A and B are one-ninth of the pulsations at the source of the DC voltage. Similarly, the pulsations at points C and D are one-ninth the pulsations at points A and B. Thus, an overall reduction of one eighty-first is achieved ($\frac{1}{9} \times \frac{1}{9} = \frac{1}{81}$). If the source has a variation of 400 to 600 volts of DC, this variation corresponds to 500 volts pure DC and 200 volts of AC peak-to-peak. The actual voltage would vary from 488.9 (500 minus 11.1) to 511.1 volts at points A and B. At points C and D, the pure

DC INPUT	X_L	X_C	DC OUTPUT
VARYING FROM 280V TO 320V	1000Ω	100Ω	VARYING FROM 297.8V TO 302.2V
VARYING FROM 280V TO 320V	1000Ω	10Ω	VARYING FROM 299.8V TO 300.2V

Figure 12 - Reduction of voltage pulsations.

DC INPUT	X_L	X_C	DC OUTPUT
VARYING FROM 350V TO 450V	2000Ω	100Ω	VARYING FROM 397.37V TO 402.63V
VARYING FROM 350V TO 450V	2000Ω	10Ω	VARYING FROM 399.75V TO 400.25V



$X_T = X_L - X_C = 1900\Omega$

$$I = \frac{E}{X_T} = \frac{100 \text{ VOLTS PEAK-TO-PEAK}}{1900}$$

$= 0.0526$ AMPS PEAK-TO-PEAK

$E_C = I \times X_T = 0.0526 \times 100$

$= 5.26$ VOLTS PEAK-TO-PEAK

(OR SIMPLY DIVIDE 100 VOLTS PEAK-TO-PEAK BY 19, OR

$\frac{100}{19} = 5.26$ VOLTS PEAK-TO-PEAK)

Figure 13 - Examples of reduction of voltage pulsations.

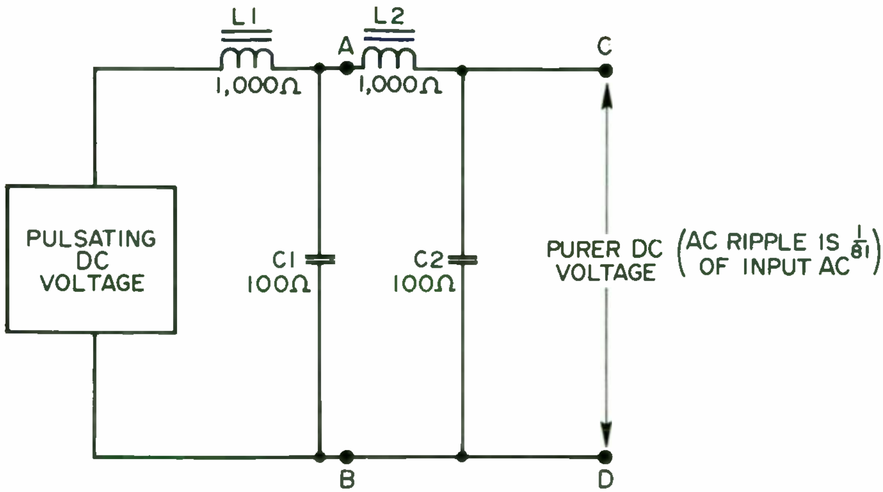


Figure 14 - Two-section reduction of voltage pulsations.

AC is one-ninth of the pure AC at points A and B. This equals 2.4 volts peak-to-peak. The actual voltage varies from 498.8 to 501.2 volts.

Figure 15A is related to Figure 14. The same parts are used, but they are connected differently. Because the same parts are used, the weight and cost is the same for both circuits.

The 2,000 ohm coil (Fig. 15B) is the equivalent of two 1,000 ohm coils in series. With two coils in series, the reactances add directly. The equivalent of two capacitors in parallel, each having a reactance of 100 ohms, is 50 ohms. Note the relative reactances in Figure 15B. 2,000 ohms is 40 times the value of 50 ohms. Therefore, the voltage across the capacitor is one-fortieth of the applied AC voltage. In Figure 14, the overall reduction of voltage variations is one eighty-first. Thus, the circuit in Figure 14 is more effective in reducing variations than the one in Figure 15A.

Reduction of Voltage Pulsations – Three Section

A circuit using three sections to reduce voltage pulsations is shown in Figure 16. The AC voltage at points A and B is one-tenth of the AC voltage at the source. If all coils and condensers are identical, the AC voltage at points C and D equals one-tenth the AC voltage at A and B. This is one-hundredth of the AC at the source. The AC voltage at E and F equals one-tenth the AC at C and D, or one-thousandth of the voltage at the input terminals. If the pure AC at the input terminals is 100 volts, the AC at points A and B equals 10 volts, the AC at points C and D equals 1 volt, and the AC at E and F equals 0.1 volts. One-section and two-section circuits of this type are often used in electronic equipment. Occasionally, three-section circuits like the one discussed above are used.

In studying the action of choke coils, it is apparent that a single

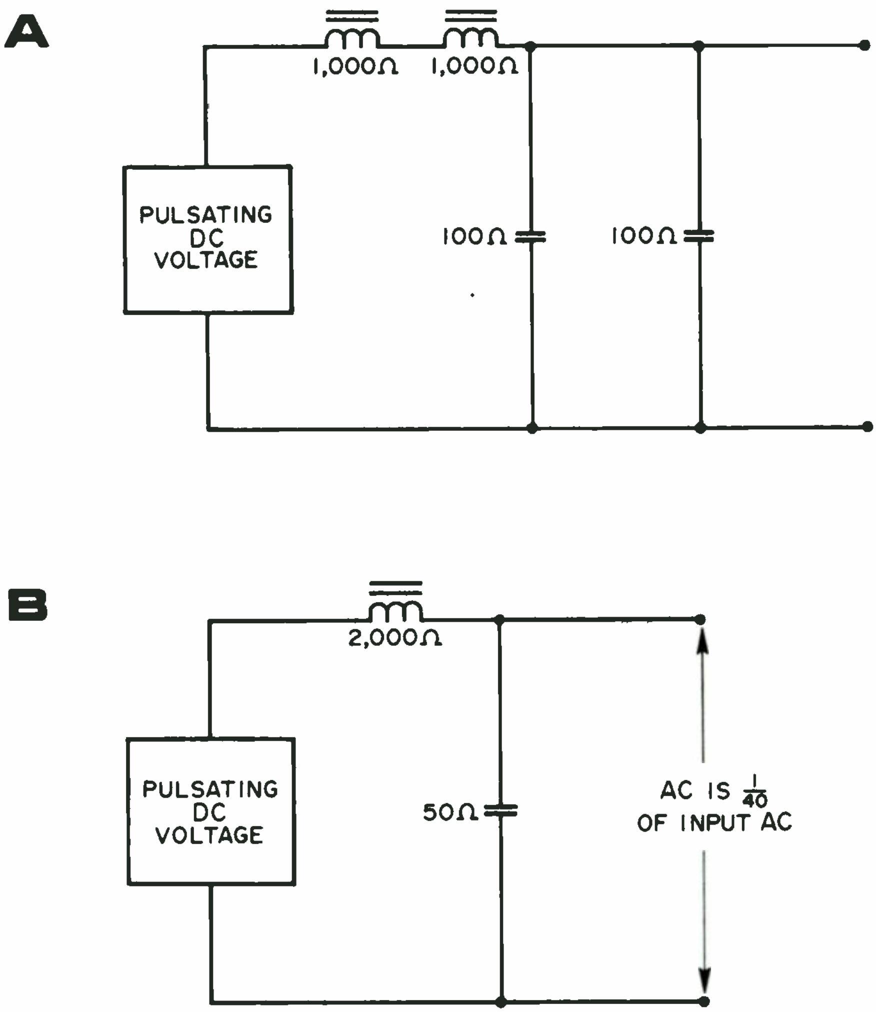


Figure 15 - Reduction of voltage pulsations in a one-section filter.

component is not very effective. Simple combinations of several components, however, permit the electrical circuit action to produce whatever is desired or required.

In most cases, having a general knowledge of basic circuit operation helps in isolating a defective component. If the AC voltage at points A and B (Fig. 11) is much higher than normal, then the relative value of the two reactances must have changed. The inductive reactance is normally higher than the capacitive reactance. Now, conditions have changed to *reduce* the inductive reactance or to increase the capacitive reactance. The inductive reactance decrease might be caused by a shorted inductor. This is checked with an ohmmeter. The capacitive reactance increase might be caused by an open capacitor. This is checked by temporarily connecting another capacitor in the circuit.

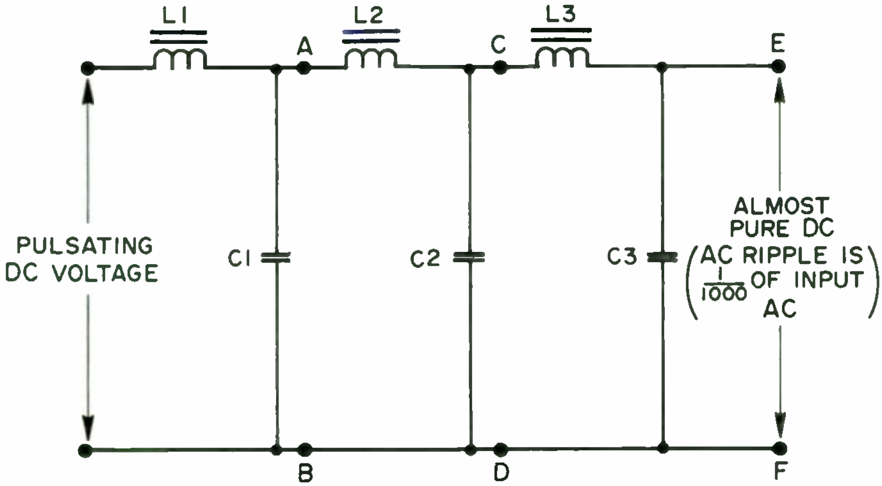


Figure 16 - Three-section reduction of voltage pulsations.

MULTILAYER COILS

There are a great variety of electronic devices. Many companies are engaged in developing and producing these devices. Therefore, it is not surprising that there are many varieties of coils. However, they are *all* coils. Some coils have few turns, while other coils have many hundreds of turns.

Wire Insulation and Wax Saturation

A multilayer inductor has turns that touch. Thus, the wire used to wind this type of coil must be covered with an insulation. Sometimes, a varnish or enamel is used for this insulation. In this case, the wire is coated with the varnish or enamel. Silk or cotton covered wires are common in many coils. After the coil is wound, the entire coil may be saturated with wax or some other insulating material, so that moisture from the atmosphere cannot deteriorate the insulation.

Breakdown of Inductors

Because the windings are tightly packed, defects do occur. Imperfect saturation may permit moisture to penetrate the coil and thereby cause a failure. There may be imperfections in the insulating material covering the wire. A shorted coil occurs when insulation breaks down under high voltage conditions and causes adjacent turns to make electrical contact. An ohmmeter is used to determine if a coil is shorted. The measured resistance of a shorted coil is lower than that of a normal coil.

Temperature of Inductors

Normally, AF inductors are warm or hot. This is due to the power dissipated in the windings. If an abnormally high current exists in an inductor, the temperature of the inductor rises quickly. It might cause the insulation to break down. This is another cause for a shorted inductor. In this case, the original defect would not have been the inductor, but

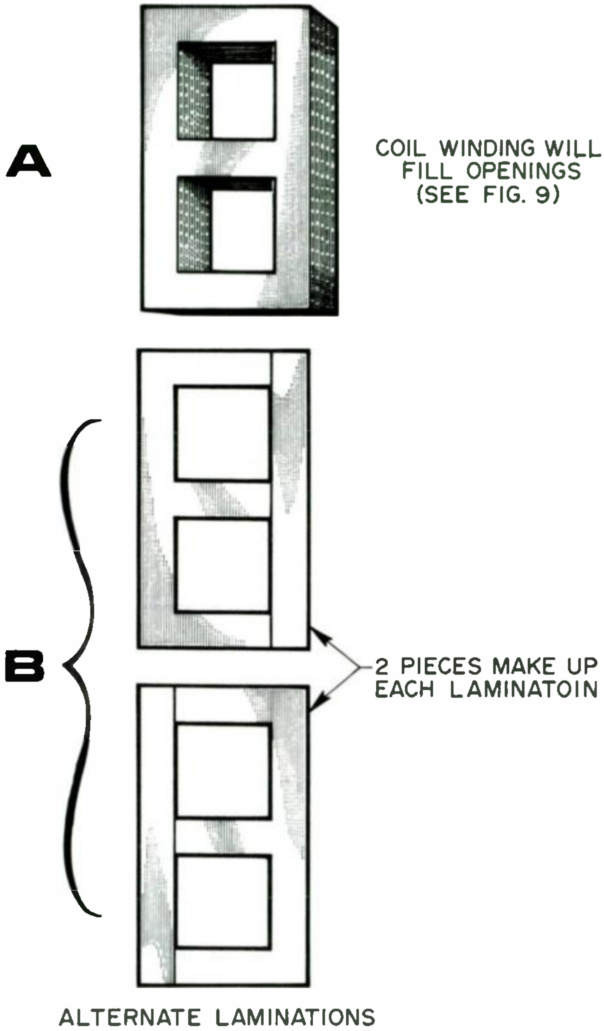


Figure 17 - Laminated core for an AF inductor.

another defective component causing the abnormally high current.

Generally, RF inductors do not overheat. They normally operate at room temperature because they do not use as much wire as AF inductors. They can still break down, however, when an abnormally high AC voltage appears across the coil.

The normal resistance of an inductor is important information. Often this information is placed in resistance charts in the technical literature associated with a particular piece of electronic equipment. It may also be found on the schematic diagram.

SINGLE LAYER COILS

Single layer coils have long lives in electronic equipment. They seldom break down. Even abnormally high voltages rarely cause a breakdown

A

B

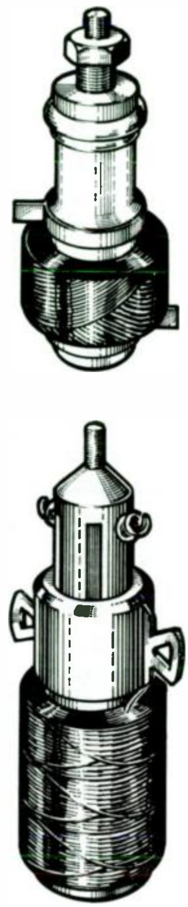


Figure 18 - RF inductors with adjustable cores.

because the voltage between adjacent turns is very low.

The DC resistance values are often less than 1 ohm because so little wire is used in the construction of the coil. If there is spacing between adjacent turns of a single layered coil, bare copper wire may be used.

CORE MATERIALS
Iron and Steel

AF inductors use iron or steel in their construction (Fig. 17). Any material placed in an inductor is referred to as the core. When an iron core is used, less wire is required for a given amount of inductance. The core is built up in layers rather than as a solid piece of iron or steel. These layers are called laminations. The inductors will not heat as much when the core is constructed using laminations. By building up the core in layers with no metallic contact between them, the heating that is due to the eddy currents flowing within the core is minimized.

Magnetic Materials

Sometimes RF coils are manufactured with cores. In this case, a magnetic material such as iron is placed at, or near, the center of the coil. No part of the core extends beyond the central portion of the coil. Figure 18 shows two RF coils with cores. Both of these have adjustable cores. The adjustment screw is at the top and the multilayered coils are at the bottom. The cores are not visible. When iron is used as a core for RF coils, it is in the form of finely powdered particles bonded with a binding substance. These are referred to as *powdered iron* cores or ferrite cores. Brass is seldom used as a core for RF coils. It decreases, rather than increases, the inductance. Sometimes a brass core is temporarily inserted within a coil. The decrease of inductance may give the circuit better operation. Thus, a smaller value of inductance would be used, or the turns of the coil would be separated. The separation of turns is possible and practical in some single layer coils.

Air

When no magnetic material is used as a core, the coil is called an air core coil. Because many RF circuits in radio and television receivers are built with relatively low power losses, most of the RF coils are air core type coils. This allows the circuit to produce the proper result when tuning in one station at a time. If the circuit losses were greater, several stations would be tuned in at the same time. This, of course, is undesirable. In AF coils, the core is divided into laminations to minimize heating losses due to eddy currents. Using powdered iron or ferrite material as a core subdivides the iron more than the laminations do. This process further reduces the eddy current losses. When coil losses are to be held to a minimum, no magnetic material is used as a core.

VARIABLE INDUCTORS

Movable Core

In some electronic circuits, a precise value of inductance is required. Otherwise, improper operation of the radio, TV receivers, or other electronic equipment results. It is not practical to manufacture precise coils as needed for electronic circuits, because a great variety of values would be required. A simple solution is to manufacture adjustable or variable coils. Each coil can then be adjusted to the desired value of inductance. An additional advantage is that the coil can be readjusted to a new and required value if necessary.

Variable AF coils are seldom used in radio or TV receivers. Variable RF coils are widely used.

Figure 18A shows an adjustable inductor. The position of the powdered iron or ferrite core within the coil is varied by turning the top of the coil assembly with an alignment tool. Some alignment tools are essentially miniature socket wrenches. Others have a hexagon (six-sided) insert. Some coils have slots for small or specially made non-metallic screwdrivers. The objective of non-metallic tools is to electrically remove the serviceman's hand from the circuit being adjusted. Sometimes the coil is designed so that the contact between the tool and the core is made within the coil. From the side, these coils appear to be air core coils.

The majority of variable inductors are constructed as described above. They have a powdered iron or ferrite core whose position within the central area of the coil can be varied. This variation is along the axis of the coil only.

Variable Spacing of Turns

In a few cases, single layer air core coils are constructed with rigid wire. It is possible to vary the inductance of these coils by varying the spacing between some or all of the turns. When this is done, an attempt should be made to have a uniform spacing between turns. This manner of varying inductance is accomplished by the use of the hands to either increase or decrease the overall length of the coil. When the turns are farther apart, the inductance decreases. Sometimes, long nose pliers are used to bring the turns closer together. For example, a coil that is 1 inch in length and is made up of 5 turns can be increased in length to about 1.25 or 1.50 inches, or decreased in length to about 0.50 inch. However, such great increases or decreases in length usually will not be necessary.

In most cases, when a coil is to be adjusted in value, a station is not tuned in. Test equipment is used to simulate the radio or TV station. Then, while the equipment under test is operating, an adjustment is made for best operation.

In the case of a coil whose inductance is varied by changing the spacing between turns, follow the procedures listed here. For safety reasons, especially when the coil is connected to a high voltage, do not touch the coil while the equipment is operating. Obtain a special plastic material rod that has a small amount of powdered iron or ferrite at one end and a small amount of brass at the other end. With the equipment operating, determine whether more or less inductance is required by inserting one end of the special tool into the coil as a core and note the effect on receiver performance. If the brass end improves performance, reduce the inductance. Turn off the equipment and spread the turns of the coil. Repeat the test with the equipment operating. When neither brass nor powdered iron improves the performance, the inductance has the proper value.

SLUG TUNED INDUCTORS

Construction

Because of its appearance, the core of a variable RF inductor is called a slug. It is a small solid cylinder or rod segment. Sometimes the turning screw is imbedded in the slug. In other types of construction, there may be threads on the inner side of the coil mounting, and the slug itself is threaded. There is a slot in the end of the slug for a screwdriver or alignment tool. The alignment tool is a rod of plastic with a screwdriver blade approximately 0.25 inches in length at one or both ends.

Caution should be exercised in order not to damage the variable coil assembly or the slug. Excessive force should not be used when the slug is at either extreme. Stops are usually provided in the construction of a coil assembly to prevent exceeding maximum and minimum positions of the core when moderate force is applied.

Precautions

It is a good idea to count the number of turns made with the screwdriver or alignment tool when first adjusting a variable inductor. This becomes important when there is no change in the performance of the receiver even though the inductor is being adjusted. The test equipment may not have been properly connected or adjusted. Therefore, the receiver is not being tested, and varying the inductor has no effect. Before leaving that inductor, the slug should be readjusted to the *original* position. If this were not done, the original settings of several adjustments might change and the receiver would be misadjusted.

Basically, making an adjustment means that results are expected. Sometimes, however, there is no noticeable change. In this case, it is wise to readjust the coil to the approximate original position before doing anything else.

SUMMARY
Induced Voltage

AF and RF inductors are basically simple devices. Electrically, all inductors behave in the same manner. A changing current at any instant causes a voltage to appear at the coil terminals during that instant. If the current is not changing, even though it is many amps, *no* voltage appears at the terminals. This is why the voltage and current in a coil are 90 degrees out of phase when sinewaves are present. When the current is maximum, for one tiny instant it is not changing at all. At the peak, the current is exactly between an increasing and decreasing condition. Thus, there is no voltage when there is greatest current in an inductor.

There is a difference between an inductor and a resistor. It is only with resistance or devices like resistors that the amount of voltage is determined by the *amount* of current.

There is also a difference between inductance and reactance. The reactance is measured in ohms and is helpful in analyzing the behavior of electric circuits. For example, a 1000 ohm coil in a parallel circuit has very little AC current if it is in parallel with a 50 ohm AC load.

The confusion about inductors probably is caused by the fact that the reactance is measured in ohms, and the resistance of the inductor is also measured in ohms. An ohmmeter measures the resistance only, *not* the reactance. Reactance is used primarily when studying the action of electric and electronic circuits. If 200 volts AC is applied to a series circuit of a 1,000 ohm coil and a 100 ohm capacitor, one-ninth of the AC voltage is *across* the capacitor.

No Need to Measure Inductance or Reactance

An electronic serviceman is never required to measure the inductance of a coil. A knowledge of inductance and reactance, however, is imperative in understanding the operation of basic electronic circuits. Then it is quite simple to know when and where to use each piece of test equipment.

Servicing involves more than replacing defective parts. Very often, misadjusted variable components can cause a radio or TV receiver to be completely inoperative. A standard joke in electronics is the conscientious serviceman who "tightened all the loose screws" in a receiver. What is meant is that all the adjustable parts that could be varied were varied by using a screwdriver. If this were done, any receiver would probably become inoperative!

Alignment

The process of making adjustments in a receiver is called alignment. Due to aging of components, a receiver that once functioned at 100 percent capacity can deteriorate in performance. Some manufacturers will age the circuitry before the final alignment. These receivers do not require realignment for many years, or perhaps not at all.

AF inductors are relatively large and heavy compared to RF inductors. This is due to the AF inductor's large number of turns and large iron core.

The word "choke" is used to convey the idea of a small amount of AC current. Obviously, if the reactance of an AF or an RF coil is large, there will be relatively little AC current.

Odor of Overloaded AF Inductors

An overloaded or burned-out AF inductor has a distinct and unpleasant odor that is different from the odor of a burned-out resistor. It would be a good idea to identify the odor when it is first experienced so that you will remember it. This will help to identify and locate overloaded or damaged AF inductors in the future.

It is also a good idea to remember the usual operating temperature of an AF inductor. The temperature is determined by touching the inductor in a *normally* operating circuit. When a receiver is malfunctioning, knowing if an inductor's temperature is normal might be of assistance in isolating defective areas of the equipment being serviced. It pays to be alert for as many normal indications of proper operation as possible. This establishes a pool of reference material that supplements other technical data such as resistance and voltage charts.

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TEST

Lesson Number 25

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 52-025-1.

1. In addition to tubes and transistors, the three parts that make up electronic equipment are
   - A. resistors, transformers, and inductors.
   - B. coils, resistors, and inductors.
   - C. capacitors, coils, and inductors.
   - D. resistors, capacitors, and inductors.

2. Inductance is measured in
   - A. henrys.
   - B. ohms.
   - C. farads.
   - D. watts.

3. Inductive reactance is measured in
   - A. henrys.
   - B. ohms.
   - C. farads.
   - D. amperes.

4. An AF choke coil is
   - A. used only in aircraft applications.
   - B. always slug tuned.
   - C. used where frequencies are below 20,000 hertz.
   - D. smaller than an RF choke coil.

5. A short circuit has
   - A. low ohms.
   - B. high ohms.
   - C. low amperes.
   - D. a broken or cracked core.

6. A pulsating DC voltage varying from 260 volts to 320 volts has a peak-to-peak AC voltage of
   - A. 30 volts
   - B. 60 volts.
   - C. 80 volts.
   - D. 100 volts.

7. Refer to Question 6. How many volts of pure DC are present?
   - A. 130 volts
   - B. 160 volts
   - C. 290 volts
   - D. 300 volts

8. In Figure 6, if the AC load had a value of 1,000 ohms, the inductive reactance of the RFC should be approximately
   - A. 100 ohms.
   - B. 500 ohms.
   - C. 750 ohms.
   - D. 10,000 ohms.

9. In Figure 7, P3 is normally connected through the circuit components only to
   - A. G4.
   - B. P4.
   - C. P2.
   - D. the next filament.

10. If a 100 ohm inductor is in series with another 100 ohm inductor, the total reactance would equal
   - A. 50 ohms.
   - B. 100 ohms.
   - C. 200 ohms.
   - D. 1,000 ohms.

Notes

Notes

Notes

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KNOW-HOW

To be a successful electronic service repairman you must know your job. . .organize your work schedule to get the most out of your time and. . .charge a fair price for services rendered.

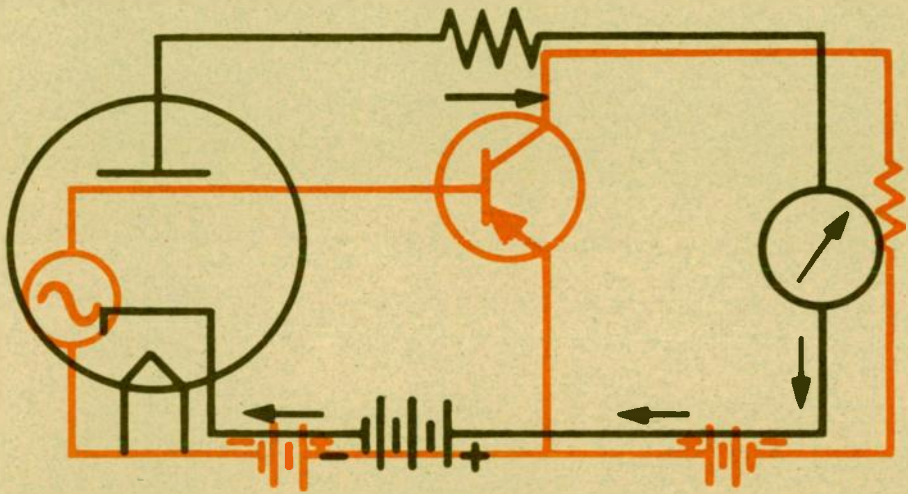
Listen to your customers, give them good service, do a good job and your business will flourish.

Your future ASI lessons will show you how to do this very thing. You will learn "short cuts" as well as practical servicing "know-how". So learn the fundamentals well – work out the practical home training projects and. . .remember what you learn and it won't be long before you will profit handsomely.

S. T. Christensen

LESSON NO. 26

POWER AND AUDIO TRANSFORMERS



RADIO and TELEVISION SERVICE and REPAIR

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CONTENTS

POWER AND AUDIO TRANSFORMERS

INTRODUCTION

Electronic equipment is dependent upon voltages that are frequently different from those provided by AC power lines. Batteries can be used for some equipment but it is usually more convenient and economical to power equipment from regular electric service.

Power transformers provide an efficient and economical means to raise or lower voltages to suit individual requirements. They also exhibit one other advantage; that is, they isolate the equipment from the power line and remove a potential shock hazard.

Other types of transformers (notably audio types) transform moderate current, high voltage signals into low voltage, high current signals that can drive loudspeakers. Audio transformers are used also in an interstage role where they couple audio signals from a source (such as the plate of a vacuum tube) to the grid of a following tube.

In this application, two dissimilar impedances can be matched, plate source to grid load for example, without an appreciable loss of signal.

BASIC TRANSFORMER

A transformer is a device that transfers electrical energy between circuits through mutual inductances. Basically it consists of two coils of wire that share a common core of some magnetic material and, thus, are in a common magnetic field. 1 3

The winding in a transformer to which a voltage or signal is applied is ordinarily called the *primary winding*. Current through the primary winding induces a magnetic field which causes a voltage to be developed in an associated coil (or coils) called a *secondary winding(s)*. 2

The construction of a simple transformer and its schematic symbol is shown in Figure 1. The core consists of a sandwich of flat iron pieces from which the centers have been removed. The windings are wound onto legs of this square, ring-type structure. In the symbol you will notice how the presence of a core is indicated by drawing a series of parallel lines between the primary and secondary windings. This particular form of construction is called a *core type* transformer.

Windings do not necessarily have to be separated or at different positions

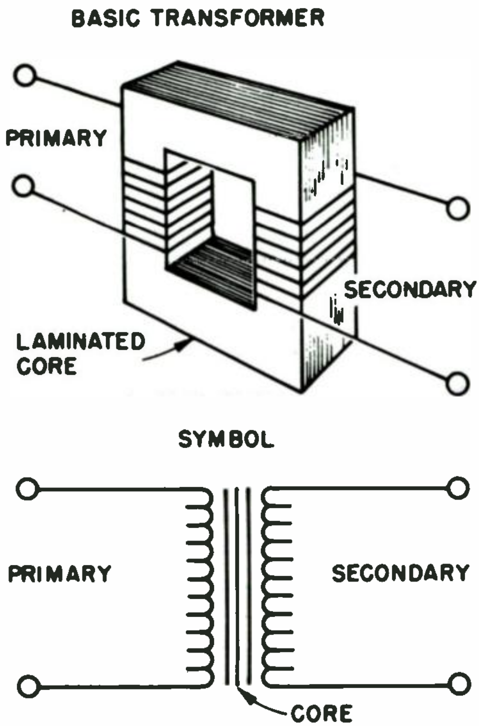

Figure 1 - Basic transformer and symbol.

on a core. They may be wound one on top of another, by providing suitable insulation between them.

Figure 2 shows two basic forms of transformer construction. Notice that the *shell type* differs from the core type in the way the core laminations are cut and the windings wrapped. The core of a shell type transformer resembles a square figure "8" with the windings wrapped onto the inner leg. Insulation is provided between each layer of wire and between windings. Figure 3 illustrates how the shell laminations are made from two individual pieces of soft iron.

You were previously introduced to mutual inductance, the principle that is responsible for transformer action. It was stated that when two coils of wire are placed in close proximity and alternating current is introduced into one coil a voltage is induced in the second coil. Lines of magnetic flux from the first coil generate voltage in the secondary as they cross turns of wire in the second coil.

The magnitude of the induced voltage depends primarily on two factors:

1. TURNS RATIO – the induced voltage in the secondary of a transformer depends on the number of turns in the secondary relative to the number of primary turns.
2. APPLIED VOLTAGE – the voltage developed across the secondary of a transformer depends also upon the amount of voltage applied to the primary.

The effects of including a core of magnetic material into a coil were discussed in previous lessons. It was explained that the core concentrates the magnetic field making it more intense. By concentrating the magnetic field of a transformer, more magnetic lines of force are available for transformer action. The core, therefore, acts to improve the efficiency of power transfer between the primary and secondary.

The amount and quality of iron in the core has considerable effect on power transfer. High quality core materials have less magnetic losses and

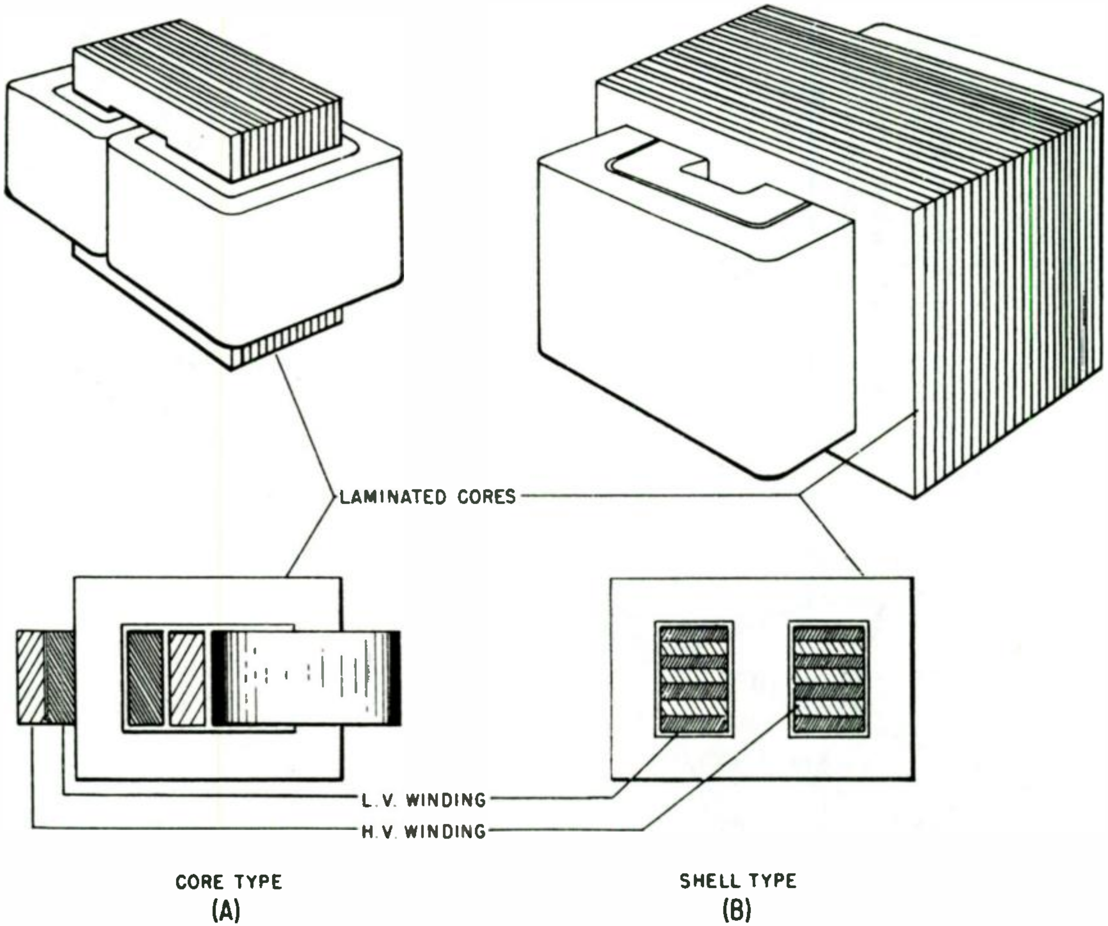

Figure 2 - Types of transformer construction.

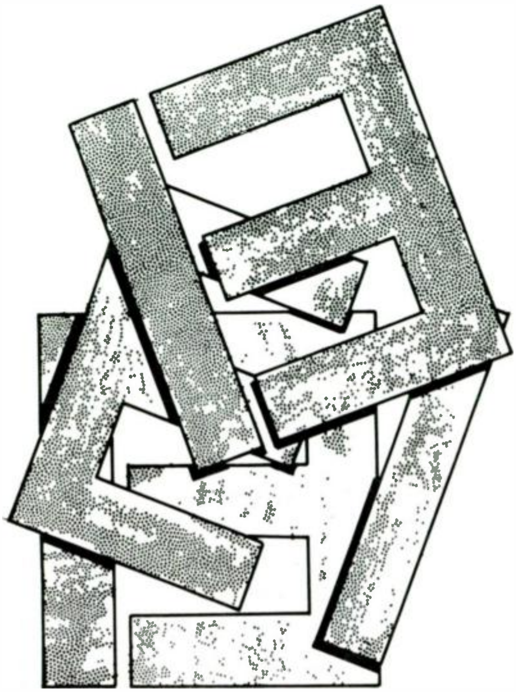

Figure 3 - Laminations for a shell type transformer.

result in greater transfer than poor materials. Another factor that determines power transfer is the way *laminations* are stacked. In most cases they are assembled in an alternate arrangement as shown in Figure 4. You will notice that each lamination consists of an "E" shaped piece with a separate bar across the ends to close the magnetic path. This provides for maximum field intensity, but it has one inherent disadvantage for certain specific applications. A closed loop core structure can become saturated magnetically under the condition of a heavy electrical load. This places an abrupt limit on the amount of power the device can deliver.

Another arrangement is shown in Figure 5 for those applications where saturation, with its limitations, cannot be tolerated. An air gap is provided to prevent saturation. In this application, additional iron is required to overcome the losses introduced by the air gap, but, the added bulk and expense are secondary considerations in applications that require superior performance. One of these applications is in high quality power supplies that are required to deliver power under varying load conditions. By using non-saturating transformers and/or filter chokes, power supplies are able to satisfy a range of power requirements with uniform efficiency.

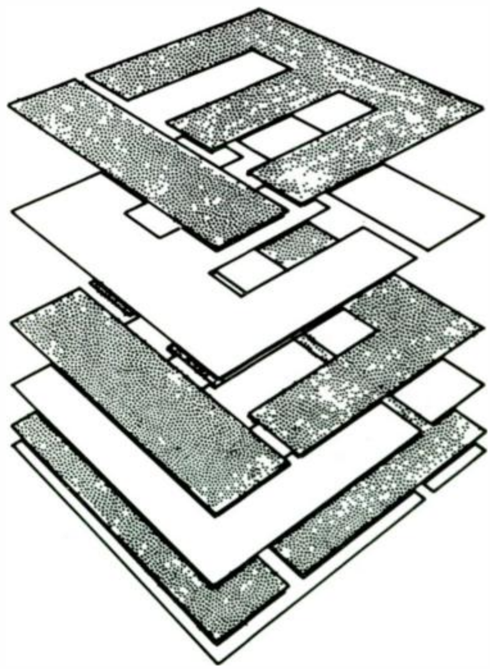

Figure 4 - Assembly of laminations in a shell type transformer.

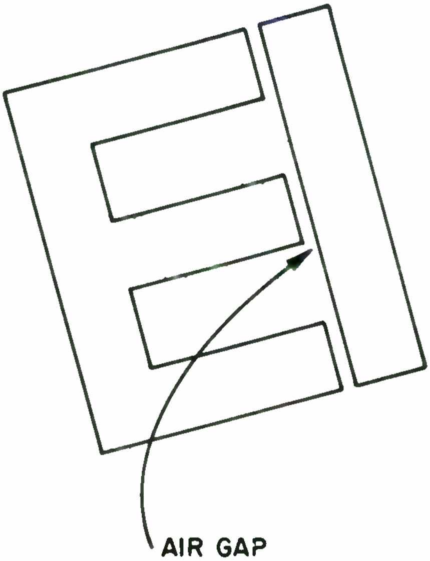

Figure 5 - A magnetic gap is provided in non-saturating type chokes and transformers.

TYPES OF TRANSFORMERS

Transformers are constructed with two or more coils of wire (windings) sharing a common magnetic field. Although there are many other similarities, there are also numerous differences between transformers designed for different applications.

Power Transformers

Power transformers are generally more massive than audio types. The core shape and core material are specifically selected to assure large amounts of power transfer. The insulation is designed to withstand both heat and higher voltages or heavy current surges.

Since only one basic frequency (usually 60 hertz) is involved in power transfer, power transformers are designed for maximum power transfer at only the power line frequency. The core material in power transformers, as in many other types, is made from soft iron. Soft iron does not retain appreciable residual magnetism, permitting its field polarities to be reversed easily by the alternating current in its windings. The core's magnetism, therefore, reverses as the current offers little opposition to power transfer.

Audio Transformers

Audio transformers are usually less massive than power types. They are designed, however, to reproduce a range of audio frequencies rather than just one frequency enabling an audio amplifier to amplify all the frequencies applied to it with equal efficiency. This, in turn, provides uniform reproduction of sounds or a *flat response.*

Powdered Iron Core Types

For applications at the higher audio frequencies, and at frequencies immediately above these, special powdered iron cores are often used. Powdered iron cores consist of high quality iron particles fused together under pressure in a mold.

Cores made from small particles of iron lose their residual magnetism more rapidly than large masses permitting a more rapid reversal of current through the transformer windings. They operate with less losses resulting in greater efficiency, more faithful reproduction of the input waveform and less heat generation. Examples of these transformers that use powdered iron cores are the flyback transformers and yokes in TV sets.

Flybacks and yokes, are pulse-type devices which handle signals having extremely fast rise or fall times and tremendously high momentary voltage and current pulses. The horizontal voltage pulse required for a large screen TV set drops from several thousand volts to zero volts in a few millionths of a second. Superior quality materials are used in the devices that handle these rapid changes to prevent arc-over and core saturation.

Auto-Transformers

Transformers do not necessarily require individual or isolated windings to supply increased or reduced voltages. A single winding with taps can and often does produce the desired result. When only one winding is used in a transformer we call it an autoformer or auto-transformer.

Figure 6 shows an autoformer of a type commonly used for power supply applications. Notice that the input voltage is applied to only a portion of the winding. Voltage in the balance of the winding is induced from the current flowing through this portion. Voltage across the total winding is the induced voltage plus the amount applied. Winding section AB serves the same purpose as the primary of a standard transformer. The input voltage is applied across this section. Due to the greater number of turns across section BC, section BC will produce a greater voltage than that applied to AB. An even larger voltage can be obtained across the total winding by connecting the load between A and C. The potential across AC includes the voltage applied to AB added to the voltage induced into BC.

Variable Autoformers

In many service shops it is desirable to have a variable source of AC voltage. Most variable AC supplies operate from a tapped autoformer (Fig. 7). The required voltage is obtained by selecting a tap on the winding.

In some cases, the taps are selected with a rotary switch. These switches have a contact for each tap and the contacts are wired in sequence. When the switch is rotated in one direction, the voltage increases a step for each position. Rotating the switch in the opposite direction results in decreasing voltage steps. Figure 7 illustrates voltage selection with a switch connected to taps on an autotransformer. A more common variable AC source has the winding closely wound on a doughnut shaped core. A contact arm is attached to a shaft through the hole in the doughnut with the shaft suspended from bearings in mounting brackets. As the shaft is rotated, the contact moves from one turn of the winding to the next causing a corresponding voltage change (Fig. 8). The shaft is provided with an

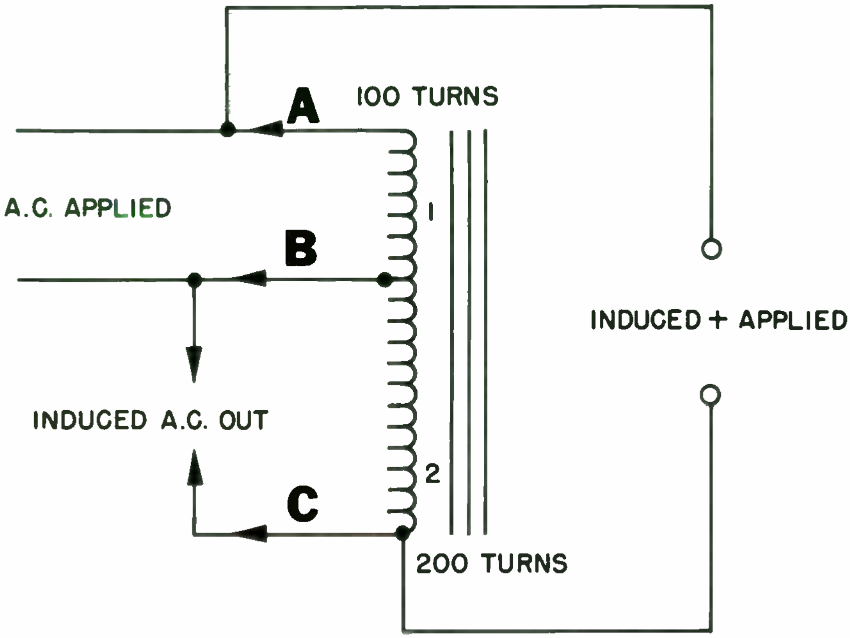

Figure 6 - Autoformer.

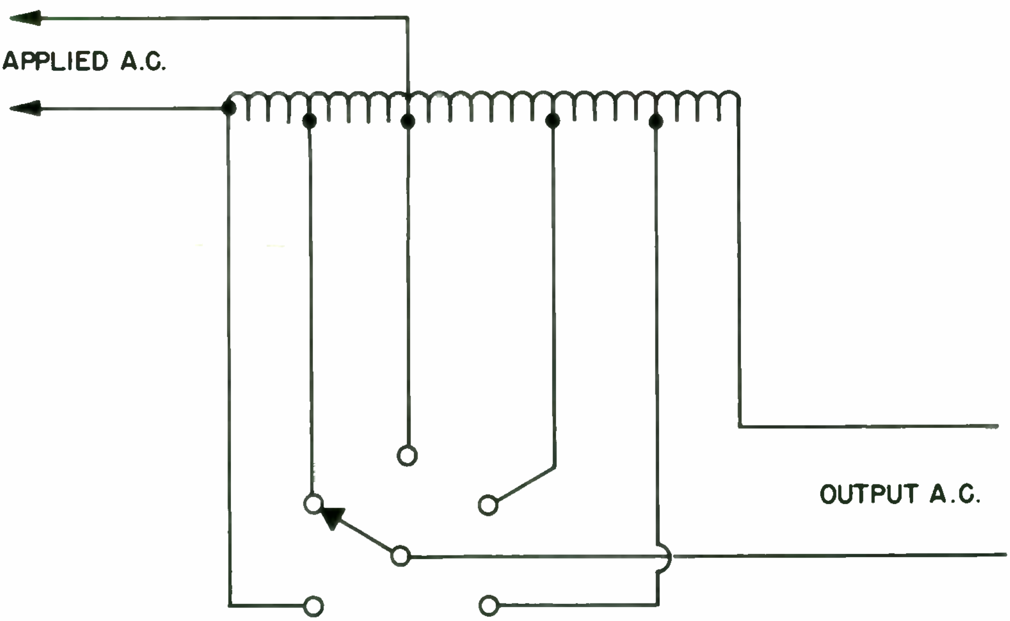

Figure 7 - Voltage selection by means of a selector switch connected to taps on an autoformer.

insulated knob, a pointer, and a numbered scale. Some models even include an AC voltmeter as an output indicator.

Variable power units are available that operate from 120V AC input. They can supply outputs from near zero volts to 150 volts, in increments of two volts or less. They are particularly handy for increasing or lowering the voltage to a service bench in the event that the power line voltage is either higher or lower than normal. They also aid in servicing some troublesome units in which the malfunction does not occur at normal line voltage.

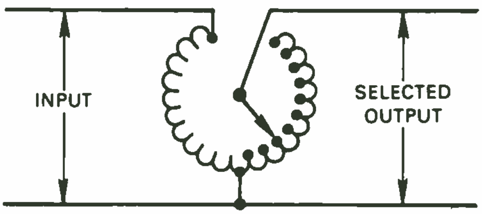

Figure 8 - Voltage selection with a variable transformer in which a rotary selector arm contacts each turn of the winding in sequence.

TURNS RATIO–VOLTAGE RATIO

As previously stated, the magnitude of the voltage developed in the secondary of a transformer depends upon the number of turns in both the primary and the secondary and upon the voltage applied to the primary. If the number of turns in the primary and secondary are equal, the voltage induced in the secondary will equal that applied to the primary. If the secondary has less turns than the primary, less voltage will be induced in the secondary. A transformer that produces less voltage in the secondary than is applied to the primary is called a *step-down* transformer. When the secondary of a transformer has more turns than the primary the induced voltage will be greater than the applied voltage. In this case the device is called a *step-up* transformer.

The amount of step up or step down in a transformer is dependent upon the turns ratio. This is a relative figure derived by dividing the number of turns in the secondary by the number of turns in the primary. Figure 9A, B, and C give three examples.

Notice from Figure 9A that the turns ratio of the transformer shown equals "1." In this case, the output or secondary voltage will equal the primary voltage.

In Figure 9B, the turns ratio equals 0.1. In this case, the output voltage will be one-tenth of that applied to the primary. This is a step-down transformer.

In Figure 9C, the turns ratio is calculated to be 10. This means that the output voltage from the secondary will be 10 times greater than that applied to the primary.

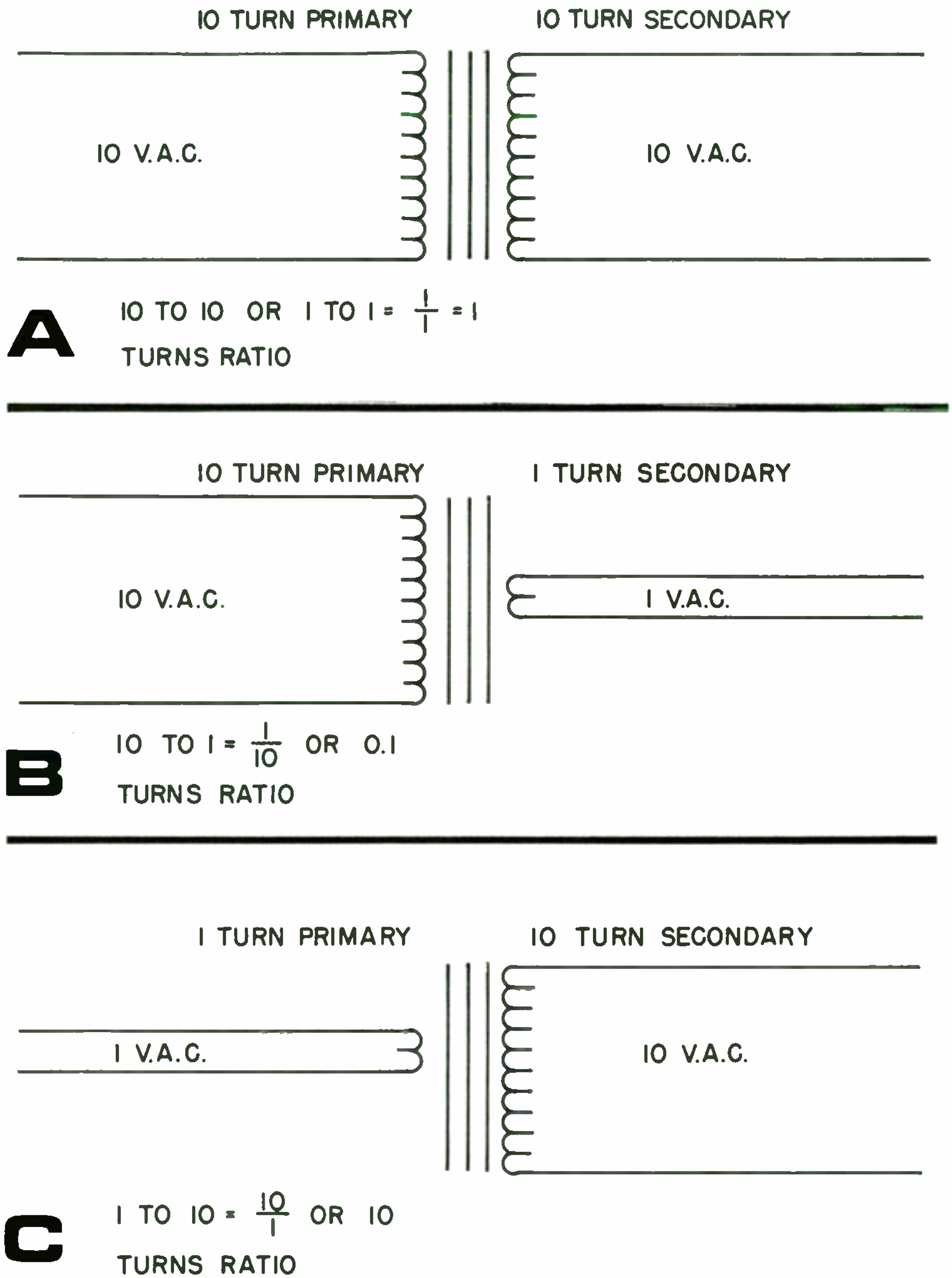

Figure 9A - Represents a 1 to 1 ratio of voltage transfer.
B - Represents a step down in both turns ratio and voltage.
C - Represents a step up in both turns ratio and voltage ratio.

From the illustrations in Figure 9, it is obvious that output or secondary voltage is equal to input voltage multiplied by turns ratio. As an example, refer to Figure 9C:

Turns Ratio x input VAC = Output VAC
OR
10 x 1 = 10 VAC

It appears that the increase in voltage gives us something for nothing. This is an obvious fallacy and may be explained once we realize that although the voltage is increased, the available current will be much less. Therefore, the actual power delivered from the secondary will not be more than the power drawn by the primary. In fact, the output power will be slightly less because of magnetic losses and some losses that occur due to the small resistance in the wire of the windings. Even with these losses, however, a transformer is one of the most efficient power transfer devices known.

POWER TRANSFER

It is interesting to note that almost no power is used in the primary of a transformer. Only a very small amount is required to overcome resistances. Nearly all the power applied to the primary is transferred to the secondary. If 100 watts is applied to the primary, for all practical purposes it can be assumed that 100 watts is available from the secondary(s). In the case of multiple secondarys with different voltages the

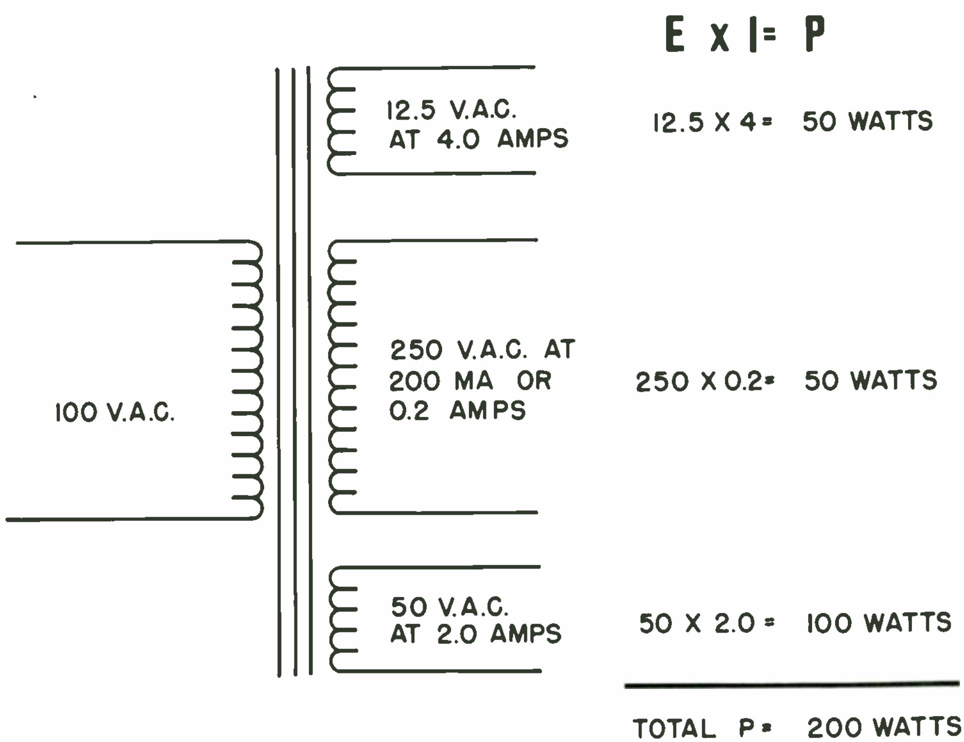

Figure 10 - Power output calculations for a multi-winding transformer.

power must be calculated individually for each winding by multiplying E x I. The results of these are then added to obtain the total output power. Figure 10 illustrates the calculations involved in determining total power from a transformer.

Efficiency of power transformers are rated in percent of power transfer. Their efficiencies range from a figure greater than 95% for good quality transformers to 85% for economy types. Always use a comparable quality unit when replacing a defective one.

In Figure 11, three physical forms of power transformers are shown. Those in A are open winding unshielded types. Figure 11B shows examples of shielded types which are enclosed by magnetic covers. The transformer in Figure 11C is a potted type, encased in a metal container and sealed with epoxy. Many other types, including audio transformers, resemble those illustrated.

IMPEDANCE MATCHING

In earlier lessons, we stated that the impedance of a source of voltage,

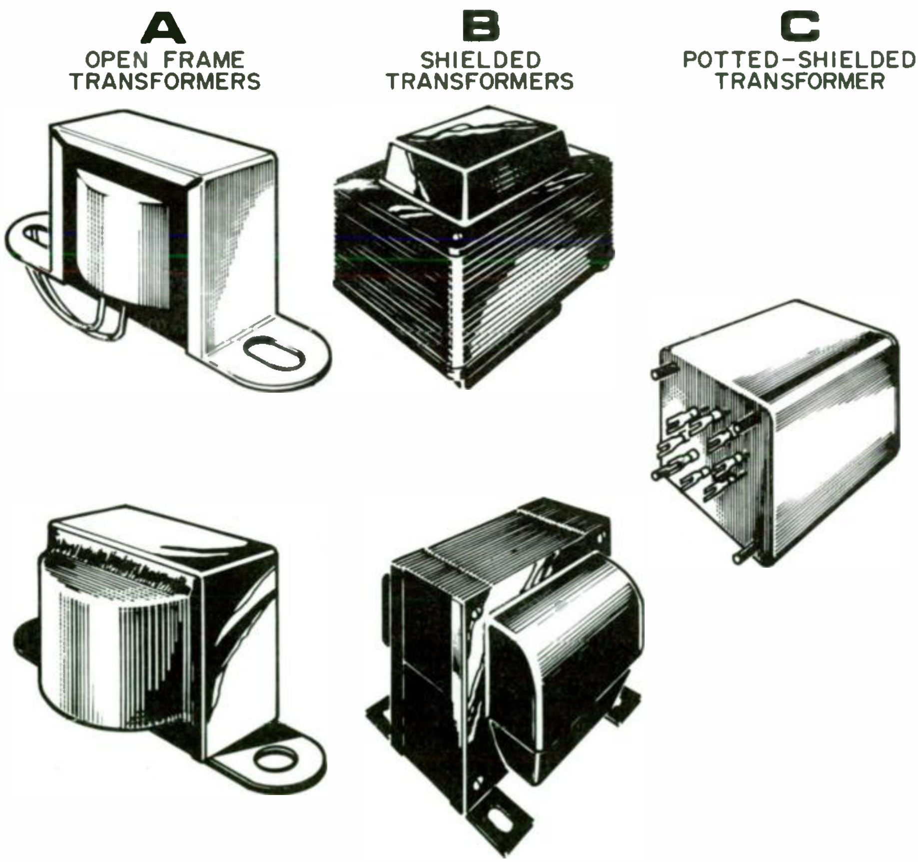

Figure 11 - Some typical transformers.

current or power should closely match the load impedance that it is supplying. Maximum efficiency results when the two (source impedance and load impedance) are equal.

Audio Output Transformers

In the case of speakers operating from vacuum tube amplifiers, the transfer efficiency would be very poor unless some kind of matching device was used. Power type vacuum tubes have an impedance (plate resistance) of several thousand ohms, whereas speakers have only a few ohms of impedance.

Audio output transformers are used to match these two dissimilar impedances. Figure 12 shows the output stage of a simple tube amplifier. The plate resistance (Rp) of the output tube is 5,000 ohms and the load it supplies should equal this value. Notice that a transformer is used that has a primary with many turns which also has an impedance of 5,000 ohms. Now that a match has been provided between the tube and its load (the primary) the audio energy must be supplied to the speaker at an impedance of 16 ohms. This is done by winding the secondary with only a few turns of wire which results in a low impedance winding. In the secon-

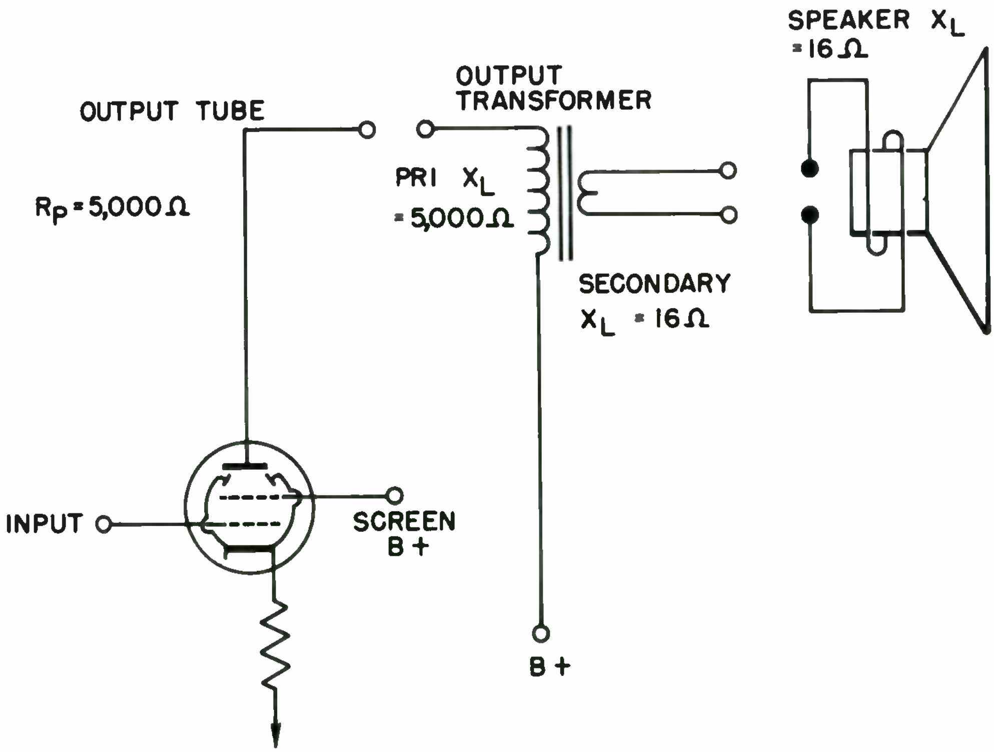

Figure 12 - Transformers are impedance matching devices.

dary of the transformer in Figure 12, the result is 16 ohms.

Popular output impedances of amplifiers are 4 ohms, 8 ohms, and 16 ohms. Other values provided from public address (PA) amplifiers to drive multi-speaker systems are: 125 ohms, 250 ohms, and, more frequently, 500 ohms. The higher impedance outputs usually supply a line from which speakers are supplied through an individual matching transformer at each speaker. Figure 13 shows a 500 ohm line with a series-parallel arrangement of line matching speaker transformers.

There are several variations of audio output transformers used. These include types with multiple secondaries, multiple primaries, tapped primaries and/or tapped secondaries. Several of the different configurations are shown in Figure 14. The one shown in A is commonly used in two tube audio output circuits called push-pull stages. An example of a push-pull stage using this transformer is shown in Figure 15. The two tubes operate on opposite phases of the audio signal to produce a back and forth current motion in the transformer's primary. The current through one-half of the transformer winding is increasing while current through the other half is decreasing; or one tube is said to be pushing when the other is pulling the current. Thus, the name, push-pull.

In Figure 14B, we see a transformer with a tapped primary. The taps may be selected instead of the ends of the winding to match tubes having lower plate resistances. This is a universal replacement type that can be used with many different tube types.

Figure 14C shows an audio output transformer with a tapped secondary. This arrangement would supply two 8-ohm speakers if the center-tap is used, or a single 16-ohm line if the center-tap is not used.

Figure 14D shows a transformer with a feedback winding. This winding provides out of phase feedback to one or more stages of the amplifier to reduce distortion.

Figure 14E illustrates a transformer that is generally used with a PA amp. The tapped secondary can match lines with different impedances.

The schematic in Figure 14F is the type occasionally used in some transistor applications. Two transistors can supply power to a speaker through isolated windings. This simplifies their DC bias networks and signal input requirements. Refer to Figure 16 for a transistor output stage using this type transformer. Notice that the two transistors are opposite polarity devices. One is an NPN and the other a PNP. The two share a common input signal so that one conducts on the positive going portion of the signal and the other on the negative going portion.

Audio Interstage Transformers

Transformers are often needed between stages of audio amplifiers for three reasons:

1. They match stages with dissimilar impedances.
2. They provide power drive for output stages that require it.
3. They provide opposite phase signals to push-pull amplifiers.

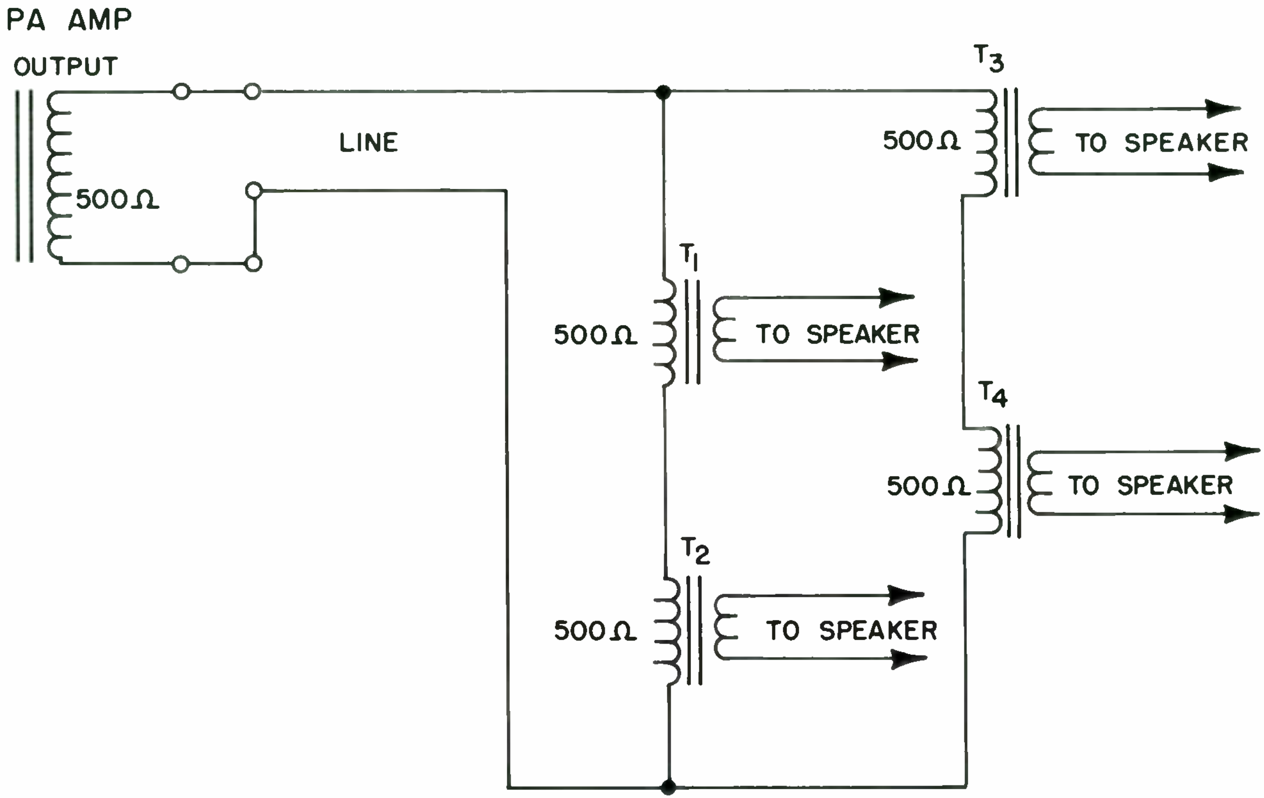

Figure 13 - A 500Ω line with line matching speaker transformers.

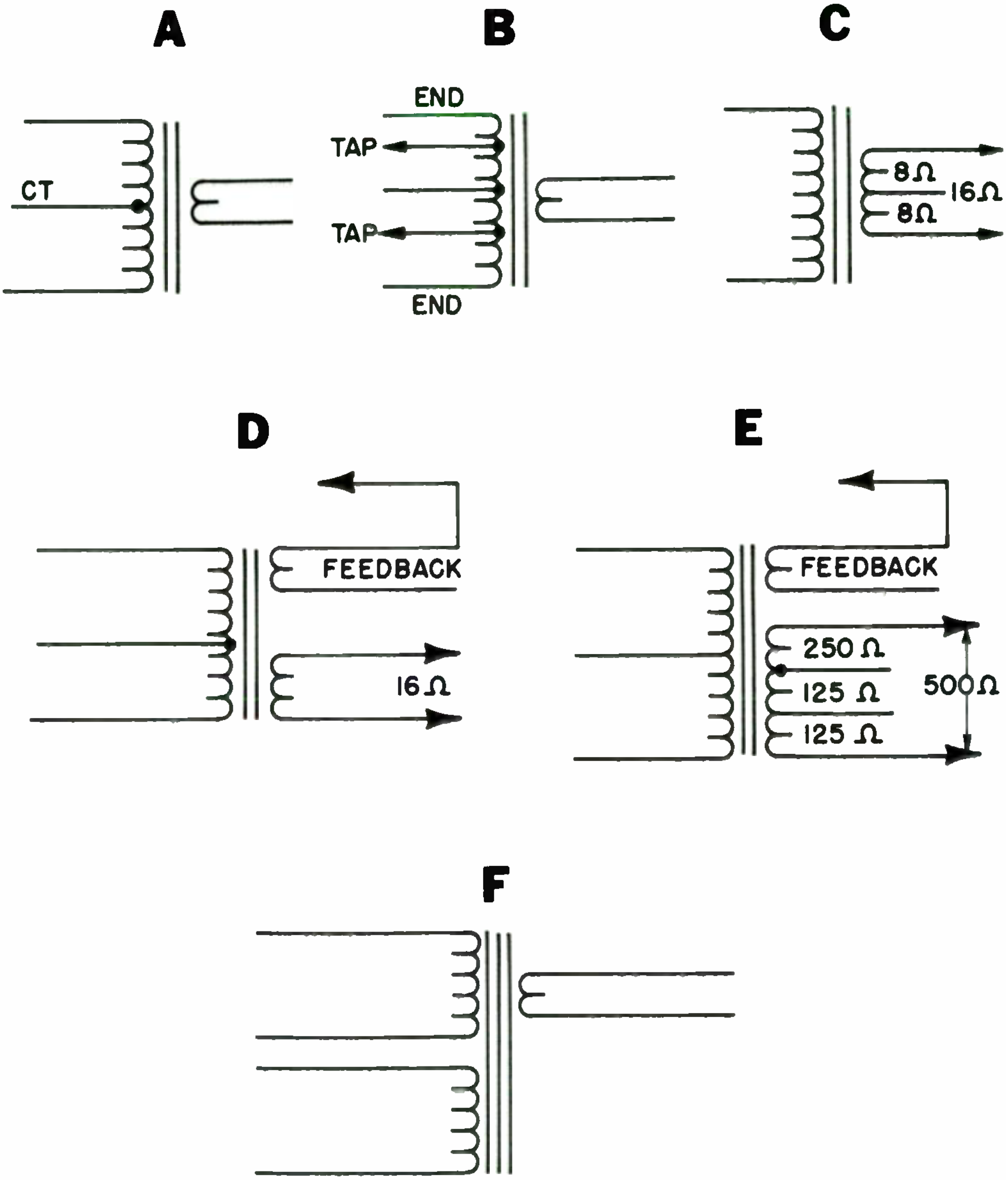

Figure 14 - Configurations of output transformers.

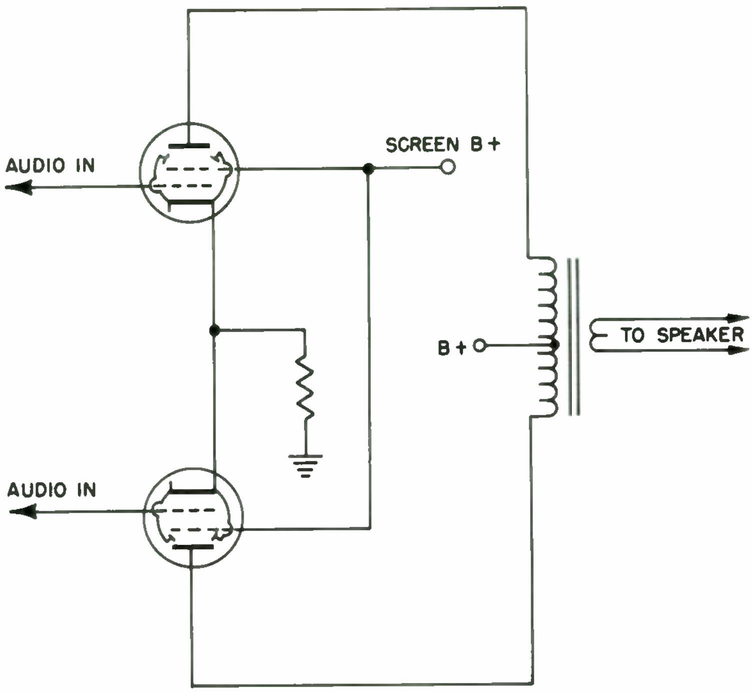

Figure 15 - A typical push-pull audio output stage.

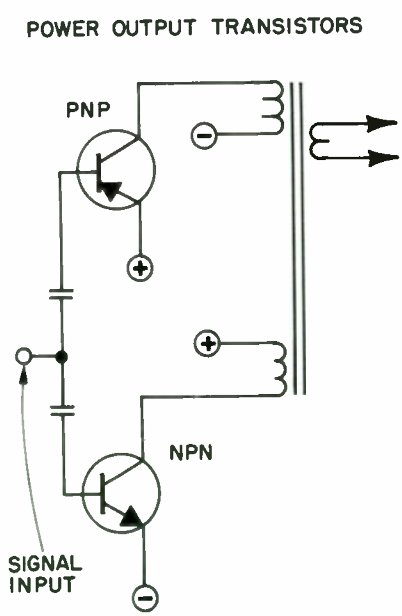

Figure 16 - Complementary transistors produce push-pull output from a single input signal.

Figure 17 shows two circuit configurations using audio interstage transformers. The circuit in "A" is called a single-ended configuration. The one in Circuit B is a push-pull configuration.

SUMMARY

Transformers are used in nearly all phases of the electronics field. Their wide spread use is prompted by their excellent efficiency and versatility. A transformer is one of the most efficient devices for transferring power or providing isolation.

Transformers perform only three basic functions:

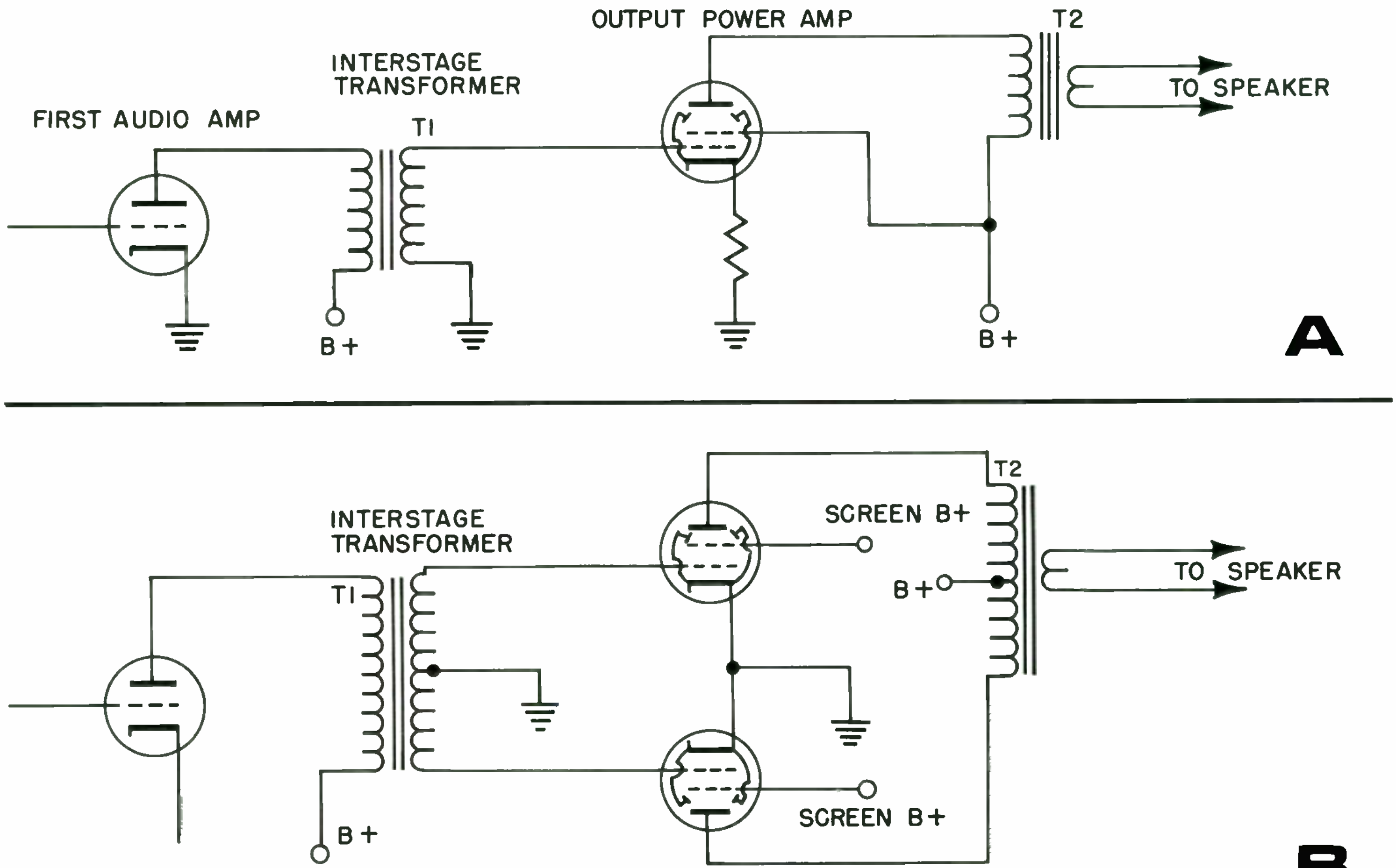

Figure 17 - Configurations using interstage transformers:
A. Provide impedance matching and power to output tube.
B. Provide opposite phase drive to push-pull output.

1. They provide power by stepping up or stepping down voltages.
2. They interconnect signals between dissimilar impedances.
3. They provide isolation between stages or they isolate equipment from the power line or power source.

You will rarely find a defective transformer in spite of their widespread use. Common malfunctions among those that do fail are: shorts between windings; shorts between turns within a winding; and open windings due to a wire breaking or corroding. Most of these failures can be located and identified very quickly with an ohmmeter.

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TEST

Lesson Number 26

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 52-026-1.

1. Transformers transfer power through
   A. Mutual inductance.
   B. electrostatic fields.
   C. resistance.
   D. capacitance.

2. The primary of a transformer
   A. always produces an output.
   B. is the winding to which power is applied.
   C. is not connected to any other winding.
   D. has no effect on current in the secondary(s).

3. The basic transformer consists of __________ sharing a common magnetic field.
   A. four coils of wire
   B. two coils of wire
   C. more than one primary
   D. none of the above

4. Power and audio transformers contain a core of __________ material to increase efficiency.
   - A. insulating
   - B. electrostatic
   - C. resistive
   - D. magnetic

5. Power transformers must operate efficiently at __________ frequencies.
   - A. only two
   - B. RF
   - C. all audio
   - D. power line

6. Audio transformers must operate efficiently at __________ frequencies.
   - A. only two
   - B. RF
   - C. all audio
   - D. power line

7. The voltage developed in the secondary of a transformer depends on
   - A. the amount of electrostatic coupling only.
   - B. the turns ratio and applied voltage.
   - C. the turns ratio only.
   - D. the excitation voltage only.

8. Autotransformers are constructed with
   - A. only two windings.
   - B. only a secondary winding.
   - C. only one tapped winding.
   - D. no core.

9. The efficiencies of power transformers range from
   - A. 25% to 75%.
   - B. 85% to 95%.
   - C. 50% to 60%.
   - D. 65% to 75%.

10. Audio interstage transformers connect power between
    - A. vacuum tube circuits only.
    - B. transistor circuits only.
    - C. power lines.
    - D. dissimilar impedances.

Notes

Notes

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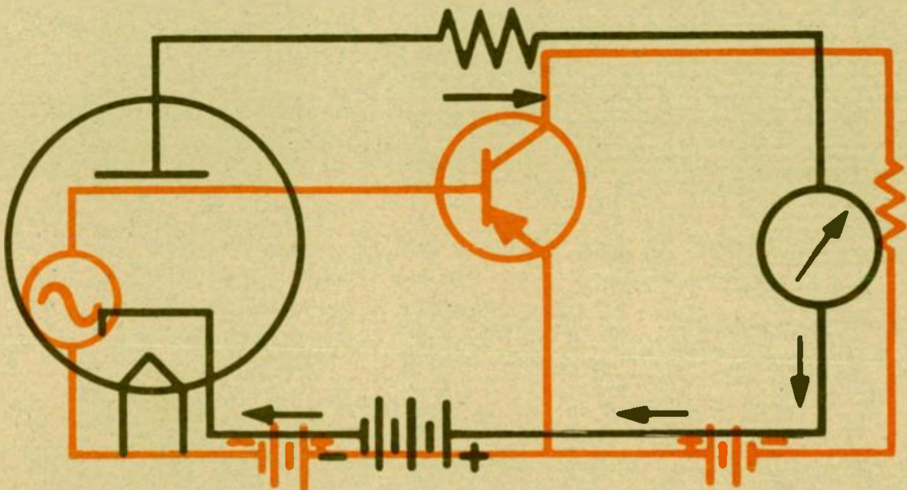
S. T. Christensen

LESSON NO. 27

RF AND IF TRANSFORMERS



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CONTENTS

RF AND IF TRANSFORMERS

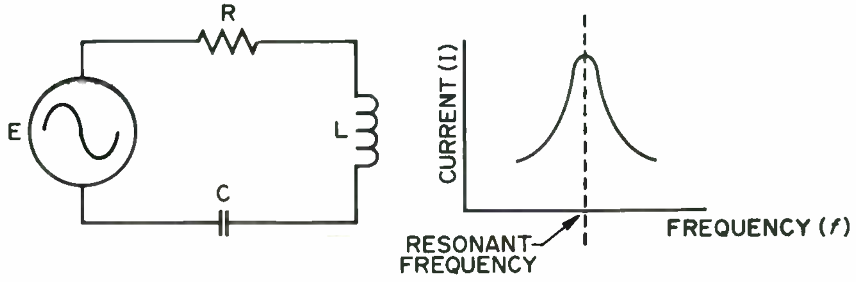
INTRODUCTION

Transformer circuits are often used in high frequency amplifiers. All amplifiers require load impedances. Resonant circuits are used as load impedances for high frequency amplifiers. A resonant circuit has inductance and capacitance. The inductor of a resonant circuit can be the primary or the secondary winding of a transformer. This lesson will cover various forms of transformer circuits that are frequently used in radio, FM, and TV receivers.

Series Resonance

A series resonant circuit has maximum current flowing at resonance (Fig. 1A). At resonance, the inductive reactance equals the capacitive reactance so that the total reactance is

A



B

FREQUENCY	X_L	X_C	X TOTAL
RESONANCE	100Ω	100Ω	0 Ω
BELOW RESONANCE	90Ω	110Ω	20Ω(CAPACITIVE)
FURTHER BELOW RESONANCE	70Ω	130Ω	60Ω(CAPACITIVE)

Figure 1 - Current variation of a series resonant circuit.

zero. This results in a heavy current flow since only the resistance limits the current. Below resonance, the capacitive reactance is larger than the inductive reactance, so total reactance is not zero. This results in less current than the current flow at resonance. The further below resonance, the more capacitive reactance increases while the inductive reactance is even less than before. The result is a large total reactance (Fig. 1B) with a smaller current. Below resonance, the circuit is capacitive because the total reactance is capacitive in nature. Above resonance (input frequency is *higher* than the circuit's resonant frequency) the circuit is inductive because the inductive reactance is larger than the capacitive reactance. Figure 1 shows how the circuit current varies as the frequency is changed from a low value (below resonance) to a high value (above resonance). The current is maximum at the resonant frequency because the total reactance is zero. Near resonance, the current is also high because the total reactance is small. When the input frequency is far from resonance, the current has a low value because the total reactance is large. The graph in Figure 1 is called a "series resonance curve" or "series resonance response curve."

Since the current in a series resonant circuit is high for a group of frequencies, we say that the circuit has a band-pass capability. This "bandwidth" is usually measured between points on the response curve that are 0.7 of the maximum value. The bandwidth of the example (Fig. 2) is 50 kHz.

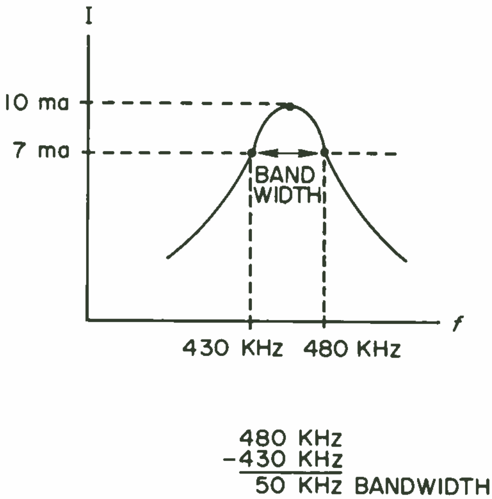
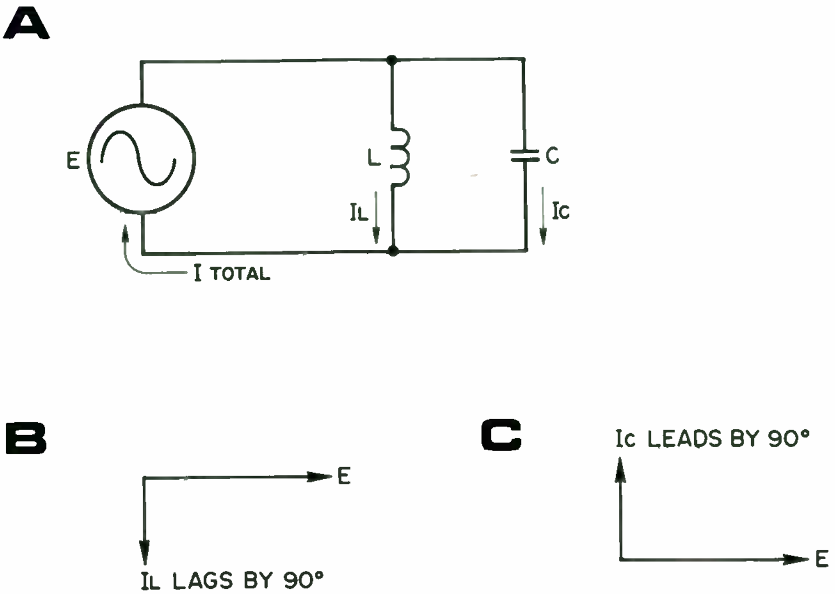


Figure 2 - Bandwidth

Parallel Resonance

In a parallel LC circuit, the two currents are 180 degrees out of phase. This is because I_L lags E by 90 degrees (Fig. 3B), and I_C leads E by 90 degrees (Fig. 3C). For this circuit, the currents add the same way that the reactances add in a series circuit. When I_L is 10 ma (Fig. 3D) and I_C is 6 ma, the total current is 4 ma and is lagging E by 90 degrees. When I_L is 20 ma and I_C is 31 ma, the total current is 11 ma and is leading E by 90 degrees.

A parallel resonant circuit (Fig. 4A) has maximum impedance at resonance. Another way of saying this is that the total current (or line current) is minimum at resonance, because the current is low when the impedance is high. Below resonance, the inductive reactance is smaller than the capacitive reactance; this makes the inductive current larger than the capacitive current, so that the circuit is induc-



D

I_L	I_C	I TOTAL
10 ma	6 ma	4 ma (LAGGING E BY 90°)
10 ma	8 ma	2 ma (LAGGING E BY 90°)
20 ma	31 ma	11 ma (LEADING E BY 90°)
25 ma	35 ma	10 ma (LEADING E BY 90°)

Figure 3 - Currents in a parallel LC circuit.

tive. Above resonance, a parallel resonant circuit is capacitive, because the capacitive current is larger than the inductive current.

Since the impedance of a parallel resonant circuit is high for a group of frequencies, the idea of bandwidth is used again. The bandwidth is usually measured between the points that are 0.7 of the maximum impedance. The bandwidth of the example (Fig. 4B) is 20 kHz.

Amplifier Load Impedance

Parallel resonant circuits are used as plate load impedances in RF amplifiers (Fig. 5A). An input signal fed to the grid of the tube causes the plate current to have the form of the input signal. When the plate current passes through the plate load impedance, a voltage results. This output signal voltage is appreciably larger than the input signal voltage. By using a resonant circuit instead of a resistor,

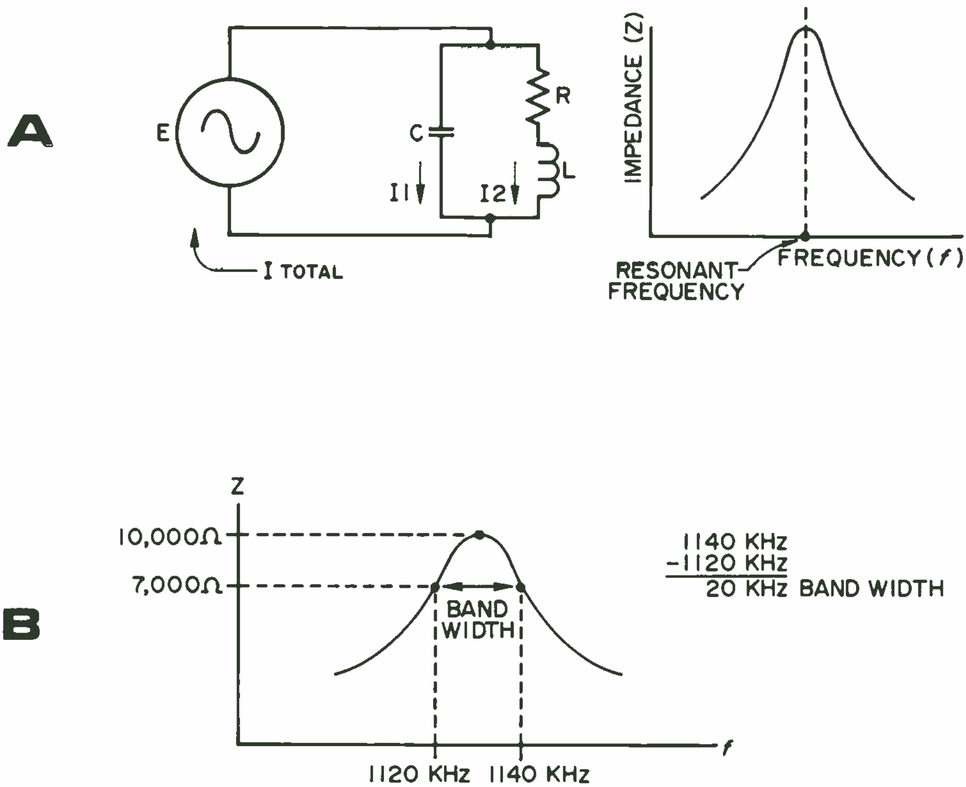
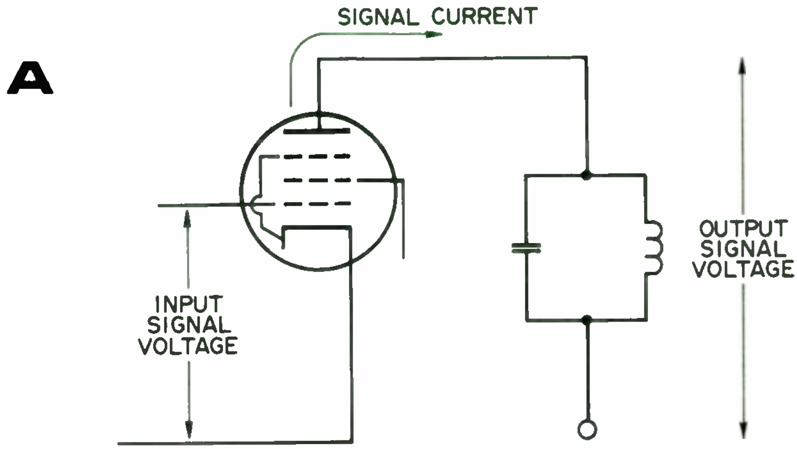


Figure 4 - Impedance variation of a parallel resonant circuit.

the amplifier amplifies only the frequencies near the resonant frequency of the circuit, thus rejecting other frequencies. This ability to reject other frequencies is called "selectivity."

When the emitter to base current of a transistor varies in accordance with an input signal (Fig. 5B), the emitter to collector current is larger than the base current and also has the form of the base current. The collector current passes through the collector load impedance and produces an output signal voltage that is larger than the input signal voltage.

A resonant circuit used as a load impedance permits amplification of a selected group of frequencies. If the inductance or capacity of the resonant circuit were to be changed in value, the resonant frequency would change. For example, if a 200-pf (picofarad) capacitor and an appropriate coil were resonant at 920 kHz, then when the capacitor is changed to 50 pf, the resonant frequency is 1840 kHz. If there was a smaller decrease in capacity, there would have been a smaller increase in the resonant



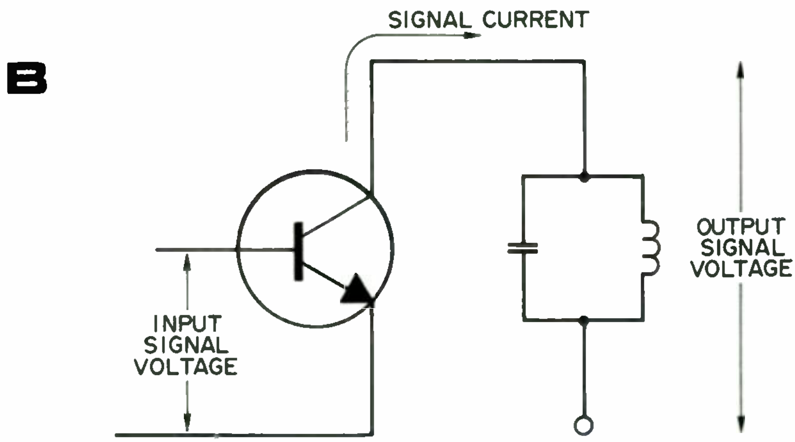


Figure 5 - Use of parallel resonant circuit as a load impedance to develop an output voltage.

frequency. Decreasing the inductance also increases the resonant frequency.

Figure 6 shows how the impedance graph shifts along the frequency axis when the resonant frequency is changed.

Review

We have seen that

a *parallel* resonant circuit has a high impedance at resonance;

Below resonance,

a parallel resonant circuit is inductive (total current lags the applied voltage);

Above resonance,

a parallel resonant circuit is capacitive (total current leads the applied voltage);

A *series* resonant

circuit has a high current at resonance;

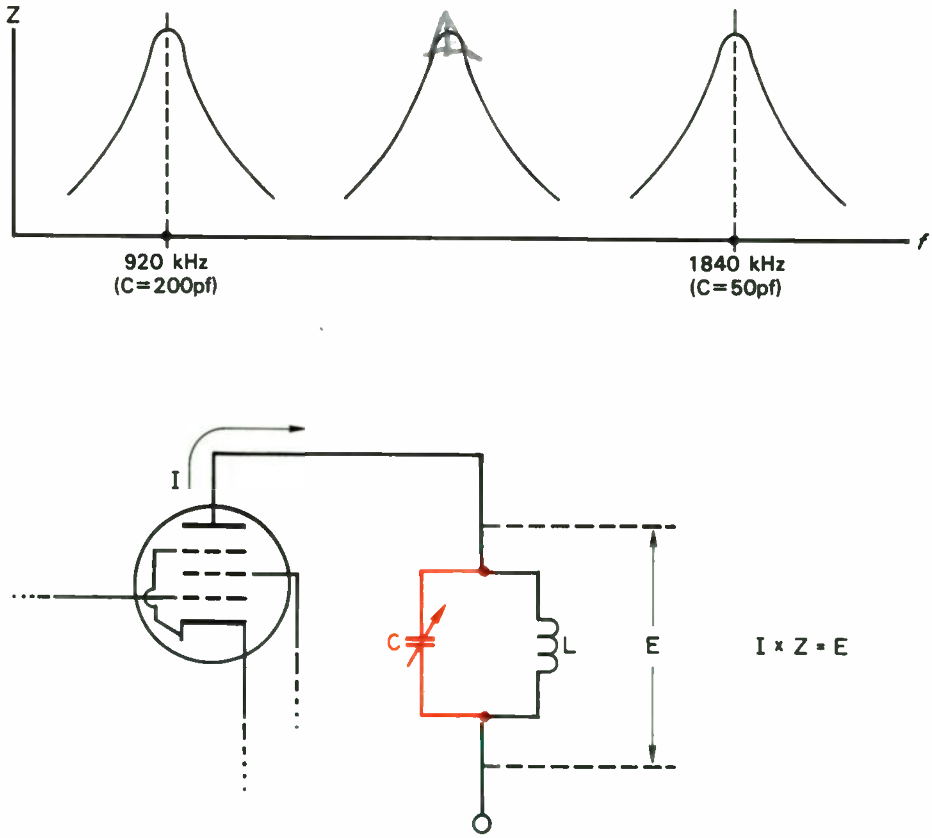


Figure 6 - Changing the resonant frequency by changing the capacity of a resonant circuit.

Below resonance,
: a series resonant circuit is capacitive (X_C is larger than X_L, so the current leads the applied voltage);

Above resonance,
: a series resonant circuit is inductive (X_L is larger than X_C, so the current lags the applied voltage).

MUTUAL INDUCTANCE

An inductor is said to have the property of *self-inductance.* That is, not only does a changing current induce a voltage, but the changing current and induced voltage are in the *same* component. In a transformer, on the other hand, a changing current in the primary induces a voltage in the secondary; also, a secondary current induces a voltage in the primary. A transformer is said to have *mutual-inductance;* that is, the changing current and the resultant induced voltage are *not* in the same component. (The same choice of word occurs in vacuum tubes in the parameter called mutual conductance. Mutual conductance is calculated by dividing a change in *plate* current by the corresponding change in *grid* voltage; the voltage and current are *not* in the same circuit).

Exact calculations of all voltages and currents in a transformer are lengthy, but these calculations are not necessary for a general knowledge of transformer behavior.

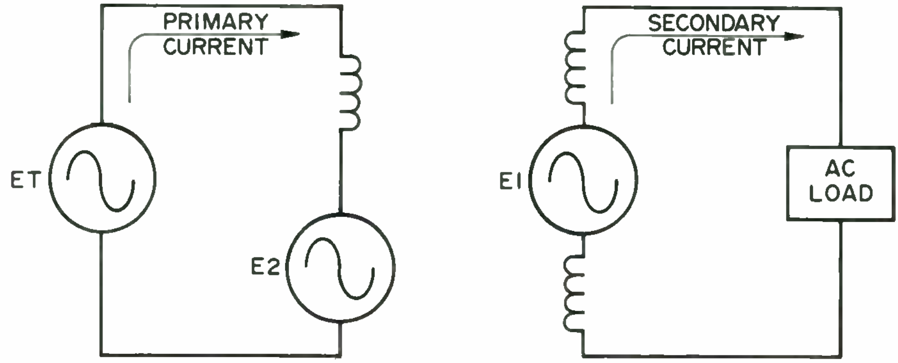
When the secondary is a part of a complete circuit, there is current in the secondary circuit. In some applications of transformers, the secondary is not a part of a complete circuit; in that case, there would be no secondary current, but there would be a secondary voltage.

Reflected Impedance

Figure 7A shows the general operation of a transformer. E1 represents the induced voltage in the secondary. E2 represents the voltage induced by the secondary current. A part of E_T will be dropped across E2 since E_T is the applied voltage. Instead of treating E2 as an induced voltage, it is customary to think of it as a circuit component that would have the same voltage. For example, if E2 is in phase with the primary current, E2 is thought of as a resistor. It is called the *reflected* resistance. If E2 leads the primary current by 90 degrees, E2 is called a reflected inductive reactance, since the current lags the voltage by 90 degrees. If E2 lags the primary current by 90 degrees, E2 is called a reflected capacitive reactance. If E2 is 20V and in phase with a 4-amp primary current (Fig. 7B), the reflected resistance is 5 ohms. If E2 is 80V and lagging a 5-amp primary current by 90 degrees, the reflected capacitive reactance is 16 ohms. If E2 is 30V and leading a 2-amp primary current by 90 degrees, the reflected inductive reactance is 15 ohms. If the primary current lags E2 by less than 90 degrees, the reflected impedance consists of resistance and inductive reactance.

The nature of the reflected impedance depends only on the secondary circuit. The secondary circuit is what

A



B

E2	PRIMARY CURRENT	REFLECTED IMPEDANCE $(Z = \frac{E}{I})$
20V (IN PHASE WITH PRIMARY CURRENT)	4A	5Ω (RESISTIVE)
80V (LAGGING PRIMARY) CURRENT BY 90°)	5A	16Ω (CAPACITIVE)
30V (LEADING PRIMARY CURRENT BY 90°)	2A	15Ω (INDUCTIVE)

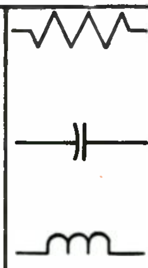
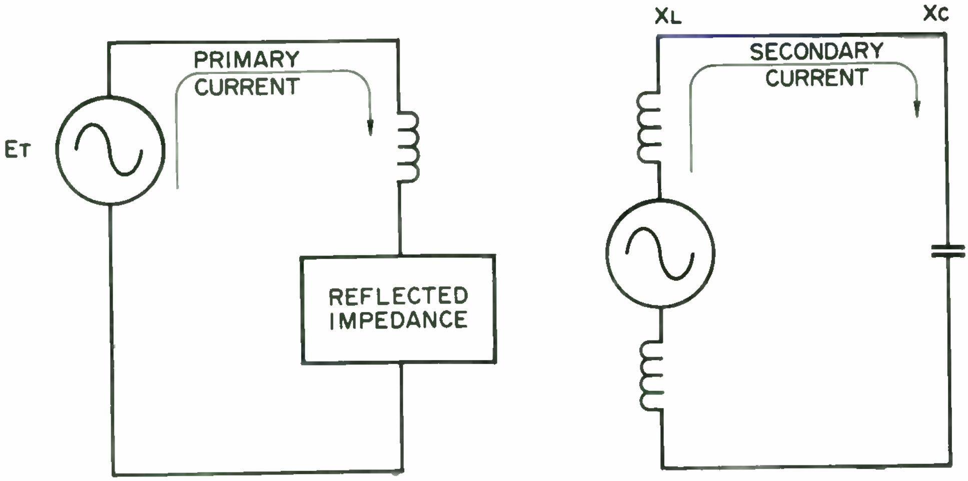


Figure 7 - Transformer operation (reflected impedance).

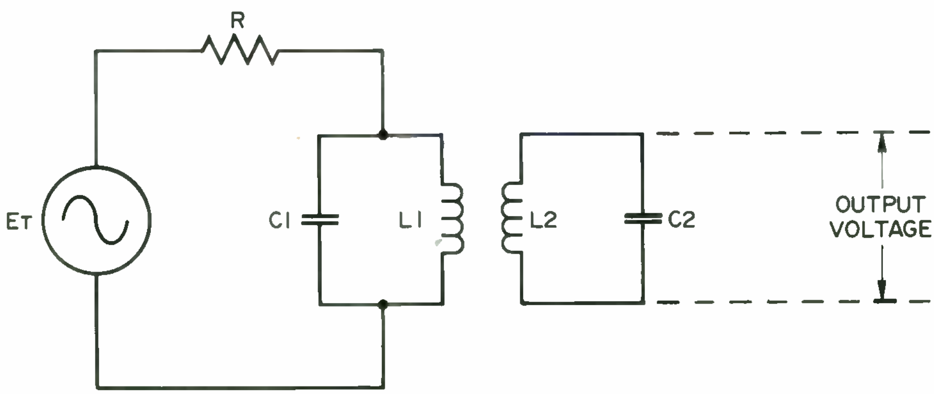
is seen by the induced voltage E1 (Fig. 7); it is a series circuit. When the secondary circuit is inductive the reflected impedance is capacitive. For example, when the secondary inductive reactance is 20 ohms (Fig. 8) and the secondary capacitive reactance is 5 ohms, the total reactance in the secondary is 15 ohms (inductive). And when the secondary current is lagging, the phase of the voltage induced into the primary by the secondary current is as though a capacitor were present in the primary circuit. If the secondary had an inductive reactance of 40 ohms and a capacitive reactance of 50 ohms, the total secondary reactance is 10 ohms (capacitive), and the reflected impedance is inductive. If the secondary circuit is purely resistive (total reactance is zero), the reflected impedance also is a pure resistance (no reflected reactance).

Figure 9 shows a circuit that is basic to many common electronic circuits. R represents the internal



XL	XC	X TOTAL	REFLECTED IMPEDANCE
20Ω	5Ω	15Ω	(CAPACITIVE)
30Ω	20Ω	10Ω	(CAPACITIVE)
40Ω	50Ω	10Ω	(INDUCTIVE)
30Ω	70Ω	40Ω	(INDUCTIVE)

Figure 8 - Reflected impedance in the primary depends on the secondary circuit.



(BOTH CIRCUITS ARE RESONANT AT THE SAME FREQUENCY)

Figure 9 - Double-tuned transformer-coupled circuit.

resistance of a generator, vacuum tube, or transistor. C1 and L1 form a parallel resonant circuit. C2 and L2 form a series resonant circuit; to see this, keep in mind that the voltage induced into L2, by the current in L1, is in series with L2.

At Resonance

At resonance, the output voltage across C2 is high because the impedance of C1 and L1 is high. This high impedance produces a high voltage across C1 and L1 which, in turn, produces a large current through L1. A large current in L1 results in a large induced voltage in L2 and so, a large secondary current. The large secondary current produces an appreciable voltage across C2.

Below Resonance

Below resonance, the impedance of the parallel circuit formed by C1 and L1 (Fig. 9) is less than at resonance because the inductive reactance is less than the capacitive reactance. However, there is reflected impedance in series with L1. This reflected impedance is inductive because, below resonance, the secondary circuit is capacitive. This added inductive reactance tends to bring the combination of L1 and C1 closer to resonance. Thus, even though the condition is below resonance, the impedance of C1 and L1 can be appreciable and cause the primary current, induced secondary voltage, and output voltage to be appreciably high.

Above Resonance

Above resonance, a similar condition exists. The impedance of C1 and L1 is less than at resonance, because the inductive reactance is larger than the capacitive reactance (at resonance, the inductive reactance equals the capacitive reactance). The reflected impedance is capacitive, however, because the secondary circuit is inductive; this reduces some of the reactance of L1 so that L1 and C1 are again near resonance. This, even though the condition is above resonance, results in the primary current, induced secondary voltage, and output voltage being appreciably high.

Far from resonance, the secondary current is so low that the reflected impedance has very little effect on the behavior of L1 and C1. Then, the impedance of L1 and C1 is quite low, resulting in less voltage across L1, less L1 current, less secondary induced voltage, and appreciably less output voltage.

The net effect of the action near resonance is to broaden the response curve at the top (Fig. 10B). If the primary is too close to the secondary, a double-peak response is the result (Fig. 10C); for this reason, loose coupling between primary and secondary windings is employed. For radio transformers, about one-hundredth of the magnetic lines of force of the primary affect the secondary. For TV receivers, about one-tenth of the primary's magnetic lines of force affect the secondary, because a wider band of frequencies is being amplified; the double-peak response is avoided by adding resistance to the circuit.

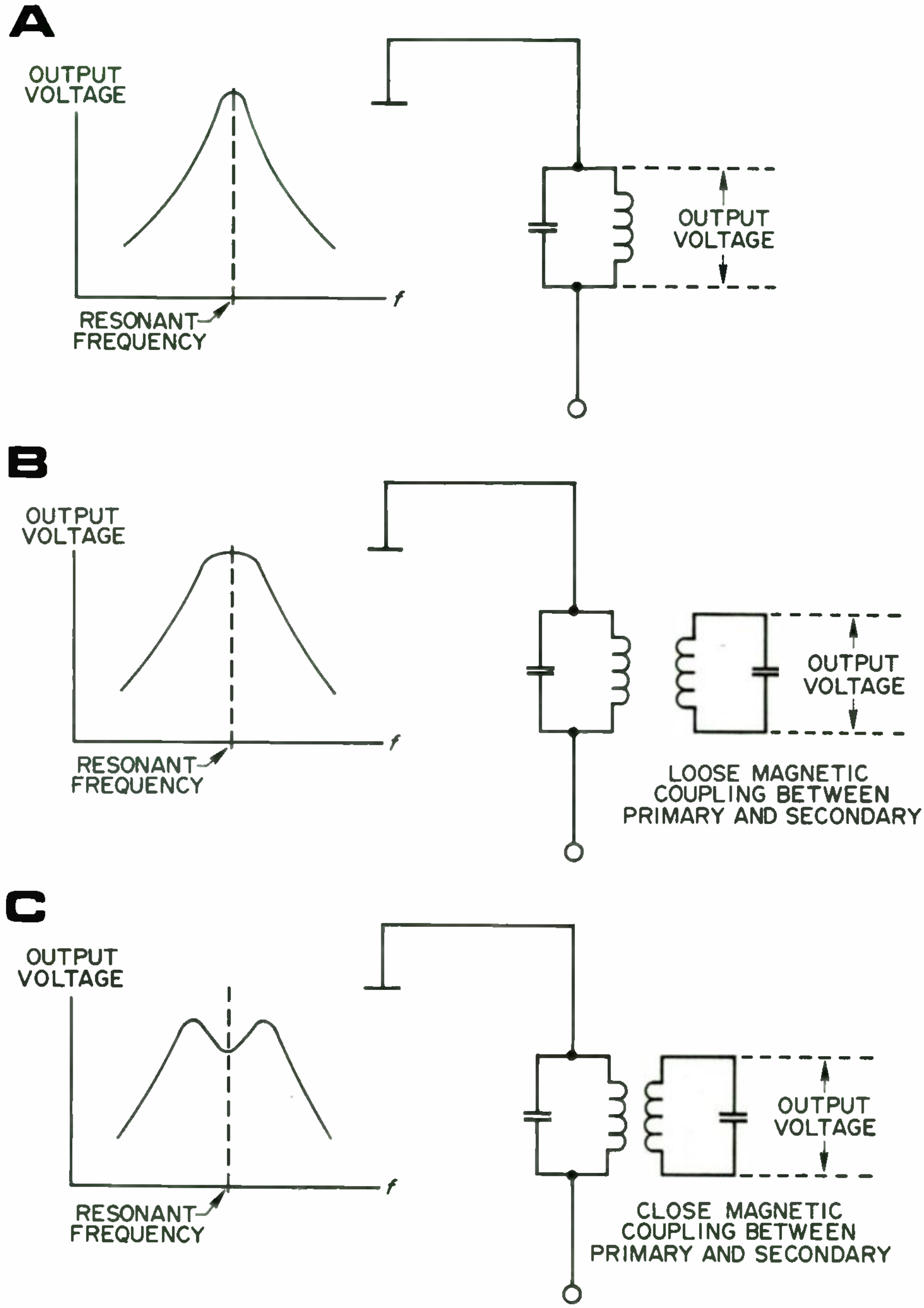


Figure 10 - Comparison of response curves.

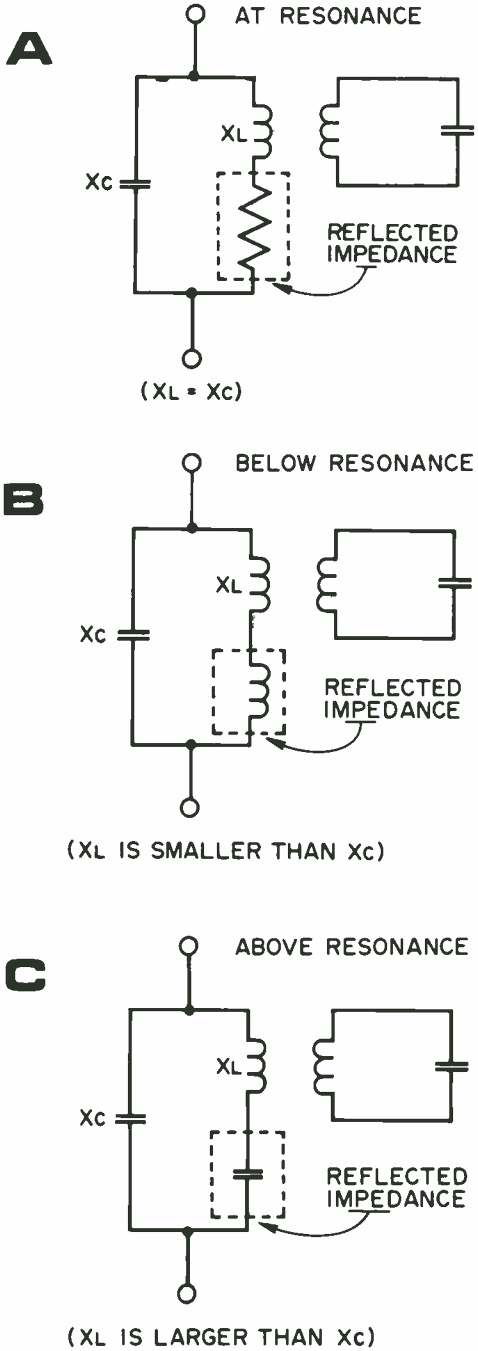


Figure 11 - Review of reflected impedance.

Review

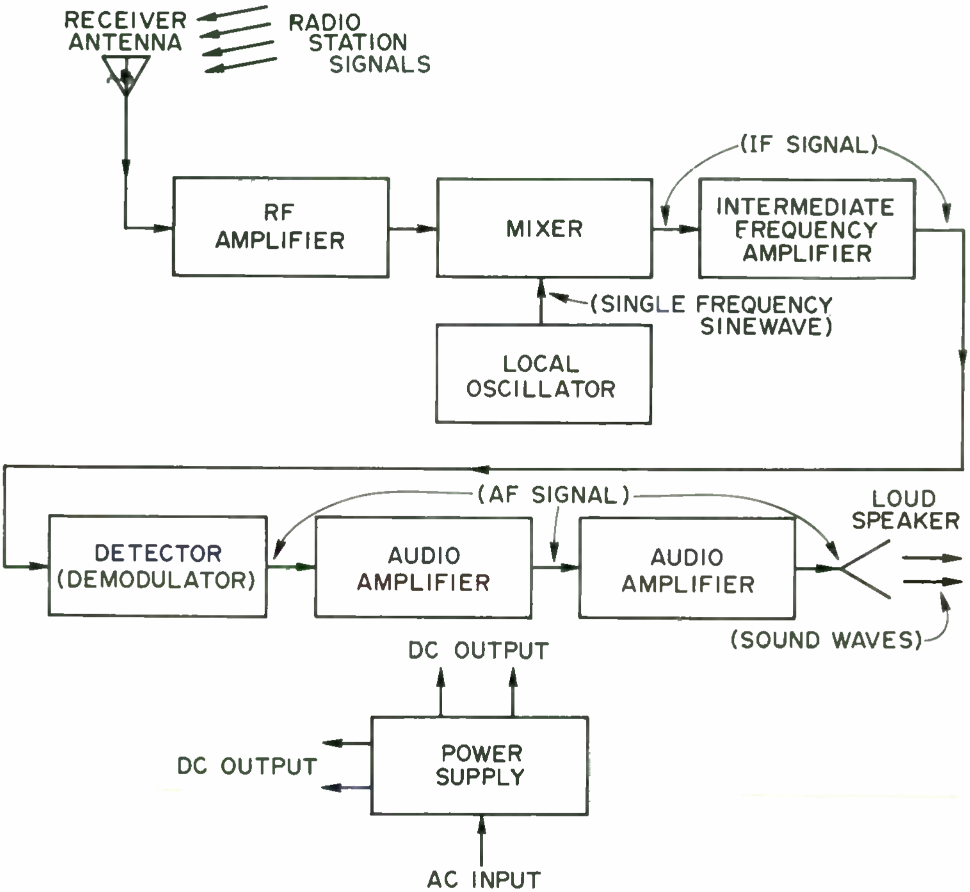
Let us review the reflected impedance in the primary. At resonance, the secondary current is relatively high, because the secondary circuit is a series resonant circuit. The secondary circuit, at resonance, is purely resistive (the reactances cancel), so the reflected impedance is only resistance (Fig. 11A). Below, but near resonance, the secondary current is relatively high. Below, and far from resonance, the secondary current is low. The amount of secondary current determines the amount of reflected impedance. Below resonance, the secondary circuit is capacitive (X_C is larger than X_L), so the reflected impedance is inductive (Fig. 11B). Above resonance, the secondary circuit is inductive (X_L is larger than X_C), and the reflected impedance is capacitive (Fig. 11C). If the secondary circuit is both inductive and resistive (secondary current lags by less than 90°), the reflected impedance is both capacitive and resistive.

BASIC RADIO RECEIVER

AM radio receivers receive radio frequencies from 540 to 1,600 kilohertz. The audio frequencies extend from 20 to 5,000 hertz. Each station utilizes 10 kilohertz of the radio frequency spectrum, because an AM signal has a channel width equal to twice the highest audio frequency. A station transmitting at 540 kHz requires spectrum space from 535 to 545 kHz. A station transmitting at 720 kHz requires a channel extending from 715 to 725 kHz. Usually, the channel width is understood to exist, and reference is made to just the carrier frequency.

Example of Tuning

Assume that signals from four equally powerful radio stations are affecting the receiver antenna (Fig. 12). These stations are at 600, 800, 1,000 and 1,200 kilohertz. If a tuned circuit is resonant at 600 kHz and placed at the input portion of the RF amplifier, the 600-kHz signal will be favored over the other three station signals. Thus, the action of the tuned



FREQUENCY TUNED IN	LOCAL OSCILLATOR FREQUENCY	MIXER OUTPUT (IF)
600 KHz	1,055 KHz	455 KHz
800 KHz	1,255 KHz	455 KHz
1,000 KHz	1,455 KHz	455 KHz
1,200 KHz	1,655 KHz	455 KHz

Figure 12 - Basic Radio Receiver.

circuit results in "selectivity" (ability to reject other signals). The four signals will all be present at the input circuit, but they no longer are at equal strength.

There will also be a resonant circuit at the output portion of the radio frequency amplifier. This resonant circuit is serving as a load for the plate of a vacuum tube or the collector of a transistor and will further reduce the relative strengths of the three stations (800, 1,000, and 1,200 kHz). The strength of the 600-kHz signal at the output is usually about 10 or 20 times the strength at the RF amplifier input.

Local Oscillator

An oscillator is an electronic AC generator. In this example, it is generating a 1,055-kHz sine wave. The IF amplifiers are tuned to accept and pass a fixed frequency of 455 kHz. The mixer output is a signal whose frequency is the *difference* between the RF amplifier output frequency and the oscillator frequency. If the 800-kHz signal were to be tuned in, the local oscillator frequency is 1,255 kHz. When the 1,000-kHz station is tuned in, the oscillator frequency is 1,455 kHz. When the 1,200-kHz signal is being received, the local oscillator frequency is 1,655 kilohertz. There is amplification in the mixer stage; that is, the strength of the IF signal at the mixer output is greater than the strength of the RF signal at the mixer input.

IF Amplifier

An IF amplifier is a high frequency amplifier. Since it amplifies the same frequency, regardless what station is being received, it can be a very specialized amplifier that would operate poorly at frequencies other than the IF frequency of 455 kHz. The IF amplifier output signal can be as much as two hundred times greater than the IF amplifier input signal. This much amplification would be impossible to realize in the RF amplifier, because compromises must be made in order to amplify frequencies covering the wide range from 540 to 1,600 kilohertz.

Detector

The IF signal is the detector input; the detector output is the original radio station audio signal. The audio signal strength at the detector output is about one-tenth of a volt. The signal at the antenna could have been much less than a millivolt (0.001 volt). If the antenna signal is 0.1 millivolt (0.0001 volt), an amplification of a thousand is necessary to raise the signal level to one-tenth of a volt.

The audio amplifiers further strengthen the audio signal, and the loudspeaker produces sound waves that conform to the audio electrical signal. The input to the power supply is AC. The power supply DC outputs are connected to the various stages. Vacuum tube and transistor circuits are basically DC circuits.

TUNED AND UNTUNED TRANSFORMERS

Receiver Input Circuit

Figure 13A shows a receiver transformer coupled input to an RF amplifier stage. The primary is untuned, and the secondary is tuned. The primary winding has currents from many radio transmitters; these currents induce corresponding voltages into the secondary winding. The secondary winding and C1 form a resonant circuit. The station having the same frequency as the resonant circuit will have a large secondary current; all other stations will have relatively weak currents in the transformer secondary circuit. The secondary current multiplied by the reactance of C1 equals the voltage connected to the grid of the RF amplifier tube. Practically speaking, the grid voltage is the signal voltage of only one station, though theoretically, other stations are present though they are much weaker. The strength of the other stations is about one-hundredth of the strength of the desired station, though a station having a frequency close to the desired station has a strength of approximately one-tenth. The plate current is controlled by the grid voltage, so the plate current has exactly the same form as the input grid voltage. C1 is the tuning control or station selector.

The same circuit, essentially, but using a transistor, is shown in Figure 13B. The primary of the antenna transformer is untuned; the secondary and C1 form a resonant circuit. The resonant circuit favors a single station frequency. C1 is variable so that various stations can be selected or tuned in. C2 is a coupling capacitor and has a low reactance at radio frequencies. Thus, the voltage across C1 is also the AC base voltage. R1 and R2 determine the DC base voltage; the emitter-to-base resistance, within the transistor, is in parallel with R1. Sometimes, R1 is omitted. An NPN transistor is being used as the RF amplifier. The collector current is controlled by the base current, so the collector current has exactly the same form as the input base current.

RF Amplifier Output

Another application of an RF transformer with an untuned primary and a tuned secondary is shown in Figure 14A. The RF amplifier plate current is also the primary current. The plate current is controlled by the grid voltage. The primary current induces a voltage in the RF transformer secondary winding. This induced voltage causes a current to circulate in the resonant circuit formed by C3 and the secondary. The secondary current multiplied by the reactance of C3 equals the capacitor voltage; this voltage is connected to the grid of the next stage. Note that C3 is a part of a series resonant circuit, even though it is connected in parallel with the secondary of the RF transformer; the reference is the voltage induced in the secondary. This induced voltage "sees" a series resonant circuit formed by the secondary winding *in series* with C3. We need to visualize that there is an AC generator in series with the secondary; this AC generator represents the voltage induced in the secondary by the primary current.

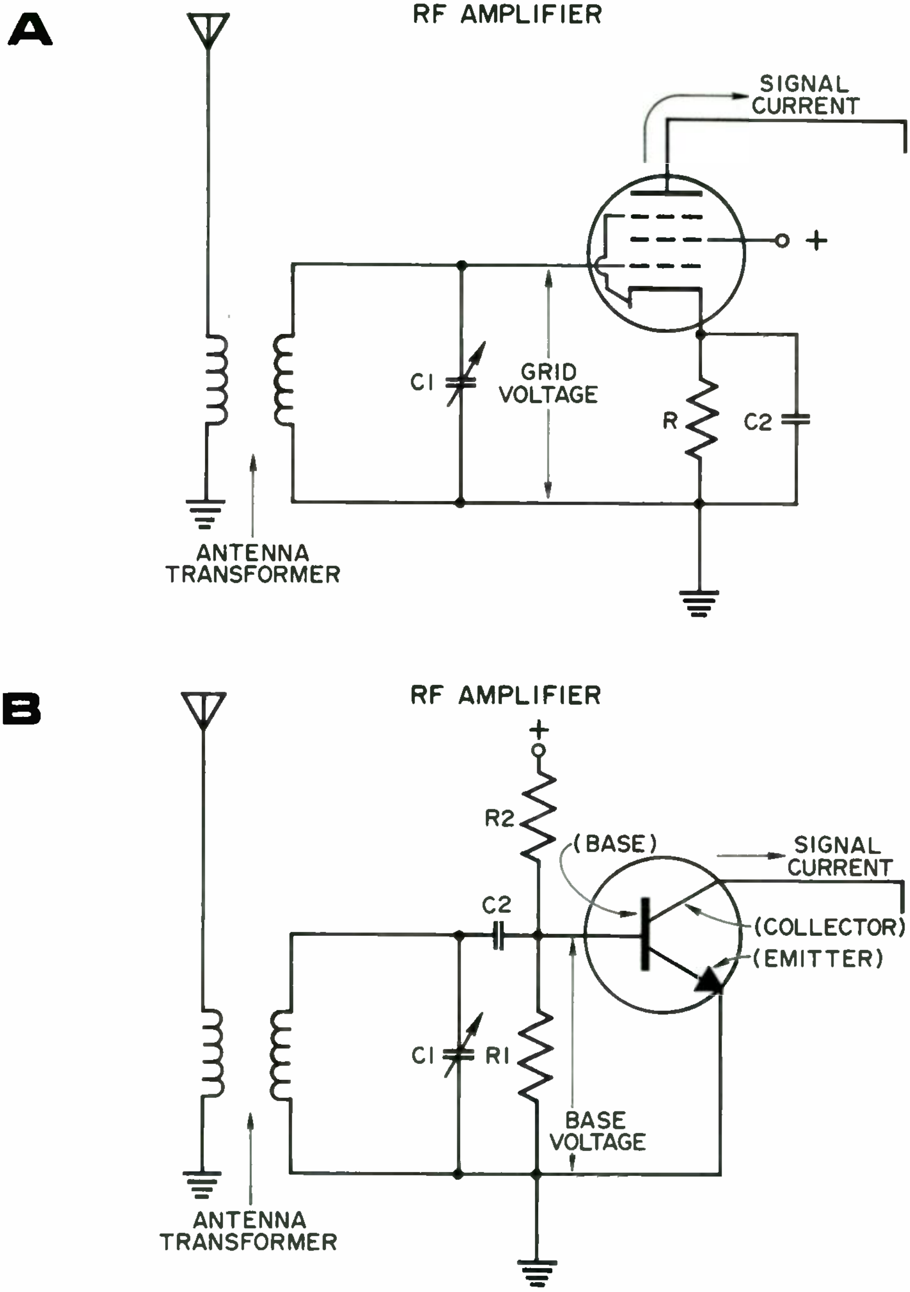


Figure 13 - Radio Receiver Transformer Input Circuit.

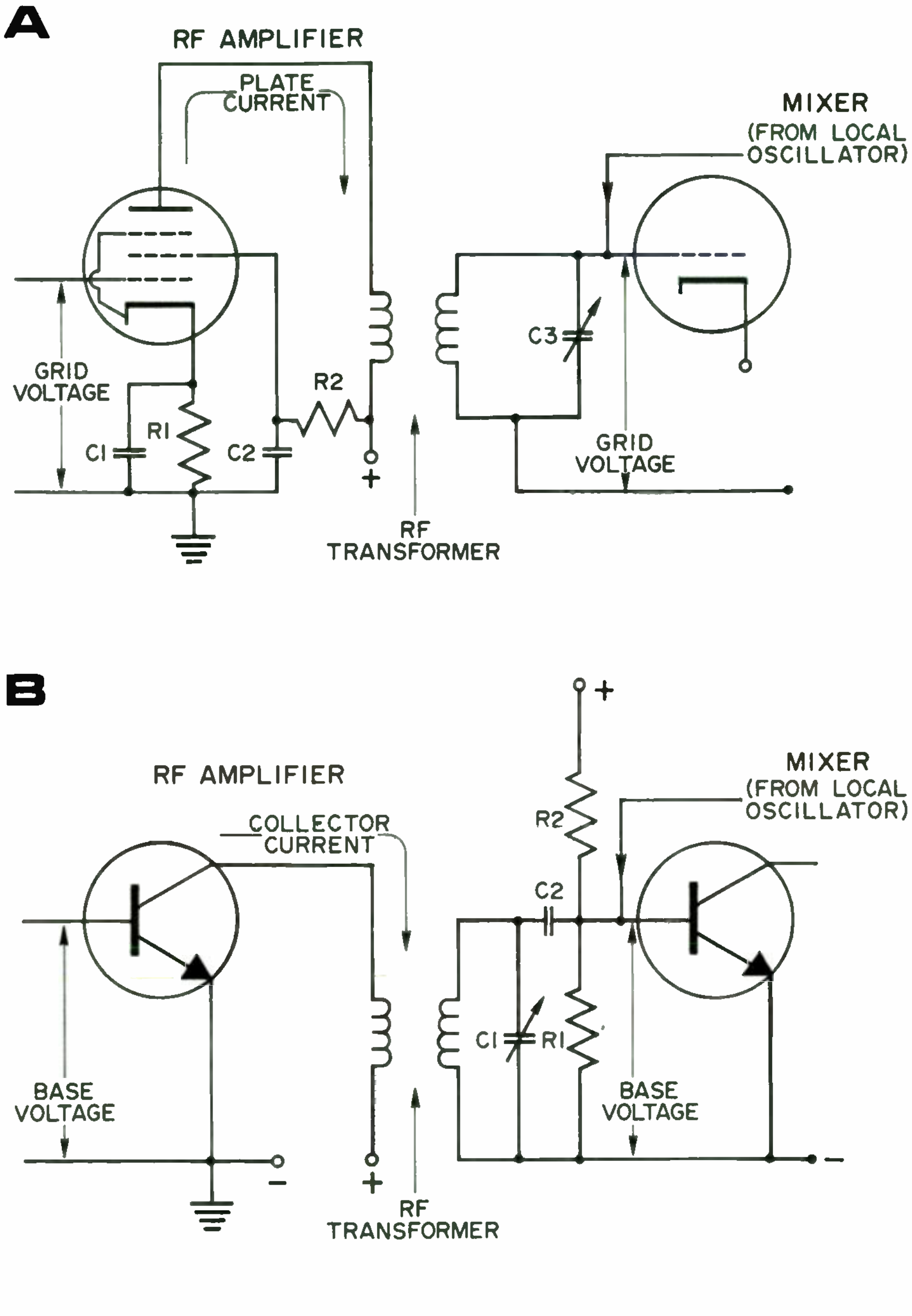


Figure 14 - RF transformer (Tuned Secondary).

The same circuit, but using transistors, is shown in Figure 14B. The base voltage of the RF amplifier determines the base current (emitter to base). The base current controls the collector current. The path of the collector current, starting at the emitter, is:

emitter to collector,
from collector to the primary,
through the primary to the power supply,
through the power supply to the emitter.

As previously stated, the primary current induces a voltage that is in series with the secondary. This voltage causes a current in the series resonant circuit formed by the secondary and C1. The secondary current causes a voltage across C1; this voltage is coupled, via C2, to the base of the mixer stage. The base also receives an AC voltage from the local oscillator. C1 is the tuning condenser or station selector. When there is to be a station change, both C1 of Figure 13B and C1 of Figure 14B are varied at the same time, since they are mechanically mounted on the same shaft and adjusted by a single knob. Not only would these two capacitors be "ganged" on the same shaft, but also a third capacitor in the local oscillator section would be mounted there. This is necessary in order to have simplified tuning. If three separate capacitors were used, many receiver owners would find station-finding cumbersome, or even impossible. If the primary of the RF transformer (Fig. 14B) were tuned, another section is required on the variable capacitor; this makes the capacitor larger and more expensive. For this reason, one winding of RF transformers is usually untuned.

The response of an amplifier section such as shown in Figures 14A and 14B is essentially that shown in Figure 10A. The amount of coupling between primary and secondary determines the amount of amplification. A large amount of amplification is undesired, because the amplifier stage then tends to be an AC generator (oscillator). This is due to there being some undesired feedback between the amplifier output and the input.

Note that throughout this discussion, no mention was made regarding turns ratio of the transformer. The idea of turns ratio applies only in the case where there is very close coupling between the primary and secondary. This occurs when an iron core is used as in power and audio transformers.

Car Radio Antenna Transformer

A tuned primary antenna transformer circuit is often used in car radios (Fig. 15). L1 is called a loading coil; it is an antenna "stretcher." Long antennas are theoretically required for broadcast frequencies, and adding an inductor in series increases the electrical length of the antenna. The capacitor C is not the tuning capacitor; it is adjusted for maximum sound volume at the high end of the broadcast band. When this is done, the antenna should be in the position that it will be when the radio is operated. L2 is the tuning inductor. Varying the position of the slug within the coil varies the inductance and so, the

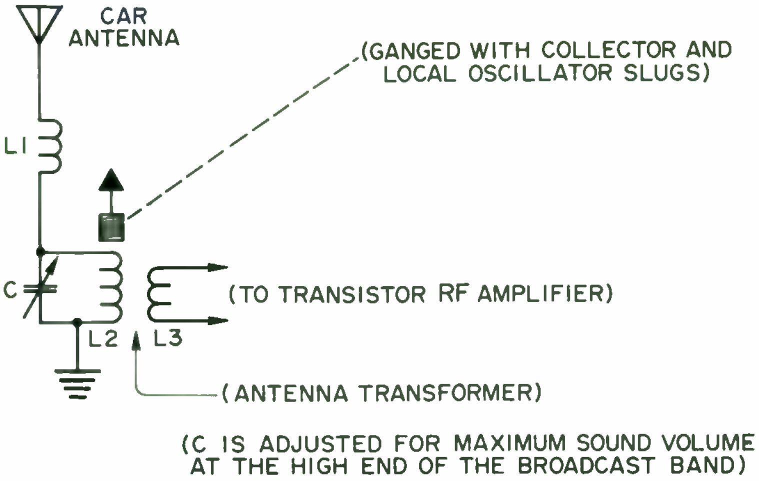


Figure 15 - Car radio antenna transformer (mobile antenna).

resonant frequency of L2 and C. For simplified tuning, this slug is mechanically linked to the transistor collector and local oscillator tuned circuit slugs. The coupling between L2 and L3 is not adjustable; this is typical for modern high frequency transformers. The response of the entire circuit is as in Figure 10A.

Single-Tuned IF Transformer

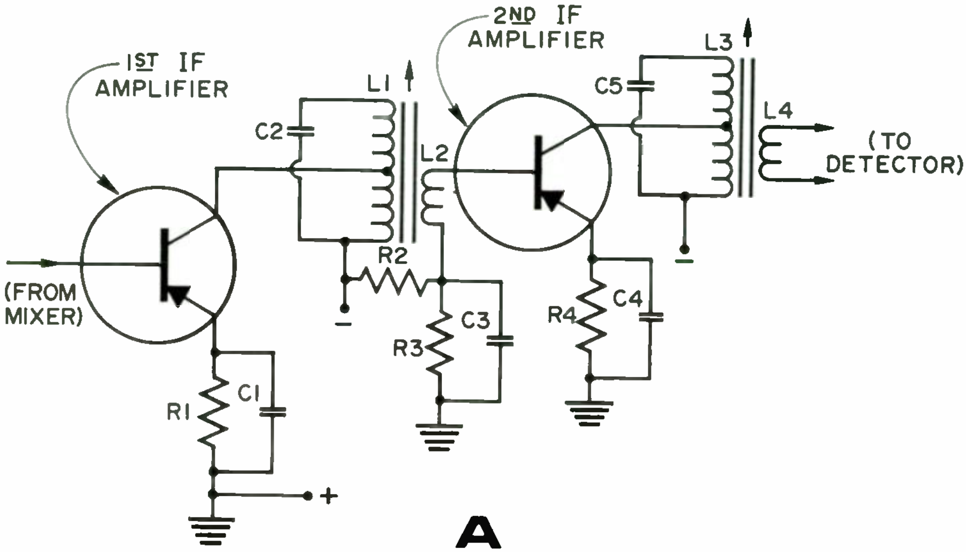
Single-tuned transformer coupled circuits are occasionally used in IF amplifiers (Fig. 16A). This broadcast radio receiver has two IF amplifier stages. The path of the first IF collector current is as follows:

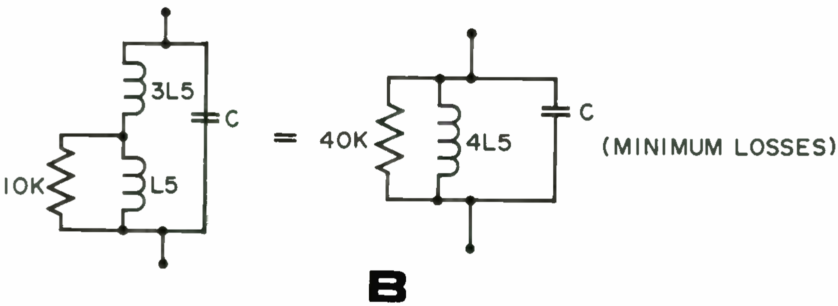
> from the minus DC voltage terminal and through the lower portion of L1, through the transistor (collector to emitter), through R1 and to the positive DC voltage terminal.

The path of the second IF collector current is very similar. The path of the second IF base current is as follows:

> from the minus DC voltage terminal through R2, after R2, there is a parallel circuit; R3 forms one branch, L2, the transistor internal resistance from base to emitter, and R4 form the other branch, the ground point is connected to the positive DC voltage terminal; electrons flow within the DC voltage source, positive to negative.

L1 and C2 form a resonant circuit. The collector of the first IF amplifier is connected to a tap on L1; this type of circuit connection minimizes the added losses of the resonant circuit. If the collector were connected to the top of L1, the bandwidth of the response would be wider; it is the transistors internal resistance from collector to emitter that is adding losses to the resonant circuit. Let us assume that the tap on L1 of Figure 16A is at one-fourth of L1; also, let us assume that the collector





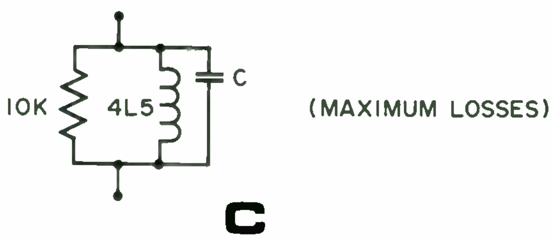


Figure 16 - IF transformer (Tuned primary).

to emitter transistor resistance is 10 K (Fig. 16B). Then placing 10 K at one-fourth of the coil is the equivalent of placing 40 K across the entire coil. A 40 KΩ resistor adds *less* loss in parallel than a 10 KΩ resistor would (Fig. 16C); a larger resistor has *less* current. The losses are calculated by using the formula E times I; E is the same for both circuits, but I is less for the larger resistor. If the resistor were in series with the coil, however, a larger resistor increases the losses.

L2 of Figure 16A is untuned so the response of the first IF amplifier is that of Figure 10A. The second IF amplifier has the same response. L3 and C5 form a resonant circuit. L4 is untuned and feeds the IF signal to the detector stage. Both transistors are of the PNP type. L1 and L3 are adjustable by means of slugs. C2 and C5 are fixed capacitors. The two resonant circuits L1/C2 and L3/C5, are resonant to the IF frequency of 455 kHz; their tuning is not changed when stations are changed. The slugs of L1 and L3 are adjusted when 455 kHz is supplied to the receiver by a signal generator; this is called receiver IF "alignment." The 455-kHz from the signal generator would not be connected to the antenna circuit but to the grid or base of the mixer stage.

SERIES AND PARALLEL TUNING

Double-tuned IF transformers are used for interstage coupling in Figure 17A. The primary is parallel resonant so that a high impedance is offered to the mixer and IF amplifier plate currents. The secondary circuits are series resonant, the reference being the voltage induced in the secondary winding by the primary current. C3 resonates with the secondary of T1, and C6 resonates with the secondary of T2. The response of each stage is shown in Figure 10B; sometimes a response similar to Figure 10C is used, providing the dip in the center is not too pronounced. The coupling between the primary and secondary is not adjustable. For IF transformers in radios, the distance between the primary and the secondary ranges from approximately one-half inch to one inch. The path of V3 DC plate current is as follows:

> from cathode to plate, through the primary of T2, into the positive DC voltage terminal, through the DC voltage source, positive to negative, out of the negative DC voltage terminal, through R2, and to the cathode of V3.

R2 is a bias resistor; its value determines the starting point or starting level of the plate current. When the IF signal is applied to the grid of V3, the plate current varies above and below this starting point. C4 is a "by-pass" capacitor; it has a low reactance in comparison with R2's resistance. If C4 is removed, there is less IF signal current through V3. To adjust C2, C3, C5, and C6, the tuning knob is first set at a point where no station is being received. Then, a signal generator is connected to the mixer grid, and the signal generator output frequency is set at the IF frequency. The local oscillator is disabled. Now these four capacitors can be adjusted for maximum sound from the loudspeaker (a 400 hertz tone is heard).

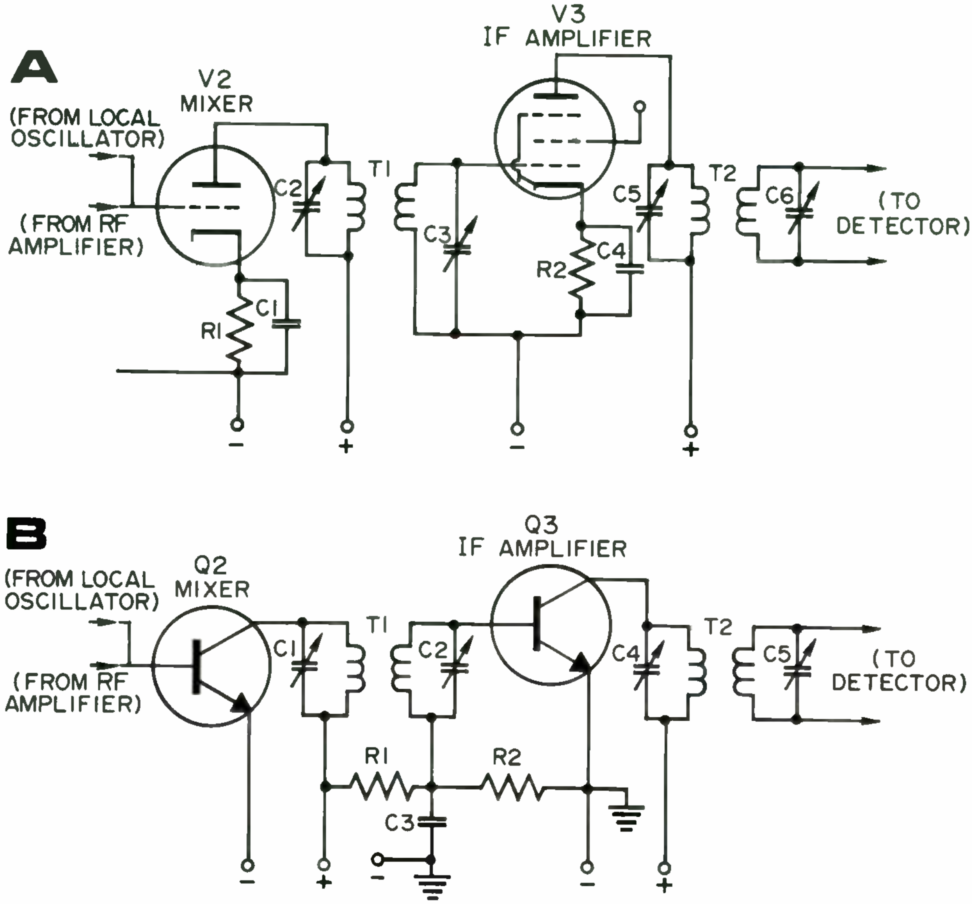


Figure 17 - Double-tuned IF transformers (Capacity-tuned).

Figure 17B shows double-tuned IF transformers with transistors. The mixer DC collector current passes through the primary of T1. However, the mixer current is pulsating DC, which means that there is also an AC component. This AC component passes through the resonant circuit formed by C1 and the primary of T1, producing a relatively high AC voltage. Figure 18A shows an example of DC current varying between 4 ma and 6 ma. The pure AC component (Fig. 18B) is varying from minus 1 to plus 1 milliampere. The pure DC component is 5 ma (Fig. 18C). The base current of Q3 (Fig. 17B) is also pulsating DC. Pulsating DC is typical of transistor and vacuum tube circuits.

R1 and R2 (Fig. 17B) form the base biasing circuit for Q3. C3 has a low reactance at the IF frequency so that, essentially, the lower terminal of C2 is connected to the emitter of Q3. C3 *is* called a "by-pass" capacitor but in its operation, it is more of a *coupling* capacitor (couples the lower terminal of C2 to the emitter of Q3).

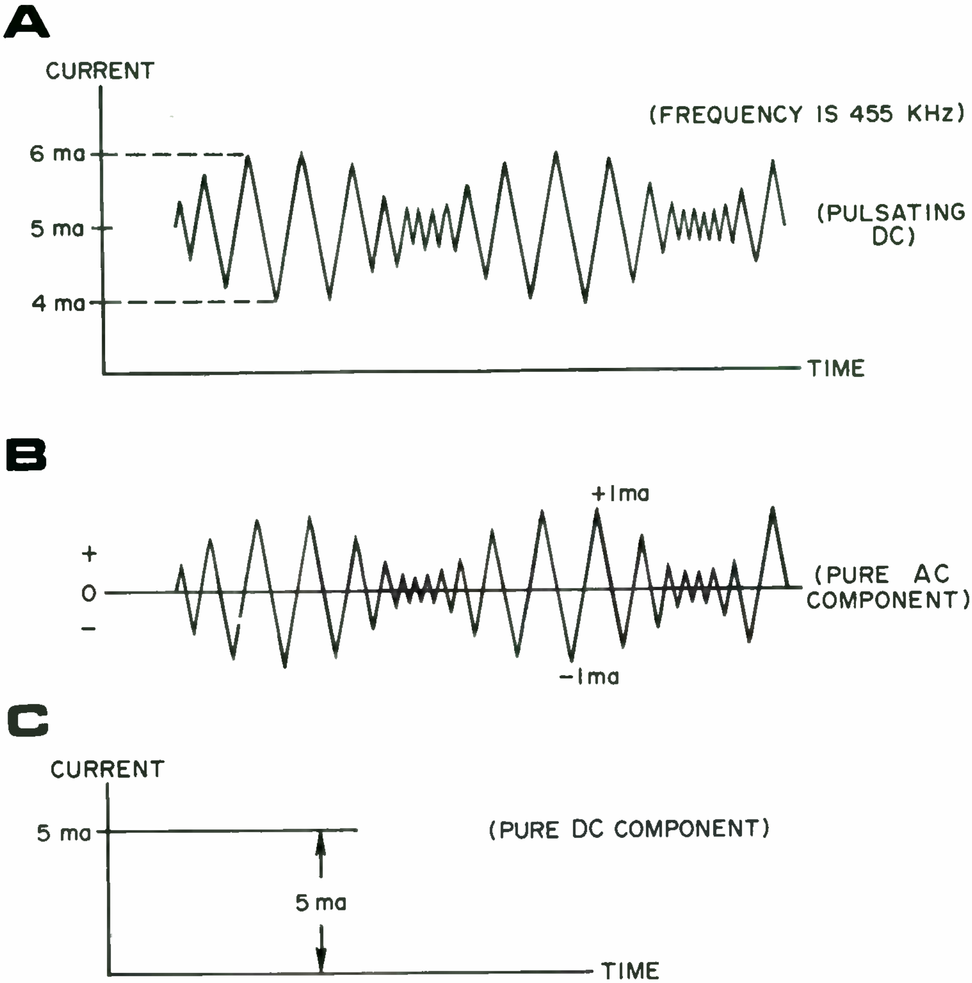


Figure 18 - Pulsating DC collector current.

Practically speaking, then, the AC voltage across C2 is connected to the base and emitter of Q3. The resonant circuits could have been slug-tuned instead of capacity-tuned; in that event, the operation and response would still be identical in all respects.

A minor variation of double-tuned IF transformers (Fig. 19A) connects both collector and base to taps on T1. This is done to minimize the losses in the resonant circuits. This variation is common when transistors are used because of the relatively low transistor internal resistances in comparison with vacuum tubes. The primaries and secondaries of T1 and T2 are tuned by adjusting the position of the slugs.

In the circuit of Figure 19B, only the secondary winding of the IF transformer is tapped. The primary and secondary of the transformer are slug-tuned.

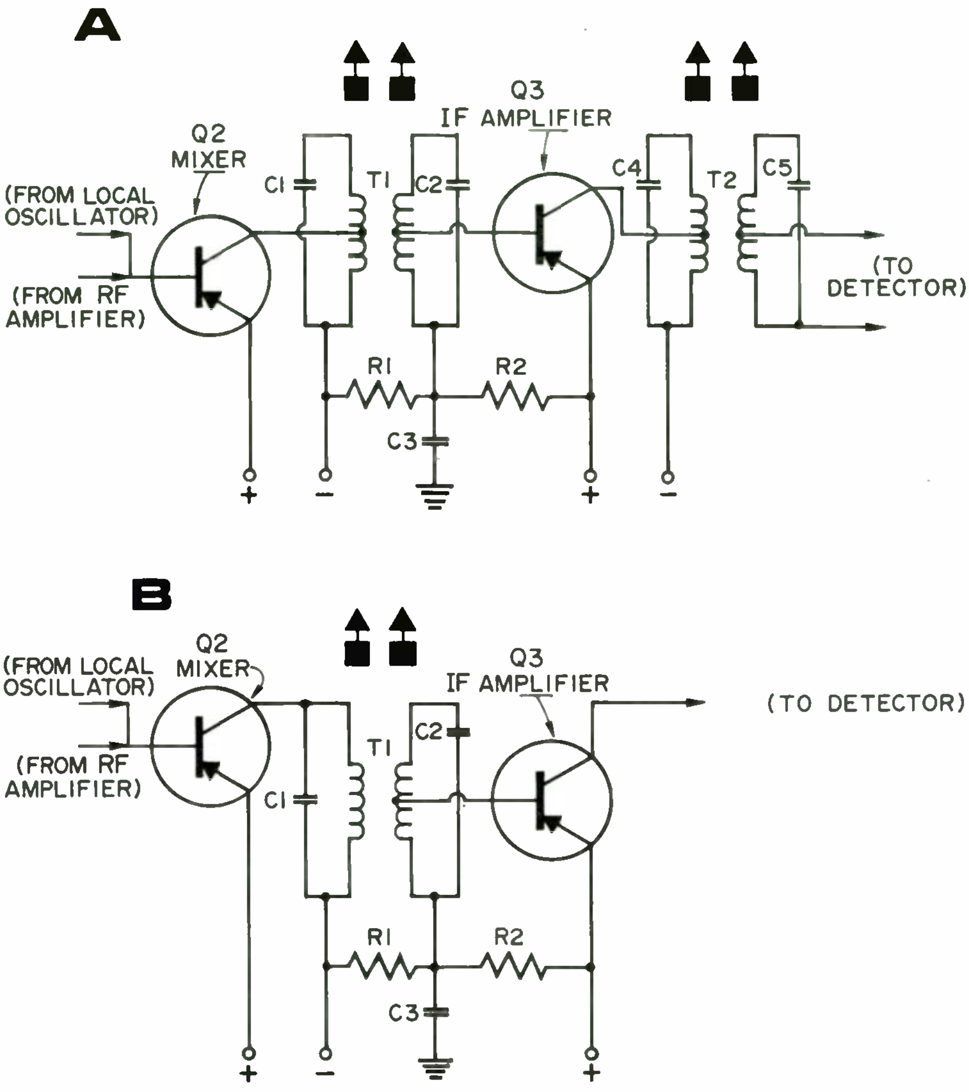


Figure 19 - Double-Tuned IF transformers (Slug-tuned).

Figure 20 shows representative RF and IF transformers. When there are metallic enclosures for the transformers, these enclosures are connected to the chassis by mounting bolts and act as electric shields. This shielding effect prevents interaction between transformers.

BROADBAND IF SYSTEMS

A TV signal is a broadband signal. TV receiver video (picture) IF amplifiers should have a bandwidth of 4 megahertz. Thus, if a receiver's video IF frequency is 25.75 MHz, the response of the video IF section

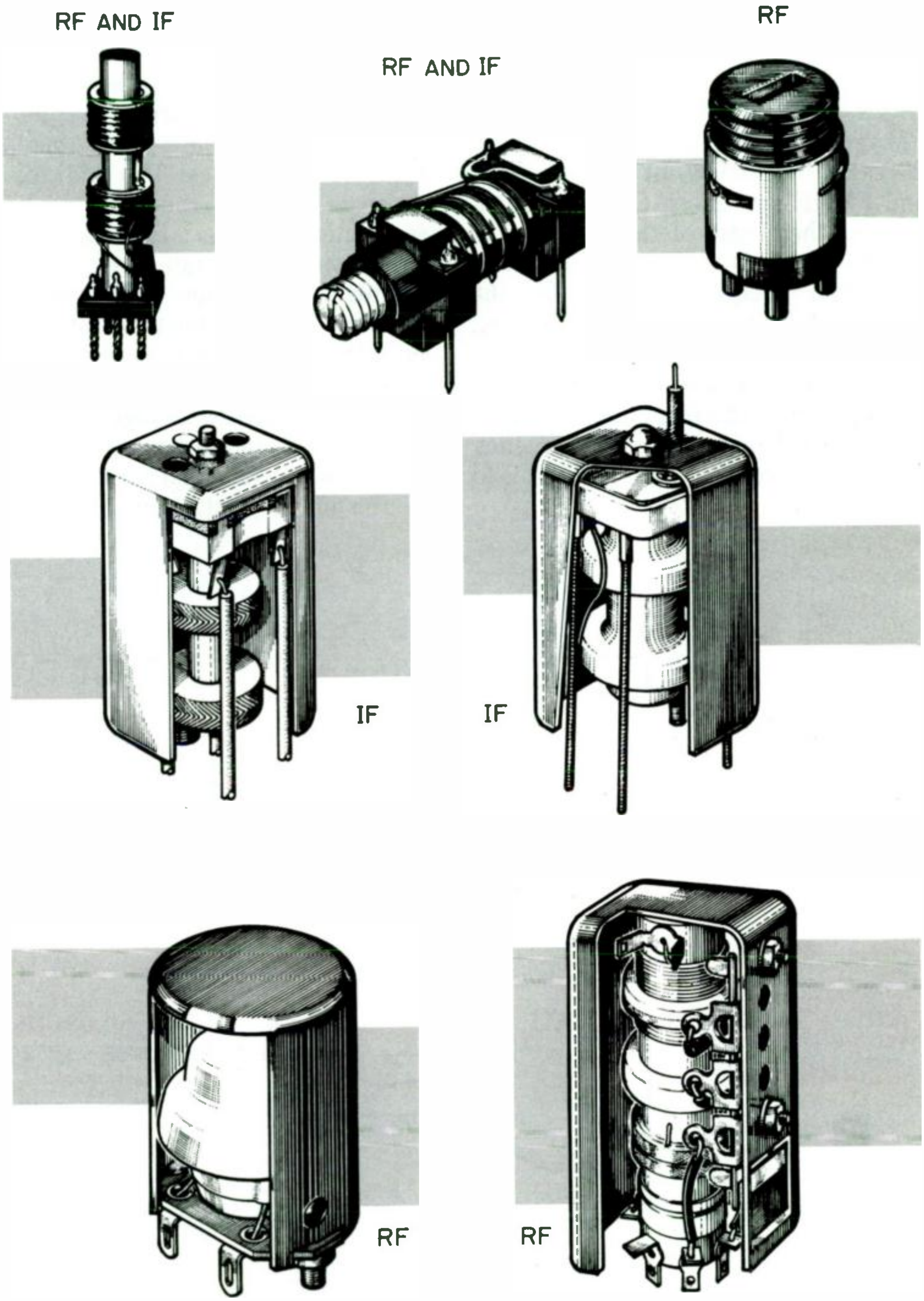


Figure 20 - RF and IF transformers.

should extend from 21.75 MHz to 25.75 MHz. This is a very wide band in comparison with AM broadcast where a 10kHz (0.01 MHz) band width is required. The IF section of FM receivers requires a bandwidth of 200 kHz (0.2 MHz). In AM broadcast and FM IF amplifiers, the IF frequency is at the center of the response. In TV receivers, the IF frequency is at the high frequency side of the response because, practically speaking, the picture signal is a single side band signal. A common video IF frequency is 45.75 MHz; the response of a video IF section having that IF frequency extends from 41.75 MHz to 45.75 MHz.

Increase of Coupling

The main method of achieving broadband responses is by the addition to the resonant circuits of resistors having low and medium values of resistance. The addition of resistors removes the high peaks at resonance and gives a leveling effect to the response. Figure 21A shows a double-tuned circuit with increased coupling and added resistors for broadening of the response. The internal resistance is that of a tube or transistor amplifier equivalent circuit. The circuits are adjusted to resonance by adjusting the capacitors C1 and C2 or the inductors L1 and L2. Neither

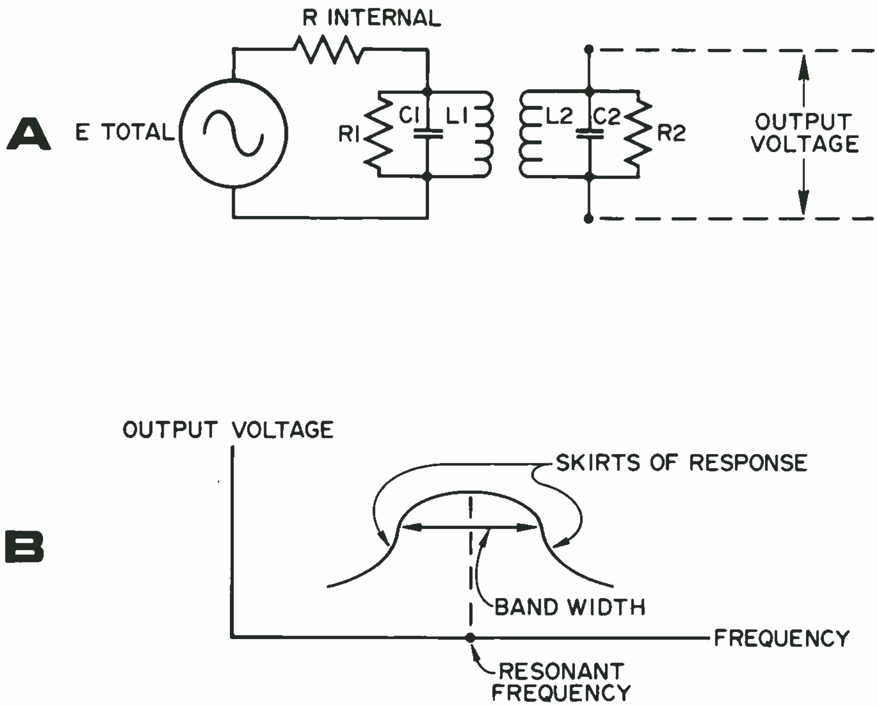


Figure 21 - Increase of band width by adding losses (Resistance) and increasing the coupling between primary and secondary.

are shown as being variable. In some cases, especially when the video IF is a high frequency, C1 and C2 are omitted for simplicity and economy. In that event, the inductors L1 and L2 still are parts of resonant circuits, the capacity being the stray capacity of the components and wiring. The values of R1 and R2 are approximately 5 to 10 K.

Figure 21B shows the broadened response when resistors have been added. The coupling between primary and secondary is greater for TV than it is for AM broadcast or FM. The response of an IF section can be seen by using an oscilloscope. A station is not tuned in; instead, a signal from an FM generator is used. The FM generator is called a *sweep* generator because the amplifiers are being tested for various frequencies in an orderly fashion (the input signal frequency is "swept" over a range of frequencies).

Transformer Equivalent T

An equivalent circuit of a transformer is an inductive T circuit. Figure 22A shows the use of an inductive T instead of a transformer in a TV wide band IF amplifier. The voltage across L3 would be the same as the voltage induced in the secondary by the current in the primary (primary and secondary in the equivalent transformer circuit). R1 and R2 are response broadening resistors;

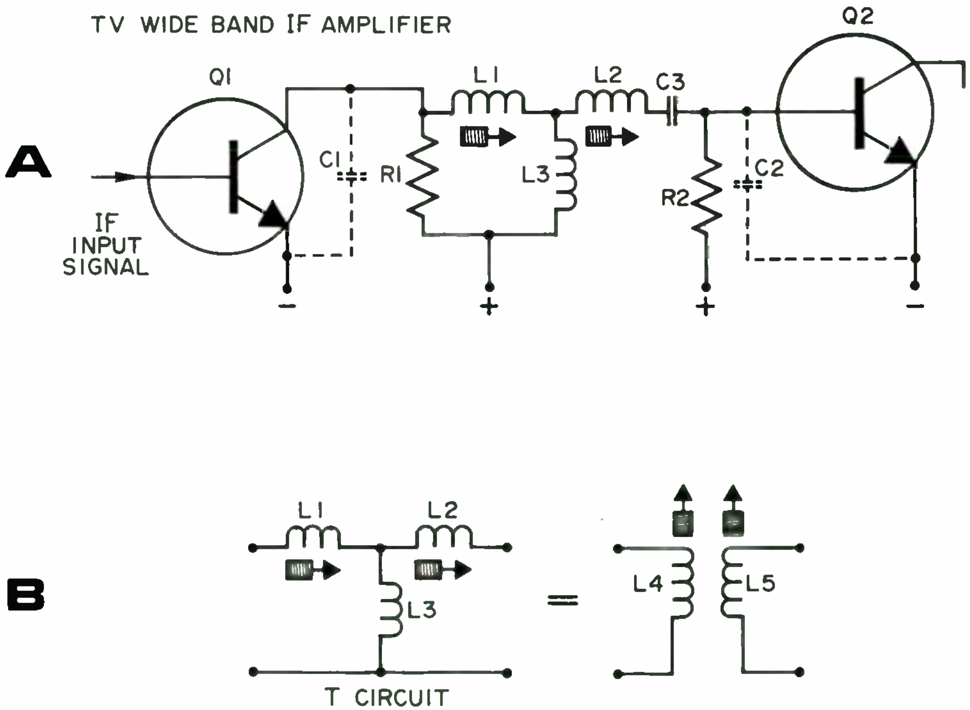


Figure 22 - Use of equivalent T circuit in a wide band IF amplifier.

their value is about 5 to 10 K. C1 and C2 represent component and wiring stray capacity; their value is about 2 to 5 picofarads for transistors and about 10 to 15 picofarads for vacuum tubes. L1 and L2 are variable to vary the resonant frequency during receiver alignment; L1 resonates with C1, and L2 resonates with C2. C3 is a DC blocking capacitor that is needed because the DC voltage at the collector of Q1 is different than the DC voltage at the base of Q2. It is also called a coupling capacitor because its capacitive reactance, in comparison with the reactance of L2 and C2, is low. Figure 22B shows the equivalency between an inductive T circuit and a transformer.

Transformer Equivalent Pi

Another equivalent circuit of a transformer is an inductive pi (π) circuit. Figure 23A shows a TV wide band IF amplifier using a pi circuit. L1 is variable and resonates with C1; L3 is variable and resonates with C2. Figure 23B shows the equivalency between an inductive pi circuit and a transformer.

Staggered Tuning

Sometimes, all the IF stages are not tuned to the same frequency. Figure 24A shows that the first video IF amplifier is resonant at f1 and the

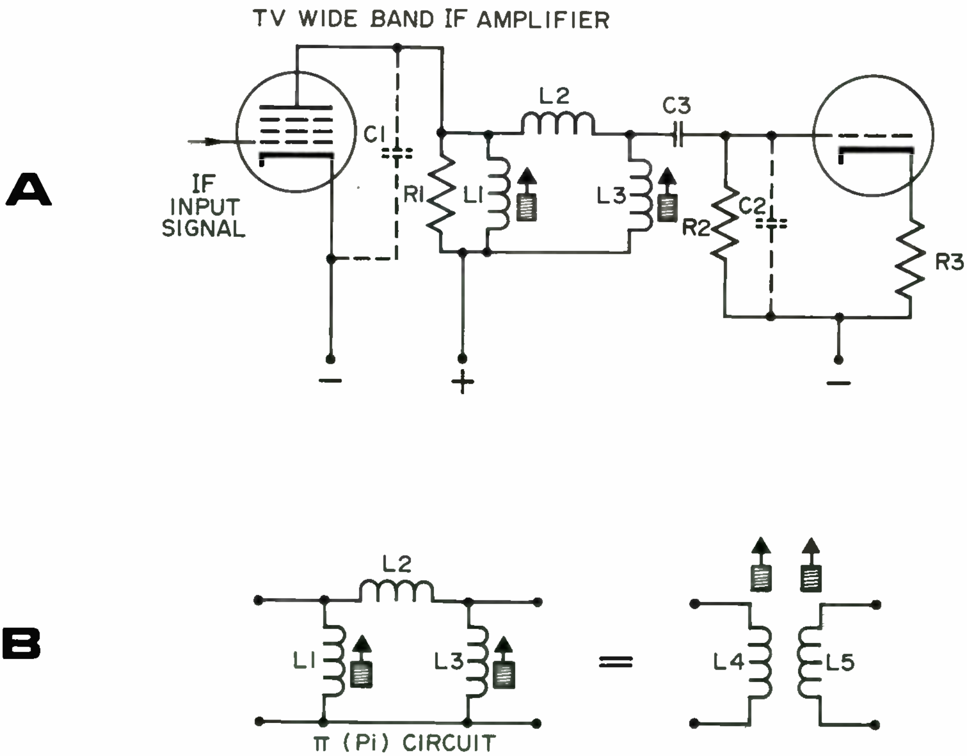


Figure 23 - Use of equivalent pi circuit in a wide band IF amplifier.

second video IF amplifier is resonant at f2. Figure 24B shows that if f1 and f2 are properly separated, then the combined response is smooth and broadband. This type of operation is called *staggered tuning* or a staggered pair (two stages). R1 through R4 are about 10 to 20 K because the response of the T1 or T2 circuit, alone, is not attempting to cover the entire 4-MHz bandwidth.

More than two stages can be staggered. Figure 25A shows three stages tuned to three different frequencies. If the resonant frequencies and the loading resistors are properly selected, the overall response of the entire three stage section is not only broadband but also smooth (Fig. 25B). During the alignment of these stages, the total response is displayed on an oscilloscope; then, the first stage is adjusted for a best appearing left side of the response, the second stage is adjusted for a best appearing center of the response, and the third stage is adjusted for a proper right side. Any of the three stages can be adjusted first.

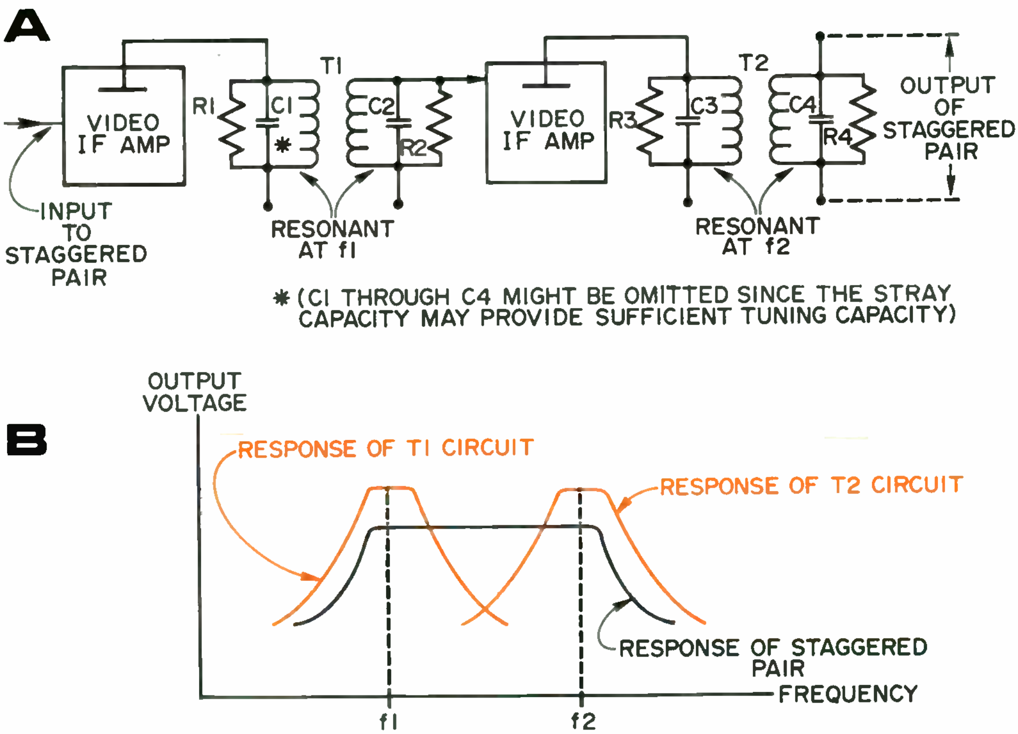
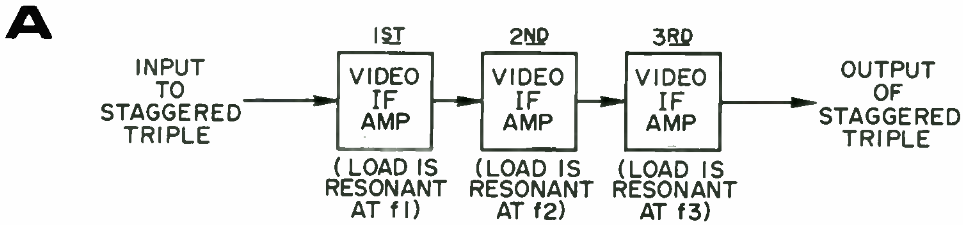


Figure 24 - Broadband staggered pair.



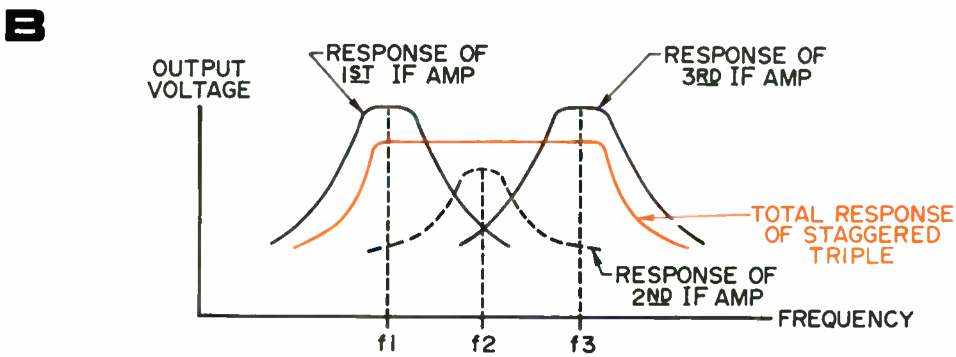


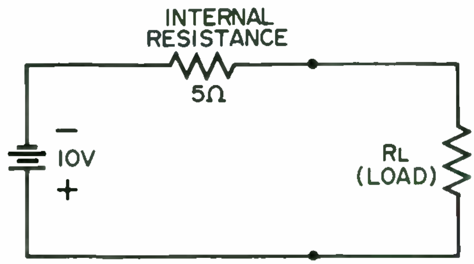
Figure 25 - Broadband staggered triple.

IMPEDANCE MATCHING

All sources of voltage and current have internal resistances or internal impedances. These sources are always connected to a load resistance or a load impedance. When maximum output current is desired, the load is as small as possible (Fig. 26A); a short circuit (zero ohms) results in maximum output current. When maximum output voltage is desired, the load is as large as possible (Fig. 26B); an open circuit (infinite ohms) results in maximum output voltage. If R_L is open, there is no current in the circuit and so, no voltage (zero volts) across the 5 ohm resistor; in that case, the voltage at the output terminals is 10 volts. When maximum output *power* is desired, the load is the *same* as the internal resistance. If the internal resistance is 5 ohms (Fig. 26C), there is maximum power in the load when the load equals 5 ohms.

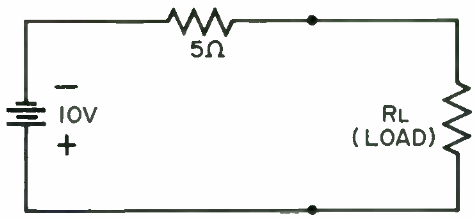
If the load is a little smaller than the internal resistance, say 4 ohms, the output power is less than the maximum. If the load is a little larger than the internal resistance, say 8 ohms, the output power is again less than the maximum. This example of Figure 26C demonstrates that there is maximum power transferred into the load when the load resistance equals the source voltage's internal resistance. When the resistances are the

A



FOR MAXIMUM OUTPUT CURRENT, RL = 0Ω

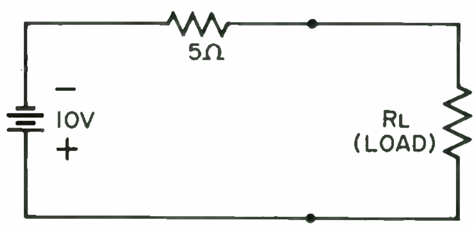
B



FOR MAXIMUM OUTPUT VOLTAGE, RL IS LARGE

RL	OUTPUT VOLTAGE
5Ω	5 VOLTS
20Ω	8 VOLTS
95Ω	9.5 VOLTS

C



FOR MAXIMUM OUTPUT POWER,
RL = R INTERNAL = 5Ω

RL	RT	I	I^2R (POWER)
4Ω	9Ω	1.11A	$(1.11)^2 \times 4 =$ (1.23 x 4 = 4.92 WATTS
5Ω	10Ω	1.00A	$(1.00)^2 \times 5 =$ (1 x 5 = 5.00 WATTS (MAXIMUM OUTPUT POWER)
8Ω	13Ω	0.77	$(0.77)^2 \times 8 =$ 0.593 x 8 = 4.74 WATTS

Figure 26 - Maximum output current, voltage and power.

same, we say that the impedances are *matched.*

Matching impedances is important in the coupling circuit between an audio amplifier and a loudspeaker. The output transformer has the proper turns ratio so that the output transformer secondary matches the low impedance of the loudspeaker. Matching the impedances is also important in TV antenna work. If the impedances are not matched, reflections can occur and result in a picture with ghosted images. (This is discussed in a later lesson). In most amplifier work, however, maximum output *voltage* is desired and impedances are *not* matched. An exception is the single-tuned transformer coupled amplifier (Fig. 14). Detailed mathematical computation shows that for this circuit, maximum output voltage occurs when the impedances are matched; the internal resistance of the tube or transistor must equal the reflected resistance in the primary at resonance. The internal resistance of triodes and transistors is sufficiently low so that impedance matching is possible. Pentodes, however, have a very high plate resistance so that it is not possible to match impedances. Regardless, pentodes are commonly used for tube single-tuned transformer coupled RF amplifiers.

BALANCED LOOP

The antenna (Fig. 27) responds to a radiated RF signal from the transmitting antenna. The length of the antenna determines the frequency at which it will respond most favorably. When the transmission line is not too long, the antenna is essentially an extension of the primary of T1, so the antenna current also circulates in the primary of T1. In reference to the RF wave, from the transmitter, however, the antenna responds efficiently whereas T1's primary does not, so the antenna is essentially a one turn

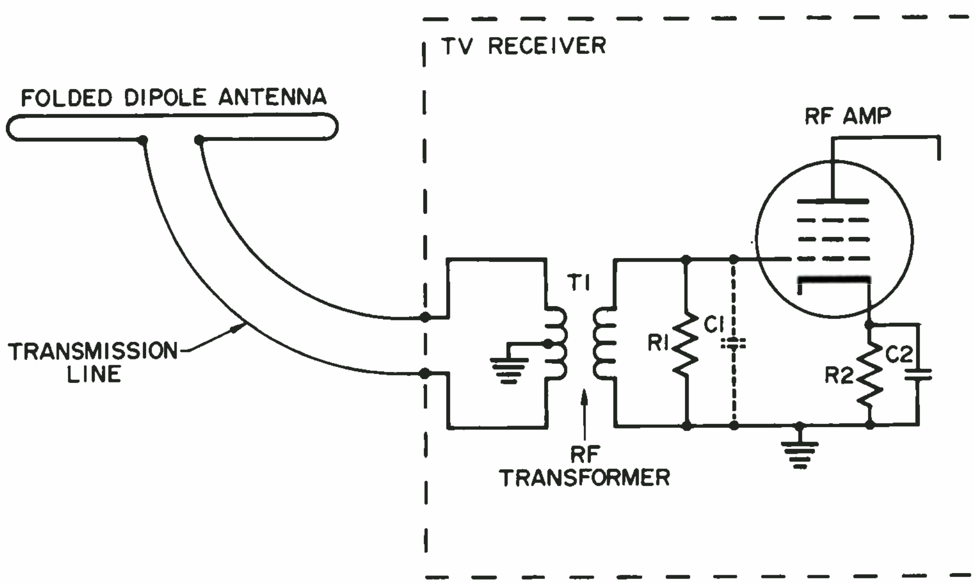


Figure 27 - Balanced loop.

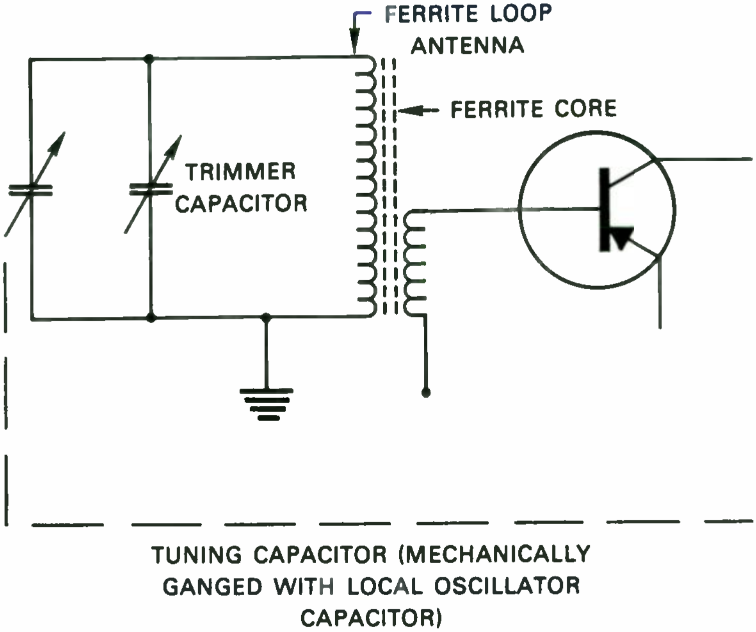


Figure 28 - Ferrite loop antenna.

primary winding. The ground connection on the primary makes the circuit a balanced circuit since any capacitive voltages picked up by the antenna or transmission line will not be transferred by T1 (each side of T1's primary receives the same voltage). The folded dipole is a closed loop in comparison with most other antennas; the grounded center tap of T1's primary makes it a balanced loop. T1's secondary is resonant with the component and wiring stray capacity. R1 is a response broadening resistor; the response should have a 6 MHz bandwidth since the picture and sound RF signals from one station lie within the 6 MHz channel assigned to each TV station.

FERRITE LOOPS

A common radio circuit component is a coil approximately six inches long wound on a powdered iron or ferrite core. This is called a ferrite loop antenna or a ferrite antenna and is used as the inductance of a resonant circuit (Fig. 28). The capacity is generally made up of two capacitors. One is a "trimmer" capacitor that is adjusted for maximum receiver amplification at the high end of the broadcast band; the other is the tuning capacitor which selects the stations. This resonant circuit responds to radio waves that are the same as the circuit's resonant frequency. A secondary winding responds to the primary current and couples the signal to the first transistor or tube amplifier. The secondary winding consists of a smaller number of turns than the primary winding. This is in contrast with the non-ferrite loop antenna where the primary consists of several turns and is usually unused; the secondary circuit, then, is a resonant circuit.

SUMMARY

High frequency amplifiers frequently employ transformer coupling. The transformers in high frequency amplifiers are not used to step up voltages or currents because the amount of coupling between the primary and secondary is much lower than the coupling in power or audio transformers. The main consideration in RF and IF amplifiers is the response. A receiver must have a degree of selectivity in order to be able to reject other signals. A tuned circuit has a response that is used to bring about selectivity. The response of a series resonant circuit is almost identical with the response of a parallel resonant circuit.

The response of a single-tuned transformer coupled amplifier is the same as the response of a parallel resonant circuit. The response of a double-tuned circuit, however, is somewhat flatter near resonance and is preferred; it is more expensive, however, since an additional capacitor is required. Also, double-tuned circuits are a bit more difficult to adjust because the adjustments of the primary and secondary interact; thus, the primary and secondary adjustments must be repeated at least once. Double-tuned IF amplifiers are always used in tube type broadcast radios.

....

TEST

Lesson Number 27

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 52-027-1.

1. A series resonant circuit
   - A. is not used in electronics.
   - B. has a high current at resonance.
   - C. has a high impedance at resonance.
   - D. is made up of inductance and resistance.

2. At a frequency below resonance, a parallel resonant circuit is
   - A. inductive.
   - B. capacitive.
   - C. purely resistive.
   - D. capacitive and resistive.

3. In a transformer, when the secondary circuit is inductive, the reflected impedance is
   - A. resistive.
   - B. inductive.
   - C. capacitive.
   - D. non-reactive.

4. In RF and IF transformers, the coupling between primary and secondary is
   - A. loose.
   - B. tight.
   - C. capacitive.
   - D. as much as possible.

5. AM radio receivers receive frequencies from
   - A. 54 to 60 MHz.
   - B. 175 to 455 kHz.
   - C. 455 to 535 kHz.
   - D. 540 to 1,600 kHz.

6. In Figure 13, the primary current is
   - A. pure DC.
   - B. also the tube or transistor current.
   - C. due to radio waves from many stations.
   - D. due to radio waves from only one station.

7. In Figure 14B, the collector current that flows through the primary of the RF transformer also flows
   - A. from emitter to base.
   - B. from collector to base.
   - C. from emitter to collector.
   - D. through the secondary winding.

8. In Figure 15, L1 is a/an
   - A. line radiation choke.
   - B. line suppressor coil.
   - C. antenna "stretcher".
   - D. RF choke coil.

9. The resonant circuits L1/C2 and L3/C5 (Fig. 16) are resonant at
   - A. 155.00 kHz.
   - B. 455.00 kHz.
   - C. 25.75 MHz.
   - D. 45.75 MHz.

10. In Figure 19A, the collector of Q2 is connected to a tap on T1 so that the
    - A. base current remains constant.
    - B. collector DC current increases.
    - C. collector DC current decreases.
    - D. resonant circuit losses are lower.

Notes

Notes

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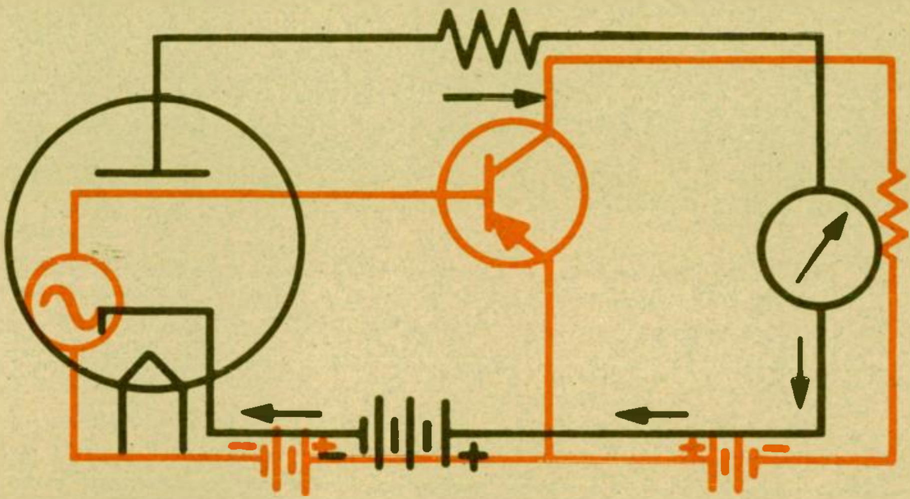
S. T. Christensen

LESSON NO. 28

SPEAKERS AND MICROPHONES



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SPEAKERS AND MICROPHONES

INTRODUCTION

All audio communication and recording begins with electro-mechanical devices that convert acoustical (sound) vibrations into corresponding electrical variations. Electrical variations at sound frequencies are called audio signals. They consist of variations in voltage, current, or both.

A microphone is the device used to convert sound energy to audio signals. These signals are then amplified in vacuum tube or transistor circuits and impressed on a radio carrier for distant transmission, or recorded on records or magnetic tape. Sound is impressed on a record by cutting physical variations into tracks on the record's surface. Sound is recorded onto tape by converting sound variations to magnetic variations. These variations are magnetized onto an iron oxide coating on the tape.

Phono-cartridges are similar in operation to microphones. Instead of responding to sound waves, however, they produce audio signals from physical impressions on a disc. Tape heads reproduce audio signals from magnetic variations.

Sound from radio or TV receivers and tape or record players is reproduced by a device called a loudspeaker, more commonly called a speaker. A speaker performs a function opposite to that of a microphone. It converts audio signals back into sound energy.

MICROPHONES

Microphones can be separated into several categories for classification. They may be grouped according to operation, use, directional qualities, impedance, or any number of other characteristics. In this lesson, we have classified them according to their principle of operation.

All microphones respond to mechanical vibrations on a diaphragm. The diaphragm is connected to a device that produces current or voltage signals in accordance with the instantaneous sound pressure applied.

Frequency Response

For good quality, the electrical signals from a microphone must correspond closely in magnitude and frequency to those of the originating sound waves.

The frequency response of a microphone must satisfy the requirements of the system with which it is used. Its response should be uniform throughout its range of frequencies and free from any sharp peaks or dips at certain frequencies.

Impedance

Crystal microphones have impedances of several hundred thousand ohms, whereas, magnetic and dynamic microphones have impedances that range from 20 to 600 ohms. The impedance of a microphone is usually measured between its terminals when some arbitrary frequency in the useful audio range—for example, 1,000 hertz—is used.

The impedance of magnetic and dynamic microphones varies with frequency in much the same manner as that of any coil or inductance—that is, the impedance rises with increasing frequency. The actual impedance of a microphone is of importance chiefly as it is related to the load impedance into which the microphone is designed to operate. If the load has a high impedance, the microphone should have a high impedance, and vice versa. Of course, impedance-matching devices may be used between the microphone and its load.

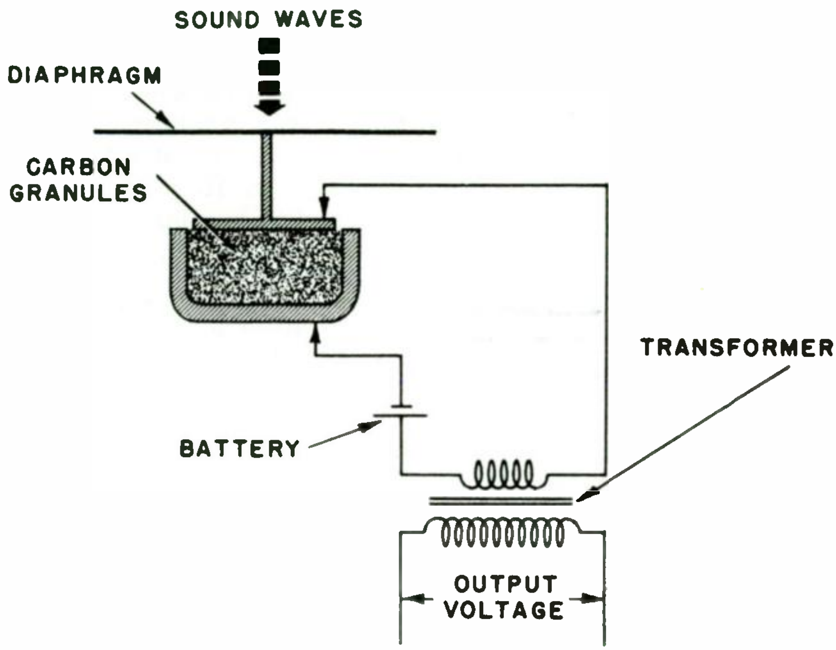
A long transmission line between the microphone and the amplifier input tends to seriously attenuate the high frequencies, especially if the impedance of the microphone is high. This action results from the increased capacitive effect of the line at the higher frequencies. If the microphone has a high impedance, the high-frequency currents drawn through the inherent capacity of the line cause an increased voltage loss within the microphone; therefore, less voltage is available at the load. Because the voltage generated by the microphone is very small, all losses in the microphone and the line must be kept to a minimum. At the lower frequencies, the capacitive effect is less and the losses are correspondingly less. If the microphone has a low impedance, a correspondingly lower voltage drop will occur in the microphone and more voltage will be available at the load.

Sensitivity

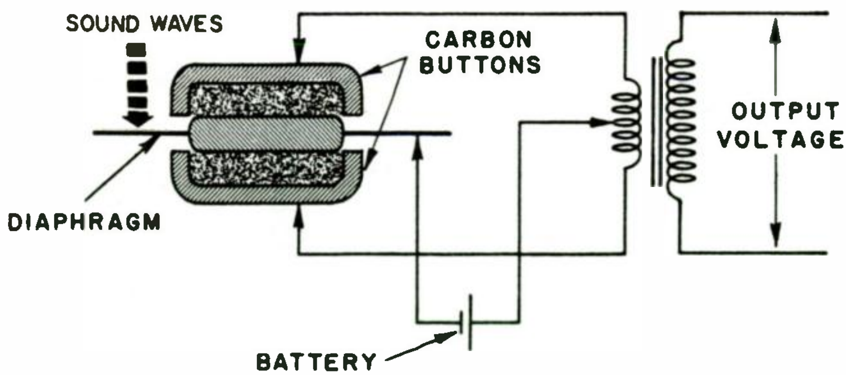
The sensitivity or efficiency of a microphone is usually expressed in terms of the electrical power that the microphone delivers into a terminating load for a given level of sound pressure.

It is important to have the sensitivity of the microphone as high as possible. High sensitivity means a high electrical power output level for a given input sound level. High microphone output levels require less gain in the amplifiers they are used with and thus provide a greater margin over thermal noise, amplifier hum, and noise pickup in the line between the microphone and the amplifier.

When a microphone must be used in a noisy location, an additional desirable characteristic is the ability of the microphone to favor sounds coming from a nearby source over random sounds coming from a relatively greater distance. Microphones of this type tend to cancel out random sounds and to pick up only those sounds originating a short distance away. When talking into this type of microphone, the lips must be held as close as possible to the diaphragm. Directional characteristics also aid in discriminating against background noise.



A SINGLE-BUTTON CARBON MICROPHONE



B DOUBLE-BUTTON CARBON MICROPHONE

Figure 1 - Carbon microphones.

TYPES OF MICROPHONES
Carbon Microphone

The carbon microphone is the most common type of microphone. It operates on the principle that a change in sound pressure on a diaphragm that is coupled to a small volume of carbon granules will cause a corresponding change in the electrical resistance of the granules.

The single-button carbon microphone (Fig. 1A) consists of a diaphragm mounted against carbon granules that are contained in a small carbon cup or button. The electrical resistance of the carbon granules varies with the pressure applied. To produce an output voltage, this microphone is connected in a series circuit containing a battery and the primary of a microphone transformer. The pressure of the sound waves on the diaphragm, which is coupled to the carbon granules, causes the resistance of the granules to vary. Thus a varying direct current in the primary produces an alternating voltage in the secondary of the transformer. This voltage has essentially the same waveform as that of the sound waves striking the diaphragm. The current through a carbon microphone may be as great as 0.1 amperes, and the resistance may vary from about 50 to 90 ohms. The voltage developed across the secondary depends upon the turns ratio and also upon the rate of change in primary current. Normal output voltage of a typical circuit is from 3 to 10 volts peak across the secondary terminals.

The double-button carbon microphone is shown in Figure 1B. Here one button is positioned on each side of the diaphragm so that an increase in pressure and resistance on one side is accompanied simultaneously by a decrease in pressure and resistance on the other. Each button is in series with the battery and one-half of the transformer primary. The decreasing current in one-half of the primary and the increasing current in the other half produce an output voltage in the

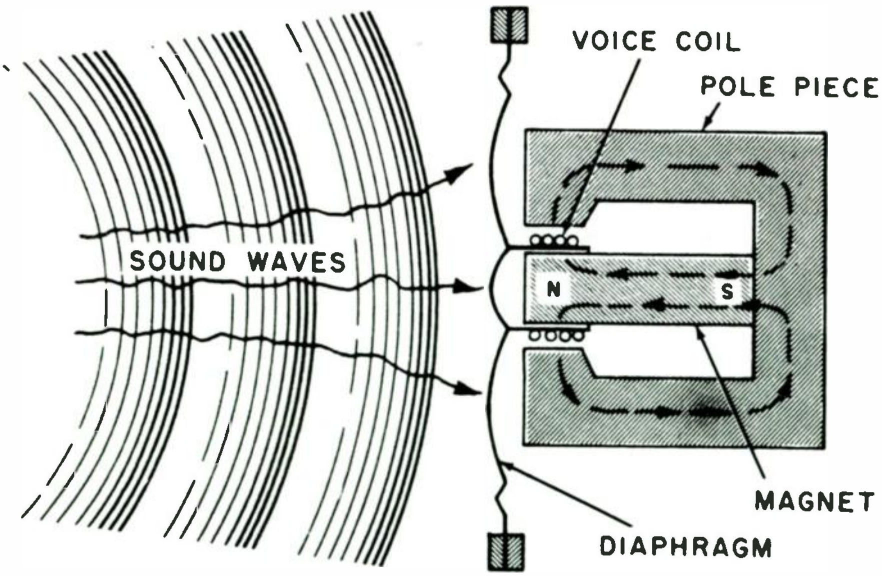


Figure 2 - Action of a dynamic microphone.

secondary that is proportional to the sum of the primary signal components. This action is similar to that of push-pull amplifiers. Commercial types of carbon microphones give essentially faithful reproduction from 60 to 6,000 hertz.

The carbon microphone has the disadvantage of requiring an external voltage source; it may also be noisy and unless the necessary precautions are taken in design, the microphone tends to peak up (have mechanical resonance) at certain frequencies.

Dynamic Microphone

The dynamic, or moving-coil, microphone (Fig. 2) consists of a coil of wire attached to a diaphragm and is so constructed that the coil is suspended and free to move in a radial magnetic field. Sound waves striking the diaphragm cause the diaphragm to vibrate. This vibration moves the voice coil through the magnetic field, cutting the lines of force. This, in turn, generates a voltage in the coil that has the same waveform as the sound waves striking the diaphragm.

The dynamic microphone requires no external voltage source, has good fidelity (approximately 20 to 9,000 hertz, and is directional for high-frequency sounds. The impedance of the dynamic microphone is low (50 ohms or less). Therefore, it may be connected to relatively long transmission lines without excessive attenuation of the high frequencies.

Crystal Microphone

The crystal microphone (Fig. 3) utilizes a property of certain crystals such as Quartz and Rochelle salt known as the PIEZOELECTRIC EFFECT. The bending of the crystal, resulting from the pressure of sound waves, produces an EMF across the faces of the crystal. This EMF may be applied directly to the input of an amplifier.

The crystal microphone consists of a diaphragm that is usually cemented directly to one surface of the crystal (Fig. 3A); in some cases, it may be connected to the crystal element through a coupling member (Fig. 3B). A metal plate, or electrode, is attached to the outer surface of the crystal. When sound waves strike the diaphragm, the vibrations of the diaphragm produce a varying pressure on the surface of the crystal causing an EMF to be produced across the electrodes. This EMF has essentially the same waveform as that of the sound waves striking the diaphragm.

A large percentage of crystal microphones employ some form of the sandwich cell. In this type of cell two crystals, so cut and oriented that their voltages will be additive in the output, are cemented together and used in place of a single crystal.

This type of microphone has high impedance (several hundred thousand ohms), is light in weight, requires no battery, is nondirectional, has a frequency response of up to 17,000 hertz for the directly actuated type and between 80 to 6,000 hertz for the diaphragm type. Crystal microphones have numerous advantages but they are sensitive to high temperatures, humidity, and rough handling. Where these conditions prevail, their use is restricted. Nevertheless, they are popular for broadcast work where their relatively high output is an advantage.

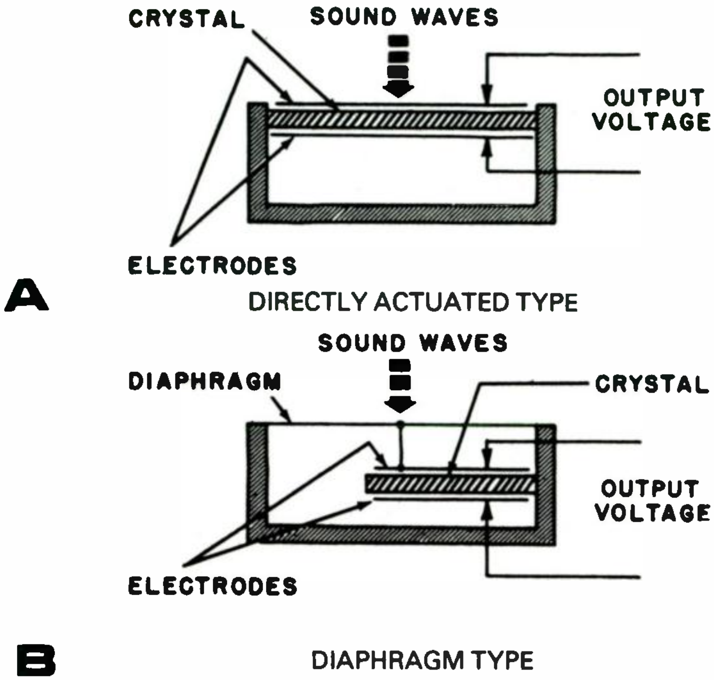


Figure 3 - Crystal microphones.

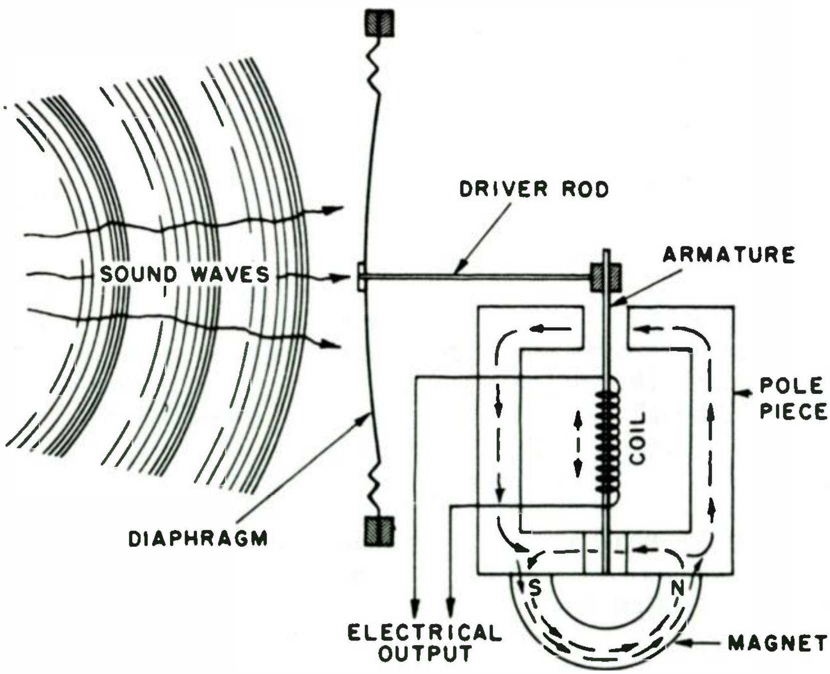


Figure 4 - Action of a magnetic microphone.

Magnetic Microphone

The magnetic, or moving-armature, microphone (Fig. 4) consists of a permanent magnet and a coil of wire enclosing a small armature. Sound waves striking the diaphragm cause it to vibrate. This vibration is transmitted through the drive rod to the armature, which vibrates in a magnetic field, thus changing the magnetic flux through the armature and, consequently, through the coil.

When the armature is in its normal position midway between the two poles, the magnet flux is established across the air gap, and there is no resultant flux in the armature.

When a compression wave strikes the diaphragm, the armature is deflected to the right. Although a considerable amount of the flux continues to move in the direction of the arrows, some of it now flows from the north pole of the magnet across the reduced gap at the upper right, down through the armature, and around to the south pole of the magnet. The amount of flux flowing down the left-hand pole piece is reduced by this amount.

When a rarefaction wave strikes the diaphragm, the armature is deflected to the left. Some of the flux is now directed from the north pole of the magnet, up through the armature, through the reduced gap at the upper left, and back to the south pole. The amount of flux now moving up through the right-hand pole piece is reduced by this amount.

Thus, the vibrations of the diaphragm cause an alternating flux in the armature. The alternating flux cuts the stationary coil wound around the armature, and induces an alternating voltage in the coil. This voltage has essentially the same waveform as that of the sound waves striking the diaphragm.

The magnetic microphone is the type most widely used in systems that are subject to vibration, shock and rough handling. It is more rugged than other types of microphones.

PHONO CARTRIDGES

A phono cartridge has a stylus attached to an audio-signal producing device. The stylus follows impressions in the groove of a record and the cartridge produces audio signals of corresponding frequency and amplitudes.

There are three kinds of cartridges in common use: the *crystal*, the *ceramic* and the *magnetic* cartridge. Crystal and ceramic cartridges produce a voltage when the crystal or ceramic element is subjected to pressure or flexing. The frequency and amplitude of the output signal is dependent upon the rate and amplitude at which the element is flexed. Magnetic cartridges produce a voltage either by allowing a magnetic pole piece to move within a pick-up coil, or permitting a pick-up coil to move within a magnetic field (Fig. 5).

Magnetic cartridges were the earliest types used in phonographs. Early magnetic cartridges were large by today's standards and very expensive. High fidelity sound reproduction was made possible, however, with a revised version of the early magnetic cartridge.

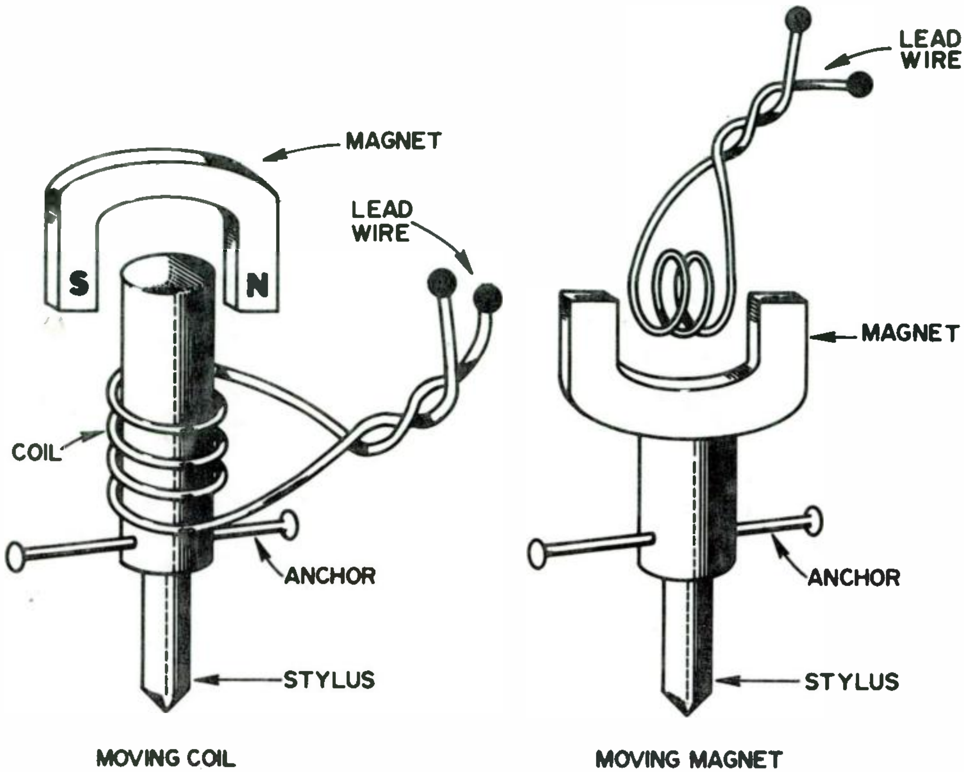


Figure 5 - Basic magnetic phono cartridges.

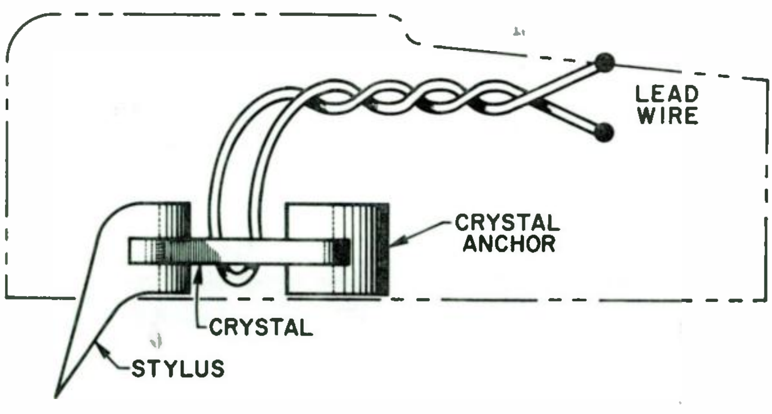


Figure 6 - Basic structure of crystal and ceramic cartridges.

Fundamentally, a magnetic cartridge is a small electric generator. A magnet in the presence of a pick-up coil is attached to a stylus. When the stylus moves, lines from the magnet's force-field cross the turns in the pick-up coil and induce a voltage.

Magnetic cartridges reproduce sound with amazing fidelity, but they do have characteristics that limit their use. They respond to the electric field surrounding most phono motors and reproduce an annoying hum signal. This is, of course, overcome in better Hi-Fi systems by using a more expensive motor with better shielding. Their output signals are low in level and must be boosted in an additional preamplifier before they are strong enough to drive a regular amplifier. In spite of their drawbacks, they are used in nearly all superior quality Hi-Fi sets.

Crystal cartridges produce a volt or more of signal and are used extensively in low-cost portable phonos. Only one tube or a couple of transistors are required to boost their output to a level that will drive a speaker.

Their reproduction range is generally poor, though adequate for most monaural recordings. Also, their output varies considerably with changes in temperatures. In addition, they are very fragile and easily damaged. Their basic structure is shown in Figure 6.

Ceramic cartridges were developed to overcome the disadvantage of crystal types. They have slightly lower outputs, but a much better frequency response. They are also relatively insensitive to temperature changes.

A ceramic cartridge operates in a fashion similar to that of a crystal type (Fig. 6). Its voltage producing element is made from a synthetic material, however, instead of Rochelle salt. (Rochelle salt is the piezoelectric element used in most crystal cartridges.)

Ceramic cartridges are widely used in Hi-Fi equipment, up to and including some higher priced units. Their performance is quite acceptable for most applications, including stereo Hi-Fi systems, but they cannot compare with magnetic types.

Stereo Cartridges

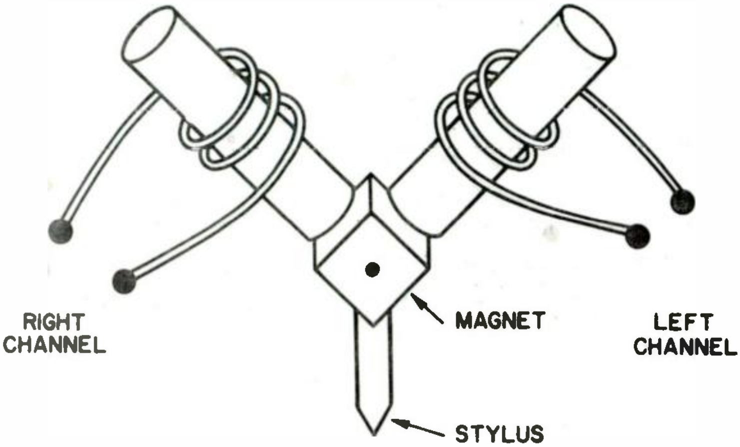
A stereo cartridge has two signal producing elements (one each for the right channel and left channel) instead of just one. These are arranged in an angular position to comply with the positions of the right and left channel information on the record.

Figure 7 illustrates, basically, the functional parts of both the magnetic (A) and the ceramic (B) stereo cartridge. Notice that right and left channel elements are angularly separated. Their angular positions correspond to the positions of the right and left channel information on a stereo record.

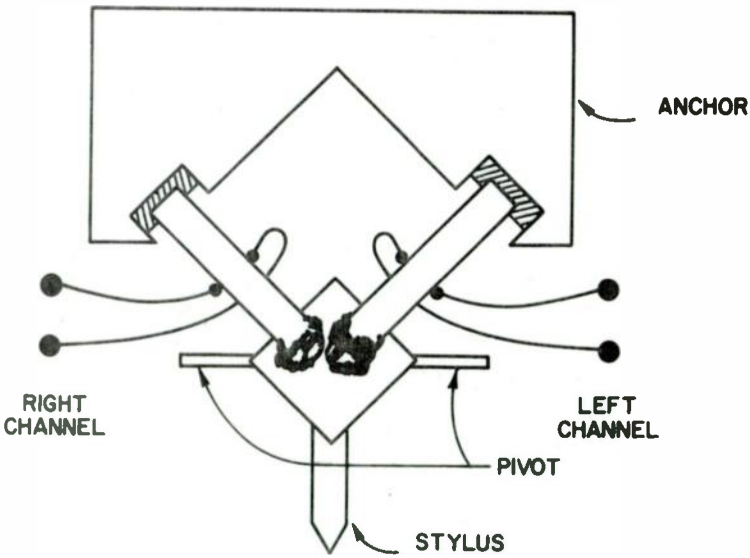
SPEAKERS AND EARPHONES

There are two kinds of reproducers that convert audio signals from the output of an amplifier to sound. The two are earphones and speakers.

A speaker contains either a permanent magnet or an electro-magnet, and a coil. The coil (voice coil) is attached



A MAGNETIC TYPE STEREO CARTRIDGE



B CERAMIC TYPE STEREO CARTRIDGE

Figure 7 - Basic stereo cartridges.

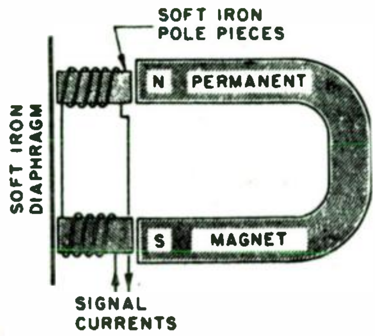


Figure 8 - Basic components of an earphone.

to a treated paper or plastic cone that is anchored at the edges and suspended at the center from a diaphragm. The voice coil is suspended in the gap between a pole piece and a yoke. When audio signal currents are passed through the voice coil, the cone moves in and out at the frequency and amplitude of the audio signal. This action causes pressurization and rarefaction of the air around the cone, thereby producing sound waves.

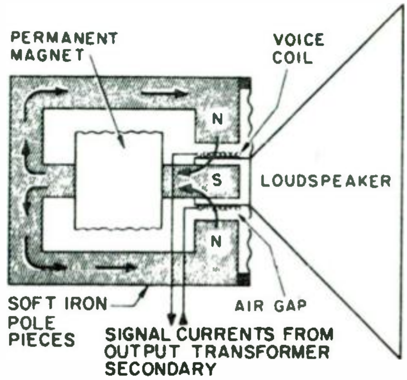
The basic components of earphones are shown in Figure 8. When no signal currents are present, the permanent magnet exerts a steady pull on the soft-iron diaphragm. Signal current flowing through the coils surrounding the soft-iron pole pieces develops a magneto-motive force that either adds to or subtracts from the field of a permanent magnet. The diaphragm thus moves in or out, according to the resultant field. Sound waves will then be reproduced that have amplitude and frequency (within the capability of the reproducer) similar to the amplitude and frequency of the applied signal currents.

Crystal earphones use a block of crystal attached to a diaphragm. When the crystal is excited with an audio voltage, it and the attached diaphragm vibrate at the rate and amplitude of the audio signal.

Figure 9 shows two types of loudspeakers (also called reproducers). In the permanent-magnet dynamic type of reproducer (Fig. 9A), a strong field is established between the pole pieces by means of a powerful permanent magnet. The flux is concentrated in the air gap between a soft-iron core and an external yoke. The voice coil is mounted in this air gap, and when AC signal currents flow in the coil, a force proportional to the strength of the current is applied to the coil. The coil is moved in or out in accordance with the direction, amplitude, and frequency of the AC signal. The loudspeaker's diaphragm is attached to the voice coil and its movements naturally follow those of the voice coil. Thus, sound waves are reproduced in the surrounding air. The corrugated diaphragm to which the speaker cone is attached keeps the cone in place and properly centered.

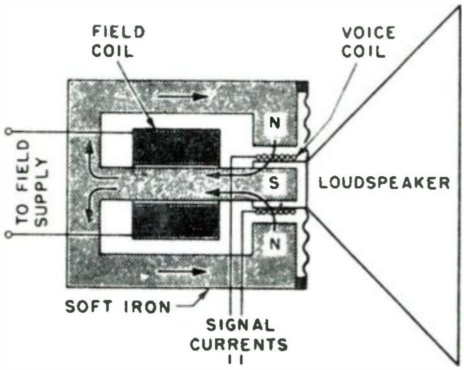
As in Figure 9B, an electromagnet may be used in place of the permanent magnet to form an electromagnet dynamic speaker. However, in this instance sufficient DC power must be available to energize the field. The operation is otherwise much the same as that of the permanent-magnetic speaker.

In addition to dynamic type speakers there are two additional types that have limited use: the electrostatic type and the crystal type. Unlike the dynamic type, they operate from a voltage-induced field instead of from a current-induced field.



A

PERMANENT-MAGNET DYNAMIC SPEAKER



B

ELECTROMAGNETIC DYNAMIC SPEAKER

Figure 9 - Basic speakers.

The crystal speaker is very similar to a crystal earphone, with the exception of the size of the crystal and the size and shape of the diaphragm.

The electrostatic speaker is becoming prominent as a reproducer of higher frequencies (tweeter). It contains a small chamber of ionized particles that react to the flow of audio current through a coil, to produce sound.

Single Unit Speakers

A single unit speaker has only one cone and voice coil and one magnetic pole piece. The ones currently in use vary in size from less than 1 inch in diameter to more than 15 inches in cone diameter. Popular oblong shaped units have cone dimensions of 3 x 2, 5 x 7, 6 x 9 inches, etc. Figure 10 shows some currently popular speakers.

The cone of a large speaker is

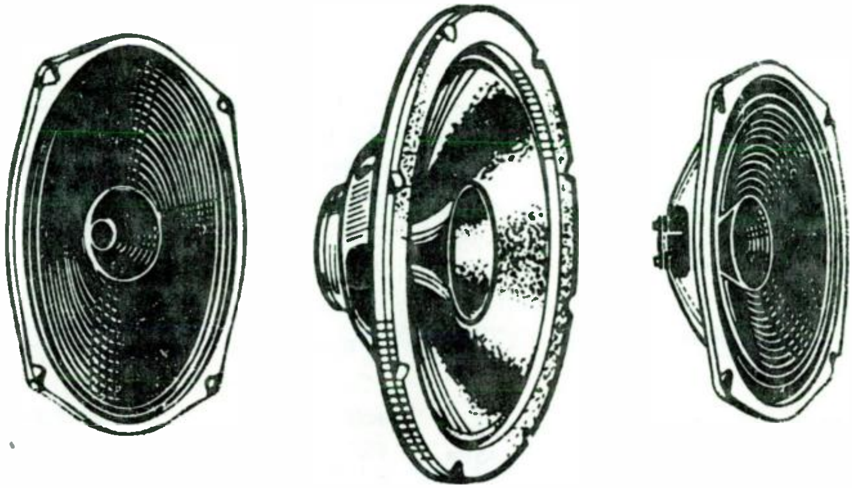


Figure 10 - Some typical speakers.

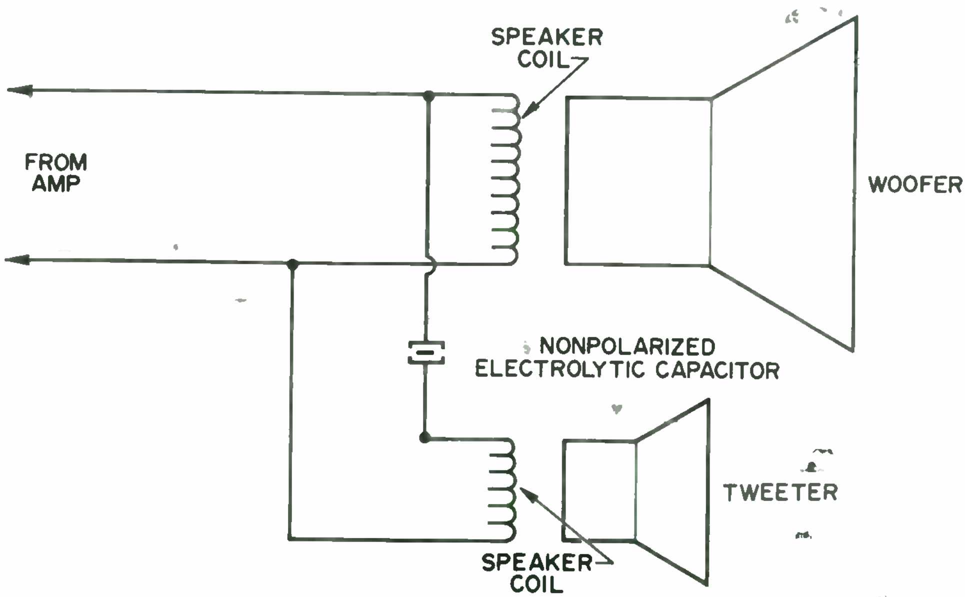


Figure 11 - Nonpolar capacitor used as a crossover.

massive and somewhat sluggish in its movement. It responds well to low frequency vibrations to produce a lot of sound, but it fails to follow the high frequency variations of the high notes.

The less massive cones of small speakers respond well to high notes, but do not have sufficient mass or surface to reproduce large quantities of sound at the lower audio frequencies.

In low-cost units, the speaker is a compromise between cost and adequacy. In Hi-Fi systems, cost is of less concern than full-range reproduction. In these, two or more speakers are sometimes used to extend the range. One has a large cone and provides good reproduction of the low notes. The speaker used for this purpose is called a "woofer." A second speaker with a much smaller cone is used to reproduce the higher frequencies. It is called a "tweeter."

A network (crossover network) may be used to separate highs from lows and route them to the proper speaker. It may be only a simple condenser or an elaborate LC network.

The schematic drawing in Figure 11 shows the placement of a non-polarized electrolytic capacitor when used as the crossover in a speaker system. The capacitor (due to its high reactance to low frequencies) isolates low frequencies from the tweeter. At higher frequencies, the reactance of the woofer is greater and that of the capacitor is smaller. The high frequencies, therefore, pass through the capacitor and tweeter instead of through the woofer.

Speaker Impedance

One of the most important considerations when selecting speakers is the voice coil impedance. This is the reactance of the voice coil (in ohms) to varying audio current. Reactance of speakers range from a low of 3 ohms to more than 100 ohms for certain types.

Early radios and many later models of the low priced vacuum tube table sets used 3 ohm speakers almost exclusively, but this has since changed. With the development of transistors and the resultant elimination of output transformers, speaker impedances for portable and other small radios have been increased to 50 ohms, in typical models.

Many early Hi-Fi sets have speaker systems with impedances of 8 ohms, but these are becoming rare. Current models are usually standardized at 16 ohms, with some units having higher values. The 8 ohm speaker is still popular, but is now used in multiples and in series or series-parallel connections.

Impedance Matching

To obtain maximum power and fidelity from an amplifier, the speaker impedance should closely match the source impedance at the output of the amplifiers. Thus, in the system shown in Figure 12, two 8 ohm speakers are connected in series across the 16 ohm secondary of an amplifier's output transformer. This provides a proper match between the source and load for optimum performance.

The system in Figure 13 uses two

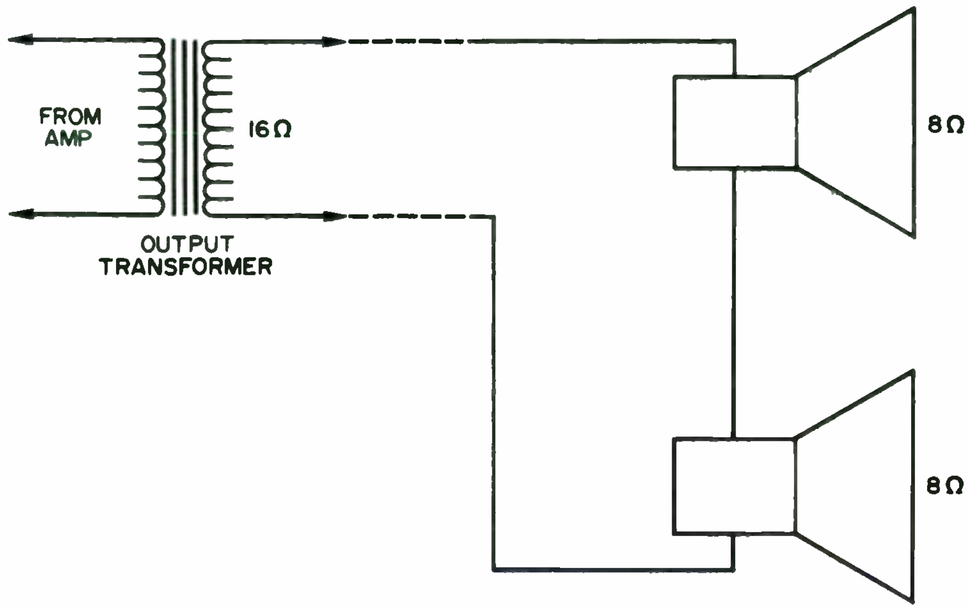


Figure 12 - Series-connecting speakers for impedance matching.

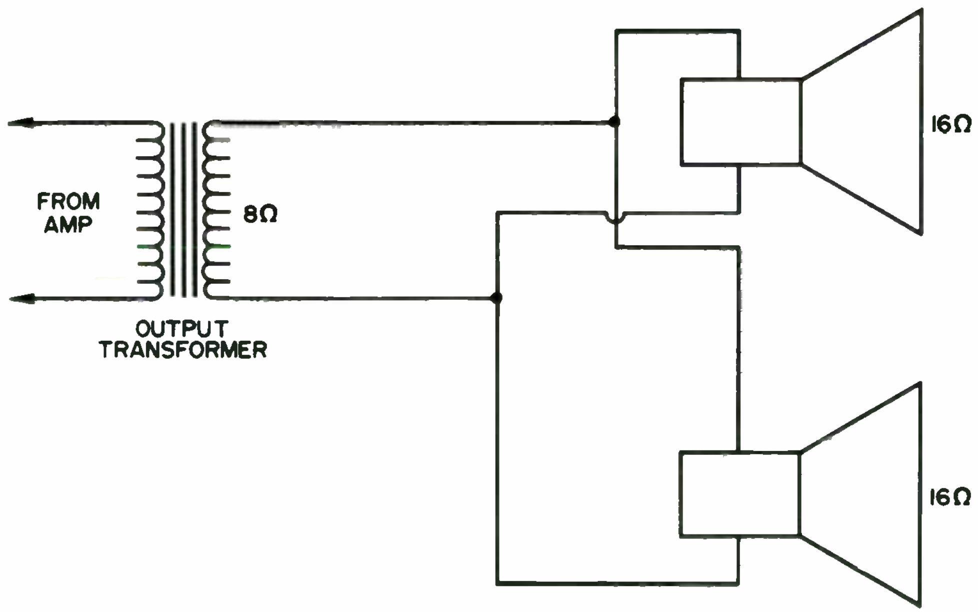


Figure 13 - Parallel-connecting speakers for impedance matching.

16 ohm speakers connected in parallel to match an 8 ohm source. Various schemes are used to obtain proper matching with multiple speakers. These include series-parallel arrangements, using several speakers or intermixing speakers with different voice coil impedances.

Phasing

To reproduce sound when multiple speakers are involved, they must be properly phased. This means that the cones must all deflect in the same direction. If one cone moves outward while another moves in an inward direction, the result will be poor sound reproduction. Efficiency will be low and the sound reproduction undesirable.

When replacing speakers, always wire them as the original was wired. Following replacement, they should be checked and this may be done very simply with a small battery. A small 1.5 volt battery (penlight or flashlight) can be connected momentarily to the line from the amplifier that feeds all the speakers (Fig. 14). Observe the cone movement and be sure that they all move in the same direction. If any of them deflect in a direction opposite to the others, simply reverse the wires to its terminals. As you gain experience, you will be able to spot misphased speaker systems instantly from their sound.

HORNS

High quality Hi-Fi systems may use one or more horns as reproducers instead of conventional speakers. The basic principle of operation is the same but the quality of reproduction from a horn is superior. Individual horns are available which handle either the mid-range or the higher frequencies. There are also combination units available that reproduce both mid-range and high frequencies in a single unit.

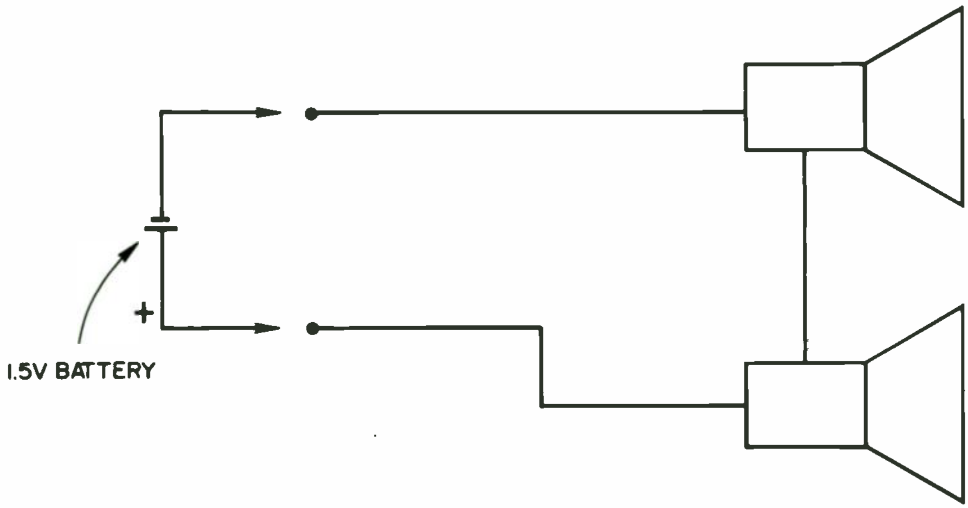


Figure 14 - Speakers can be checked with a battery for phasing.

Figure 15 - Typical horn.

Figure 15 shows a combination mid-range tweeter horn. It is designed with a response of from approximately 600 hertz to 15 kHz. This particular horn is used with a separate woofer that reproduces the lower frequencies.

MULTIAXIAL SPEAKERS

The functions of both woofer and tweeter are often combined into a single unit called a coaxial speaker. A coaxial speaker resembles ordinary woofers with a small tweeter suspended in the center. They actually contain two separate voice coils and may or may not be equipped with a crossover network. Figure 16 shows typical full-range coaxial units.

Triaxial units have been tried with limited success. These contain three concentric speakers in a single unit. They function as woofer, midrange and tweeter and, like coaxial units, may or may not contain a crossover.

PUBLIC ADDRESS AND COMMERCIAL INSTALLATIONS

Many technicians become involved in installation and service of public address type systems. Permanent installations using many speakers are used universally in airports, motels-hotels, theatres, depots, etc. Because several speakers with long runs of wire are used, they are treated somewhat differently from ordinary home entertainment equipment.

Large public address systems are used mainly for announcing, and generally use a system called *constant voltage* distribution. A master amplifier supplies audio usually on 500 ohm lines to a series of area amplifiers located strategically throughout the system. Transformers or RC networks, called pads, are used at the inputs of area amplifiers to provide a proper match for the 500 ohm output of the master amplifier.

The area amplifier in each leg of the system feeds a line of speakers at a constant voltage instead of at a constant impedance. These lines are called constant voltage and usually operate at 70 volts. The 70 volts refers to a given audio level at a constant frequency. Matching of the output of area amplifiers to the load is not critical and speakers may be added or removed according to requirements.

In constant voltage systems, each speaker is connected to the line from the area amplifier through a line transformer. The secondary of the line transformer equals the speaker imped-

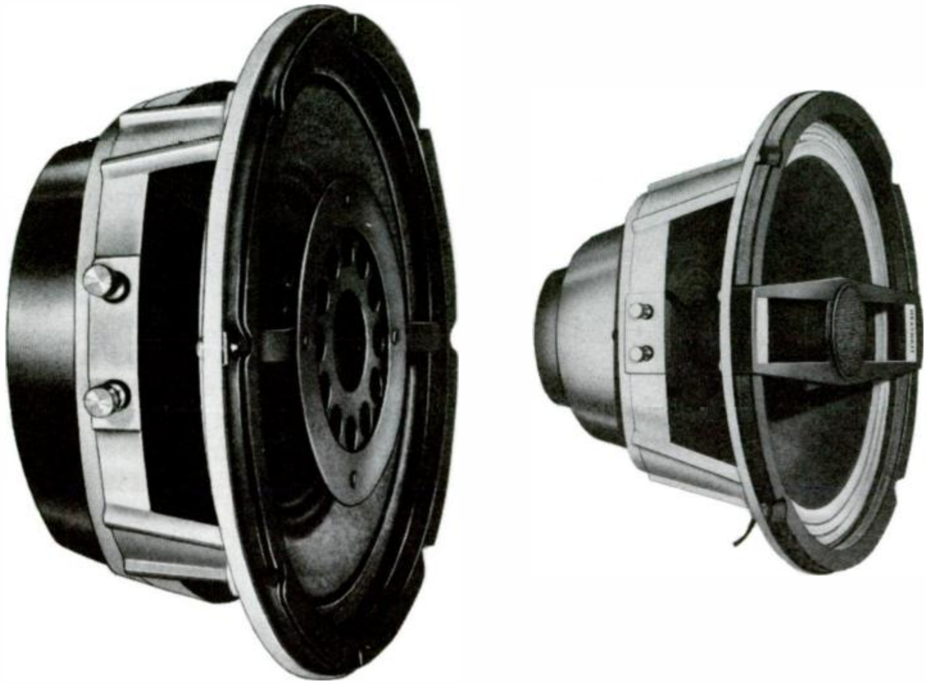


Figure 16 - Coaxial speakers.

ance and, therefore, provides a source-load match at each speaker. Constant voltage systems are efficient and flexible for speech, but they lack the required fidelity for reproduction of music.

In theaters and concert halls another system is used to provide full range reproduction: the *constant impedance system.* Constant impedance systems usually operate into a 500 ohm line with matching transformers at each speaker. The primaries of all the transformers are arranged in series-parallel configurations to provide a total load of 500 ohms. The secondary of each line matching transformer is equal to its associated speaker and provides the source-to-load match at this point. Constant impedance systems have excellent fidelity but they are less versatile than constant voltage systems. Speakers cannot be removed or added without rearranging the remaining ones to provide the required line impedance.

From the above, it seems that impedance is a super-critical thing that requires tedious handling. In practice this is not quite the case. Actually, a two-to-one mismatch is frequently tolerated, with four-to-one being the maximum amount permitted as a rule of thumb.

In case of long runs of wire, a more critical factor than impedance matching is wire size. Wire should be large enough so that it does not introduce additional impedances into the system. Because of the considerable amount of capacitance and inductance in long runs, they can cause severe distortion and loss of efficiency at higher frequencies unless the wire is large enough to contain very low resistance.

SUMMARY

Microphones respond to mechanical vibrations on a diaphragm. The diaphragm acts on a device that produces current or voltage variations in accordance with the mechanical vibrations.

Two important characteristics of microphones are impedance and sensitivity. Microphone impedances vary from several hundred thousand ohms for crystal to 20 ohms for magnetic. It is important that the microphone impedance match the input impedance of the amplifier to assure proper power transfer. Sensitivity is a measure of the efficiency of a microphone and should be as high as possible.

The type of microphones commonly used are the carbon, dynamic, and crystal. The carbon microphone is the most common type of microphone but requires an external voltage source for proper operation. The dynamic microphone works on a moving-coil/permanent-magnet principle; therefore, it does not require an external power supply. The impedance of the dynamic microphone is low; therefore, it may be connected to a relatively long transmission line. The crystal microphone is susceptible to damage from exposure to high temperatures, humidity, and rough handling.

Speakers or reproducers convert electrical signals into sound. There are basically two types: the permanent magnet and the electromagnet. The impedance range for speakers varies from 3 to more than 100 ohms. Again for maximum power transfer, the speaker impedance should match the output impedance of the amplifier. To obtain the desired impedance, the speakers can be connected in series, parallel, or series-parallel.

....

TEST

Lesson Number 28

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 52-028-1.

1. A device that changes sound to audio current or voltage is called a
   A. speaker.
   B. microphone.
   C. earphone.
   D. horn.

2. Microphones have important characteristics, including
   A. frequency response.
   B. impedance.
   C. sensitivity.
   D. all of the above.

3. A device that converts physical impressions from a disc to audio current or voltage is called a
   A. coaxial speaker.
   B. mid-range horn.
   C. tweeter horn.
   D. phono cartridge.

4. The element in a magnetic microphone generates audio current from a (an)
   A. magnetic field.
   B. electrostatic field.
   C. semiconductor.
   D. variable resistance.

5. The carbon microphone produces an electrical signal when the pressure of sound waves, acting on the diaphragm, produces a/an
   A. magnetic field.
   B. electrostatic field.
   C. inductive field.
   D. varying resistance.

6. A speaker that has one voice coil and one cone is a ________ speaker
   A. single unit.
   B. coaxial.
   C. mid-range and tweeter.
   D. triaxial.

7. A speaker that has two voice coils and two cones is a ________ speaker.
   A. single unit
   B. coaxial
   C. tweeter horn
   D. triaxial

8. A speaker that reproduces high frequencies only is a
   A. woofer.
   B. tweeter.
   C. mid-range speaker.
   D. none of the above.

9. A speaker that reproduces intermediate frequencies only is a
   A. woofer.
   B. tweeter.
   C. mid-range speaker.
   D. none of the above.

10. A speaker that reproduces low frequencies only is a
   A. woofer.
   B. tweeter.
   C. mid-range speaker.
   D. all of the above.

Notes

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SECOND WIND

Champion sprinters select a steady pace for running long distances. As they near the finish line, their "second wind" gives them that added burst of speed to put them across the finish line as winners!

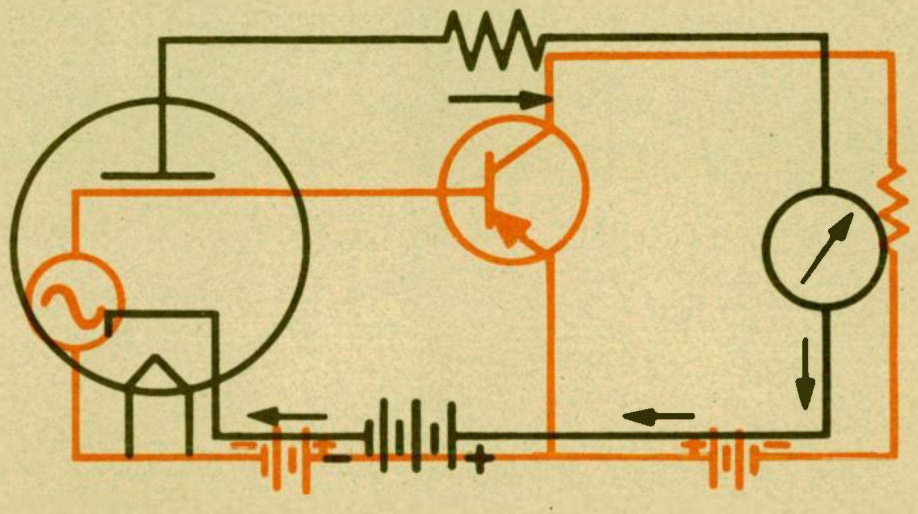
A second wind in your studying will help you across the finish line. . .as a winner.

If you become sleepy after studying or working awhile. . . relax before you go on. When your second wind has refreshed you mentally and physically get right back to your ASI studies. Your studying will again be worthwhile.

S. T. Christensen

LESSON NO. 29

REVIEW FILM LESSONS 25-28 BOOKLET



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-029

412

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

Revised September 1973
Reprinted December 1974

REVIEW FILM TEST

Lesson Number 29

The ten questions enclosed are review questions of lessons **25, 26, 27, & 28** 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 52-029-1.

1. An iron core in an inductor makes a__________inductance possible.
   A. small
   B. large
   C. positive
   D. negative

2. A transformer with a 10-turn primary has a 25-turn secondary. This type of transformer is called a__________transformer.
   A. step-up
   B. step-down
   C. tuned
   D. variable

3. Applying 20 volts AC to the primary of the transformer of Question 2, how many volts appear at the secondary?
   A. 25 volts AC
   B. 250 volts AC
   C. 100 volts AC
   D. 50 volts AC

4. IF transformers
   A. are E core type transformers.
   B. are used only in the audio frequency range.
   C. are auto transformers.
   D. can be tuned with a threaded ferrite core.

5. In a series resonant circuit, the__________through the circuit is maximum.
   A. inductance
   B. resistance
   C. current
   D. voltage

6. At resonance, the impedance of a parallel circuit is
   A. minimum.
   B. maximum.
   C. equal.
   D. zero.

7. A flyback transformer
   A. is also called an inductive kick transformer.
   B. is a high voltage transformer.
   C. operates at 15,750 Hz.
   D. all of the above.

8. The pickup pattern of crystal and ceramic microphones is usually
   A. omni-directional
   B. bi-directional
   C. cardioid
   D. none of the above.

9. The pickup pattern of the dynamic microphone is
   A. omni-directional
   B. bi-directional
   C. cardioid
   D. none of the above

10. Which of the following speaker combinations may be connected in series and placed across the 16 Ω output of an amplifier?
   A. four 4 Ω speakers
   B. two 8 Ω speakers
   C. eight 2 Ω speakers
   D. all of the above

Notes

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FOLLOW THROUGH...

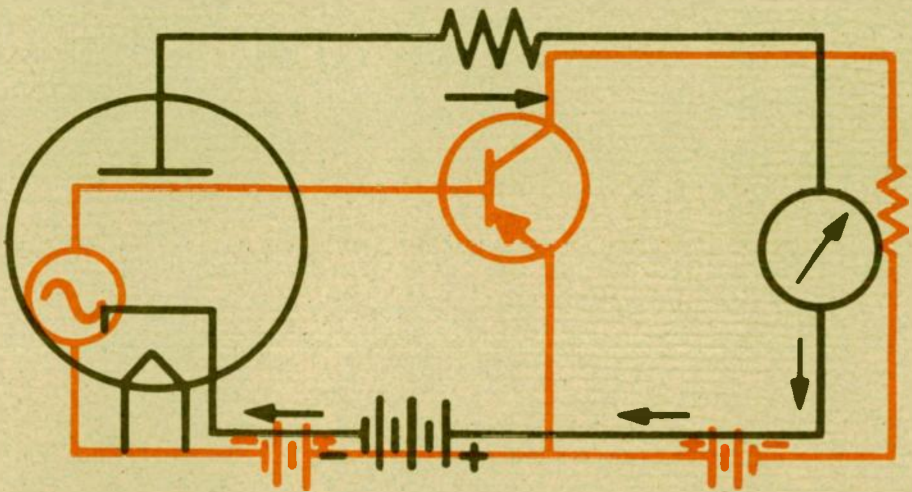
Getting off to a good start each morning is certainly the best way to begin your day. But it takes good habits to keep the day going well. The difference between an amateur and professional golfer is "follow-thru". Most of us with a little practice can hit a golf ball but, without good follow-thru, we lose control of the direction the ball will travel after it is hit.

The same goes for studying your ASI lessons. Always be on guard against a lack of enthusiasm in your studies. Follow thru with your plan of study and you will turn yourself into a professional. Only you can make it happen!

S. T. Christensen

LESSON NO. 30

TUNED CIRCUITS



RADIO and TELEVISION SERVICE and REPAIR

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$$Z_L = j\omega L$$

$$Z_C = j\omega C$$

$$j \times j = -1 \qquad \omega = 2\pi f$$

$$X_L = \omega L = 2\pi f L$$

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$$Z = \sqrt{R^2 + X^2}$$

$$Z = \sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f C}\right)^2}$$

CONTENTS

TUNED CIRCUITS

INTRODUCTION

Anyone who has operated a radio has learned that the set must be tuned to the transmitting station before the signal can be received. A direction to "tune the radio" is a request that the *tuning dial* on a radio be carefully rotated to a definite position to insure that the desired station will be heard clearly.

A TV receiver operates in a similar, but simpler fashion. The major tuning is accomplished by first selecting the desired channel and then rotating the *fine tuning* knob to obtain the clearest picture.

This action of rotating knobs, selecting channels, and adjusting fine tuning controls performs the electronic action of tuning the radio or TV to the exact frequency of the transmitting station. The circuit in the radio or TV receiver is properly said to be in resonance at the exact frequency of the transmitter. It is even more exact to say that the tuned circuits are in resonance, because they have been energized at the particular frequency that will produce resonance.

Tuned Circuit

A tuned electrical circuit consists of capacitance and inductance, plus the inevitable resistance present in every electrical circuit. The capacitance and inductance may be connected in a series or a parallel combination. The series arrangement is called a series resonant circuit, and the parallel arrangement is a parallel resonant circuit.

Application of Tuned Circuits

In radio receivers, tuned circuits are used both for the selection of the desired frequency and for the rejection of undesired frequencies. The relative ability of a receiver to select the desired signal while rejecting all others is called SELECTIVITY.

In radio transmitters, the entire process of radio-frequency power generation and amplification depends on the proper functioning of tuned circuits. Test instruments (such as signal generators, oscillators, and frequency meters) as well as other electronic devices (for example, television transmitters and receivers, and radar and sonar equipment) employ many tuned circuits.

Action of Capacitors and Inductors

In the previous lessons on Capacitance and Inductance, we learned what happens when an AC source is supplying power to a capacitor and an inductor. The capacitor is alternately charged and discharged at the frequency of the AC supply source. Likewise, a magnetic field around a coil is also alternately increased and decreased in step with the frequency of the AC supply source.

The action of capacitors and coils can also be understood by considering that:

Capacitors *store* electrostatic energy during the charging portions of the cycle and *release* this energy during the discharging portions of the cycle.

Inductors *store* electromagnetic energy during increasing portions of the cycle and *release* this energy during the decreasing portions of the cycle.

These actions of capacitors and inductors take place at opposite times because electrically they are 180° out of phase. Using the words ELI and ICE, we can verify this when we remember that it is convenient to have the current (I) along the horizontal axis (Fig. 1).

ELI E (voltage) in L (inductor) leads I (current) by 90°, while

ICE I (current) in C (capacitor) leads E (voltage) by 90°.

The voltage of the inductor (E_L), therefore, leads the voltage of the capacitor (E_C) by 180°.

A Resonant Circuit

When the circuit is energized at the resonant frequency, an interchange of energy occurs between the coil and capacitor. This interchange of energy tends to increase the amplitude to an amount far greater than that delivered by the energizing source. This is known as a resonant circuit condition.

At resonance, the inductor stores energy during the half cycle that the capacitor discharges, and returns the energy during the next half cycle to recharge the capacitor. Because the circuit resistance, acting in series with the inductor and capacitor, is low, large amounts of energy may be exchanged at the resonant frequency with minimum loss of energy in the circuit. The small energy loss in the circuit is regained from the source feeding the circuit.

At resonance, the time needed to charge the capacitor must be equal to the time needed to discharge the coil; otherwise, the charge and discharge will be out of step, and cancellation will result.

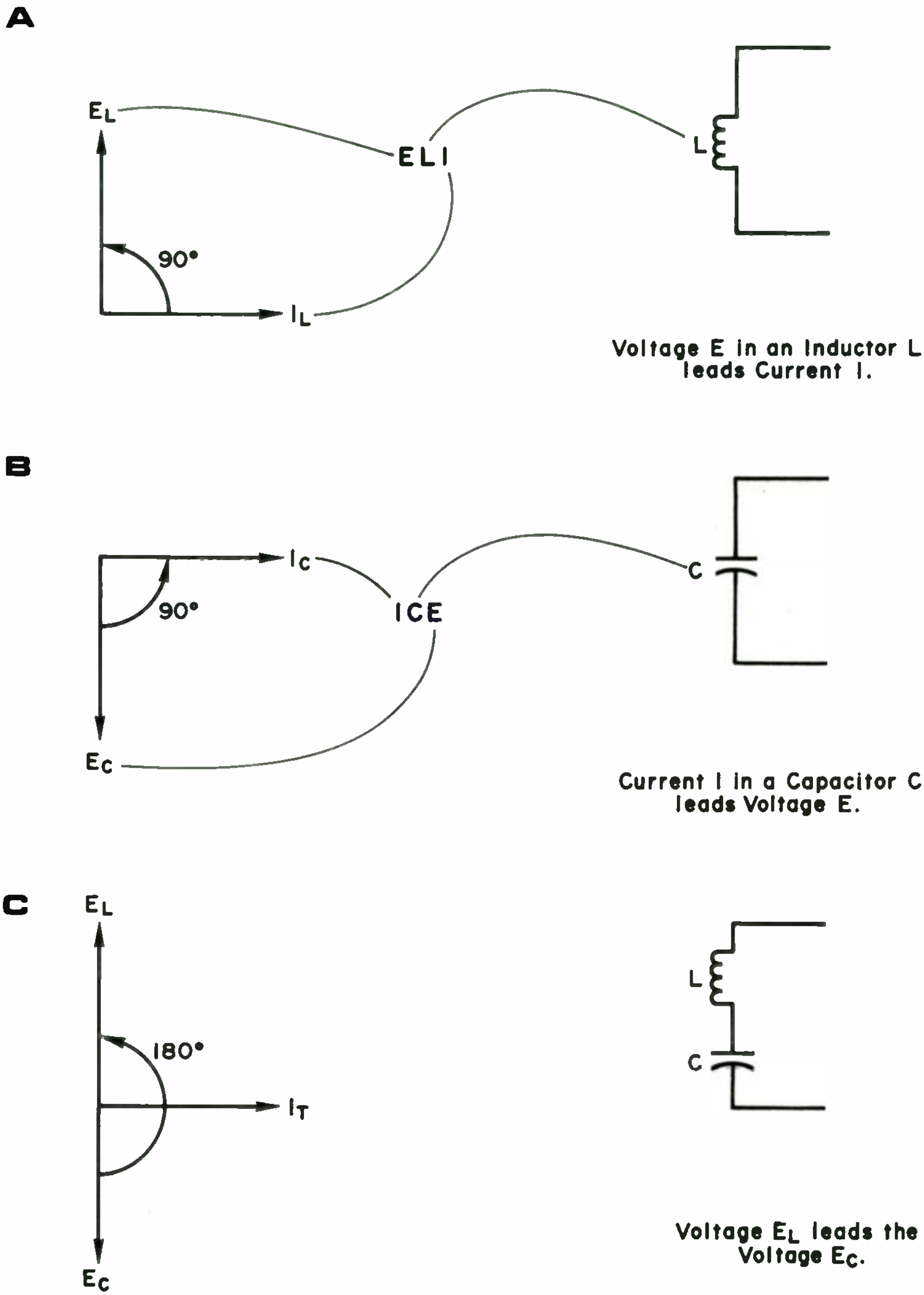


Figure 1 - The phase relationship of voltage and current in an inductor and a capacitor.

SERIES RESONANCE

Series Circuit Action

A series-resonant circuit is composed of a capacitor, an inductor, and a resistor (Fig. 2A). The circuit losses that occur in the capacitor, the inductor, and the connecting leads are totalled in the resistor (R) in the circuit.

In a series circuit (Fig. 2A) that is tuned to the frequency (f_o) of the AC power supply, the impedance in ohms across the terminals T_1 and T_2 of this series circuit is:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

It has been explained in previous lessons that at resonance the time needed to charge the capacitor must be equal to the time needed to discharge the coil. This indicates that the impedance of both must be the same;

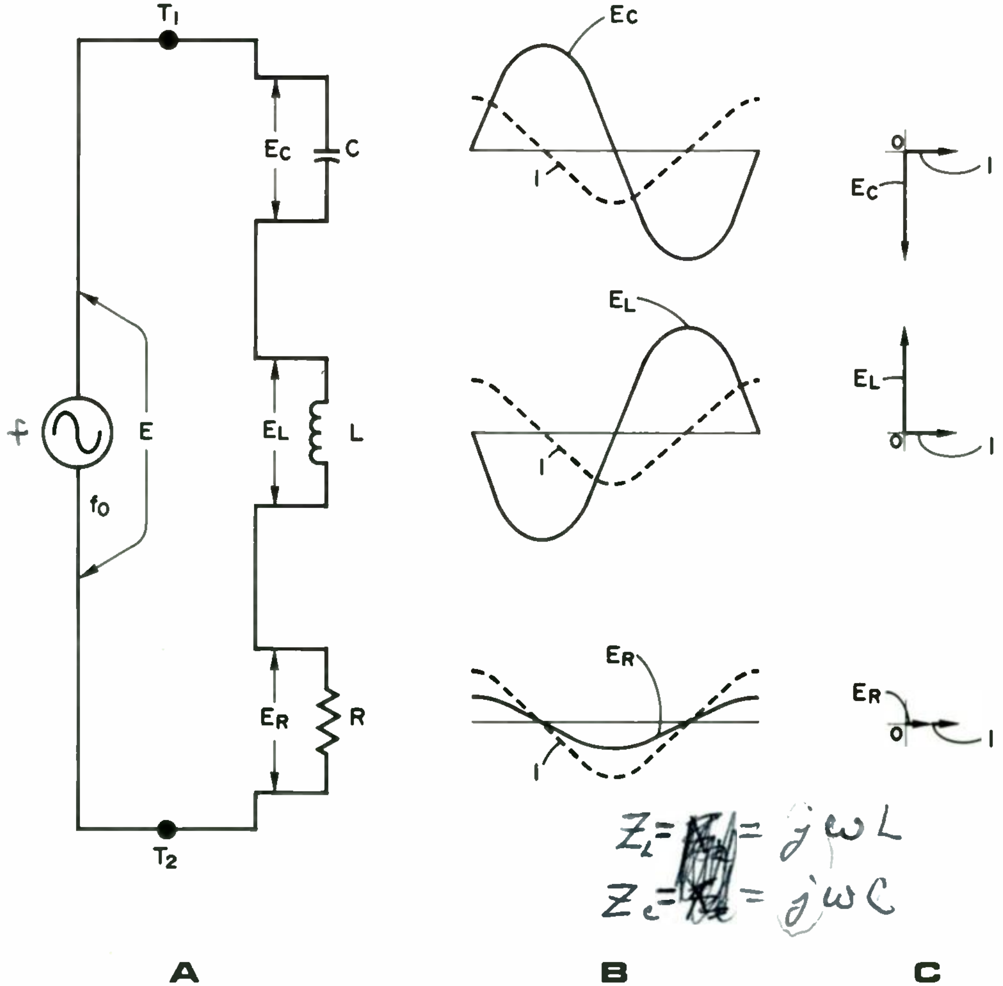


Figure 2 - The series-resonant circuit in A has voltage and current relationships as shown in B, with the vector relationships shown in C.

therefore, X_L must equal X_C. Since $X_L - X_C$, the last term in the equation above equals zero, or

$$Z = \sqrt{R^2 + 0^2} = \sqrt{R^2}, \text{ or } Z = R$$

The total impedance is now only that of the resistance (R) of the circuit, and the circuit current is maximum. In other words, at resonance the generator is looking into a pure resistance. Furthermore, at the resonant frequency, the power factor is unity or 1.00, because the inductive reactance cancels the capacitive reactance. The current (I) and voltage of the resistor E_R are in phase (Fig. 2B) due to the lack of any reactance in the circuit.

The vector relationship of these voltages is shown in Figure 2C. The combined vectors in Figure 1C illustrate the individual vectors of the capacitor, of the inductor, and of the resistor (Fig. 2A).

Resonant Frequency

Since X_L is equal to X_C at resonance, we use this equality of $X_L = X_C$ to determine what the resonant frequency (f_o) will be. We know that

$$X_L = 2\pi fL \text{ and } X_C = \frac{1}{2\pi fC}$$

from our previous study; therefore, we may substitute these values in

$X_L = X_C$, and obtain

$$2\pi fL = \frac{1}{2\pi fC}$$

When we assemble the similar numbers and symbols, we get

$$f \times f = \frac{1}{2\pi \times 2\pi LC}$$

$$f^2 = \frac{1}{4\pi^2 LC}$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

If we substitute the value of L in henries and C in farads, we will obtain the frequency (f) in hertz.

Because the circuit (Fig. 2A) is a series circuit, the same current flows in all parts of the circuit. Therefore, the voltage across the capacitor is equal to the voltage across the inductor, because X_L is equal to X_C. These voltages (Fig. 2C), however, are 180° out of phase, since the voltage across a capacitor lags the current through it by approximately 90°, and the voltage across the inductor leads the current through it by approximately 90°. The total value of the input voltage then appears across R and is shown as E_R in phase with the current I.

Circuit Characteristics

When a series-tuned circuit is at a resonant condition,

- the circuit impedance is at its minimum value, and
- the circuit current is at its maximum value.

If the frequency of the supply voltage is varied both above and below the resonant frequency (f_o) the circuit impedance increases, which means that the current decreases (Fig. 3). At any frequency the current can be calcu-

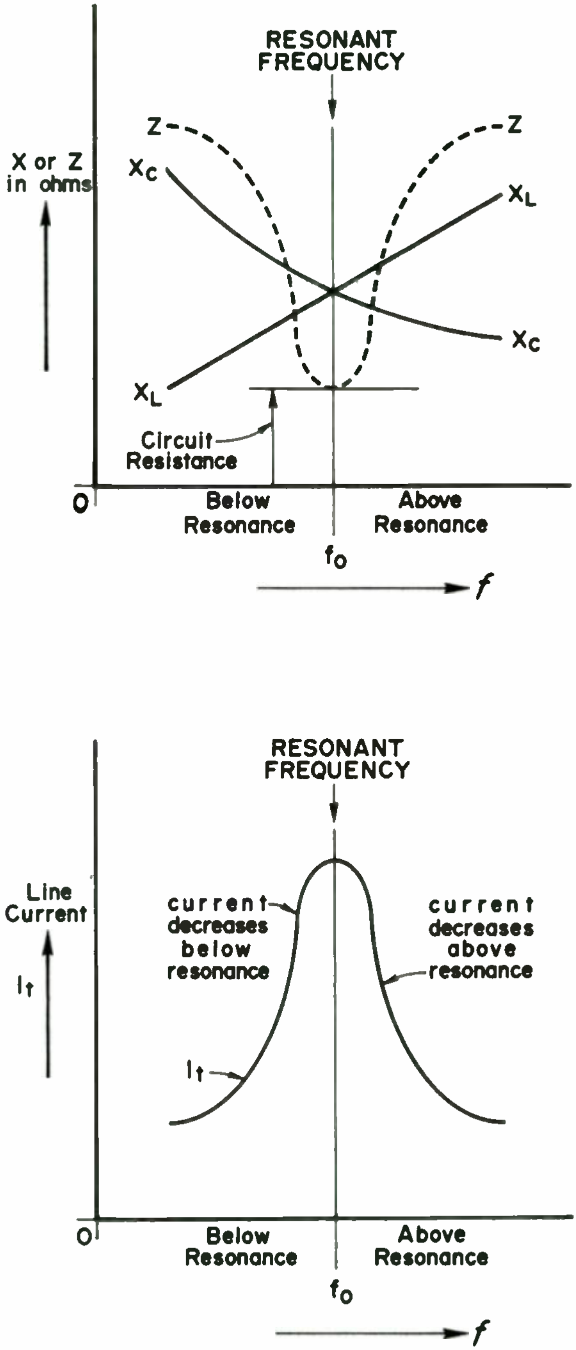


Figure 3 - The impedance of a series-tuned circuit is minimum at resonance, while the line current is maximum.

lated by Ohm's law, whether it is applied to each component or to a complete series LCR circuit (Fig. 4).

At resonance, the voltage across the capacitor and the voltage across the inductor are equal in magnitude. Because the series resistance is low, the source voltage is small in relation to the voltage across the coil and capacitor. Under these circumstances, the voltage appearing across either the inductor or the capacitor may be much higher than the input voltage (Fig. 2).

At frequencies below resonance (Fig. 3), X_C is greater than X_L, and the circuit contains resistance and capacitive reactance. At frequencies above resonance, X_L is greater than X_C, and the circuit contains resistance and inductive reactance. At resonance, the current is limited only by the relatively low value of resistance.

A Mechanical Analogy

A simple mechanical analogy of the series resonant circuit is helpful in describing the interchange of energy between the inductance and the capacitance. It can also illustrate the relatively large increase in voltages appearing across the inductance and capacitance when the circuit is resonant.

The analogy consists of a weight (about 4 oz.) attached to a loop made of about six thin rubber bands or one thick rubber band. When one end of the rubber band loop is suspended from the fingers, the weight will bounce up and down with a very slight motion of the hand.

The weight represents inductance in the series circuit (Fig. 5A). Its inertia is like the inductance of the coil. The rubber bands represent capacitance in the series circuit. Their elasticity resembles the capacitance of the capacitor. The amplitude of motion of the hand represents the magnitude of the input voltage. The frequency of motion of the hand represents the frequency of the input voltage.

When the hand is moved slowly up and down, the weight will follow the motion with little or no change in the length of the rubber bands (Fig. 5B). This action corresponds to that in a series LC circuit when the frequency of the applied voltage is considerably below resonance. Little or no change in the length of the rubber bands represents a reduction of current. The capacitive reactance of the capacitor is large and restricts the current. The weight follows the motion of the hand. The inductive reactance of the coil is low (below resonance), and only the capacitive reactance restricts the current.

Conversely, when the motion of the hand is very rapid (above resonance), the weight stands still and the rubber bands elongate and shorten in step with the motion of the input (Fig. 5C). Little or no change in the position of the weight represents a reduction of current. The inductive reactance of the coil is large and restricts the current. The rubber bands follow the

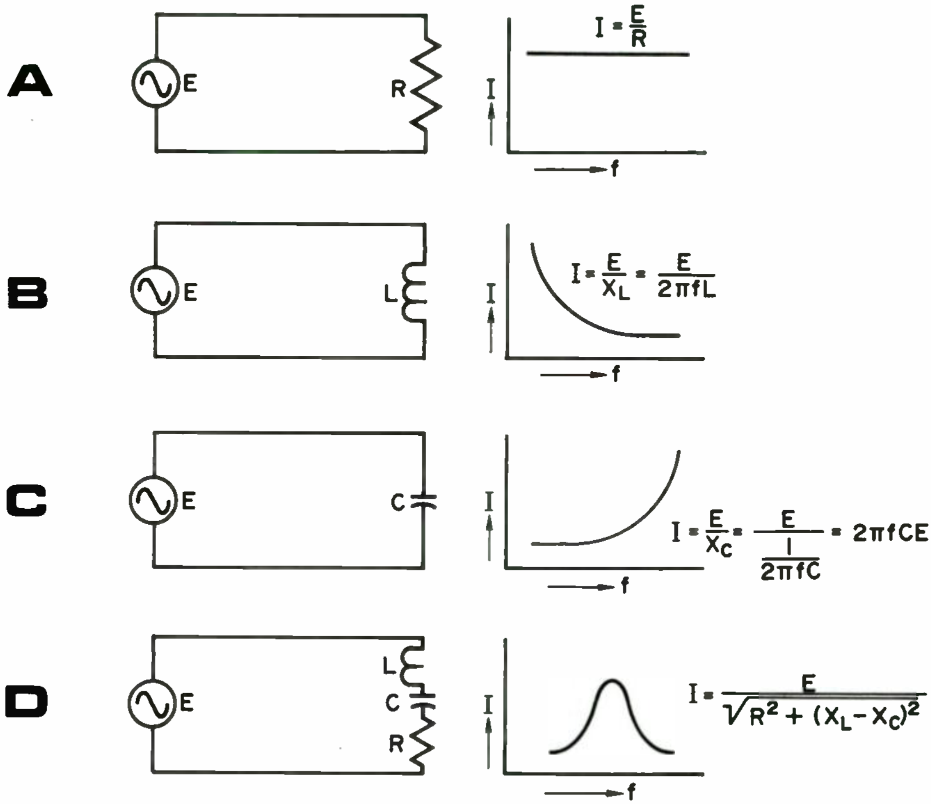


Figure 4 - The load current I in a series circuit varies with the type of component and the frequency.

motion of the hand. The capacitive reactance of the capacitor is low, and only the inductive reactance restricts the current.

Thus, both below and above resonance, current is reduced. When the rate of motion of the hand is adjusted to the mechanical resonant frequency of the system, the weight will bounce through a much larger range of motion than that of the input (Fig. 5D). The large amplitude of motion of the weight and rubber bands represents a large (maximum) increase in current and voltage developed across both the coil and capacitor. The weight is pulled up as the rubber bands shorten, so that the direction of the two amplitudes is opposite. This action corresponds to the 180° phase-shift between the voltage across the coil and the voltage across the capacitor.

The analogy of resonance can be summed up as follows: maximum elongation of the rubber band represents maximum energy stored in the capacitor. The rubber band's shortening, and thus lifting the weight, represents the capacitor's discharging its energy to the inductor. The weight at maximum elevation represents the maximum energy stored in the inductor's magnetic field. The falling weight's stretching the rubber band represents the inductor's discharging of its energy to the capacitor. Thus, the interchange of energy between the capacitor and the inductor is repeated.

The ratio of the amplitude of motion of the weight to the input amplitude represents the voltage gain of the series resonant circuit. The interchange of the energy between the weight and rubber bands keeps the system moving with very little input energy. The ratio of the energy stored periodically in the weight (or rubber bands) to the input energy is called the quality (Q) of the system.

The Q of a Circuit

It was mentioned earlier that when tuned circuits are properly designed, they have the ability to select a desired signal and reject unwanted signals. As there are many cases where signals are quite close together and only one is desired, a circuit should have a high degree of selectivity to provide this action. The measure of this *quality* of a circuit is known as the Q of the circuit. Figure 3 shows that at resonance the only factor that limits the current flow in the circuit is the circuit resistance. We also remember that the voltage drops across the coil and across the capacitor are many times larger than the voltage drop across the resistor (Fig. 2). Whenever we can increase the value of the current flowing in a series circuit, we can increase the drops across the coil and the capacitor.

These facts give us a means of evaluating a circuit by comparing the voltage existing across either the coil or capacitor (which are the same value at resonance) to the voltage across the resistance. This comparison establishes

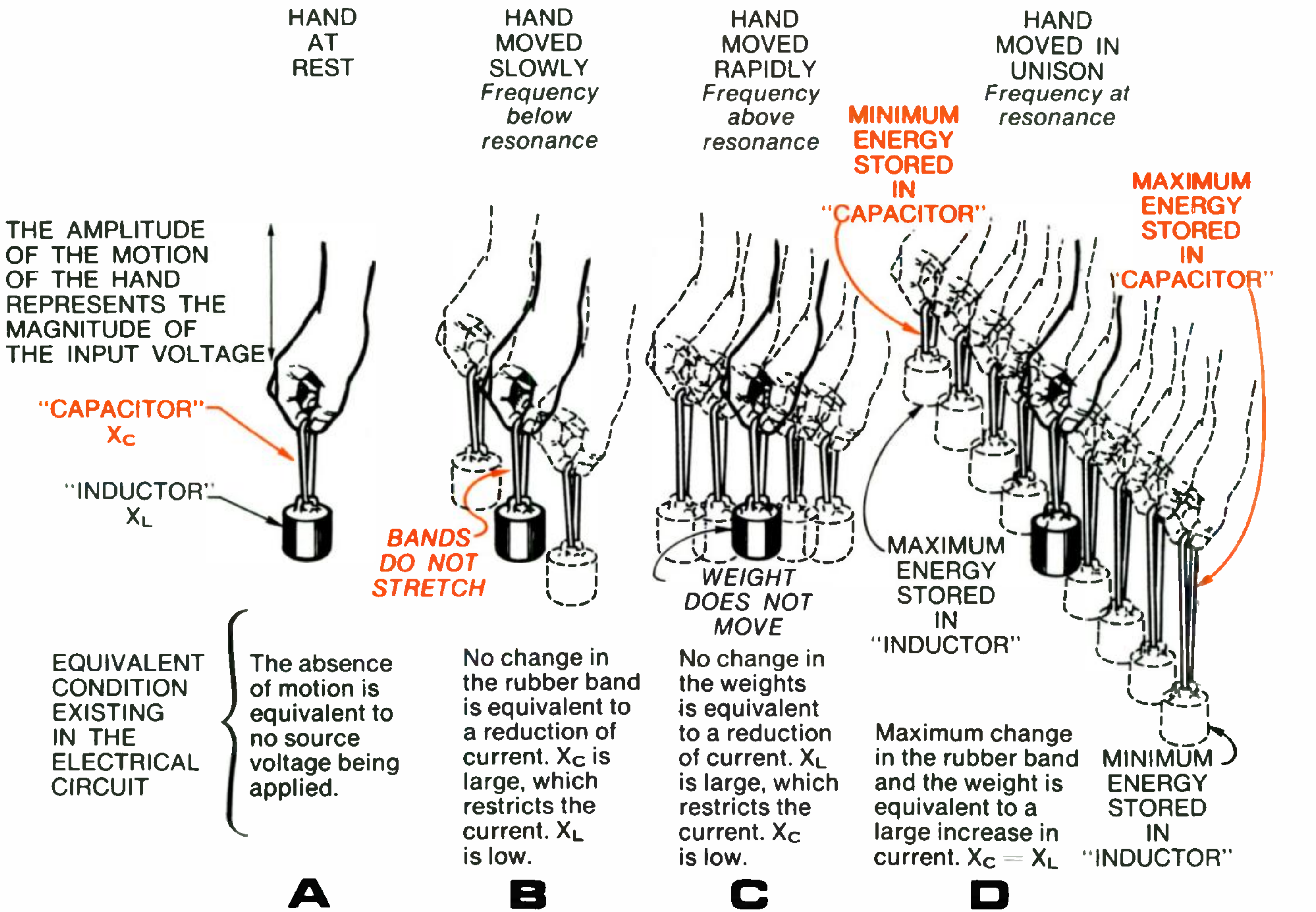


Figure 5 - The mechanical analogy of a series-resonant circuit shows how energy is interchanged between an inductance and a capacitance.

the ratio of $\frac{E_L}{E_R} = Q$ or $\frac{E_C}{E_R} = Q$ since

$E_L = IX_L$, $E_C = IX_C$ and $E_R = IR$, we can write it

$$\frac{E_L}{E_R} = \frac{IX_L}{IR} = \frac{X_L}{R} = Q \quad \text{or}$$

$$\frac{E_C}{E_R} = \frac{IX_C}{IR} = \frac{X_C}{R} = Q$$

These last ratios are the usual form used for representing the quality of a circuit. When we plot these values, we obtain curves like those shown in Figure 6.

Circuit Selectivity

These curves show that the circuit with the least resistance has developed the largest current flow; as we would expect, the smallest current flows in the circuit with the most resistance. If the resistance in the circuit has about the same value as either the coil or the capacitor, the current that is developed at resonance decreases in value very slowly as the frequency is moved in either direction away from the resonant frequency (f_o). The shape of these curves gives us an indication of the *selectivity* of a tuned circuit (Fig. 7).

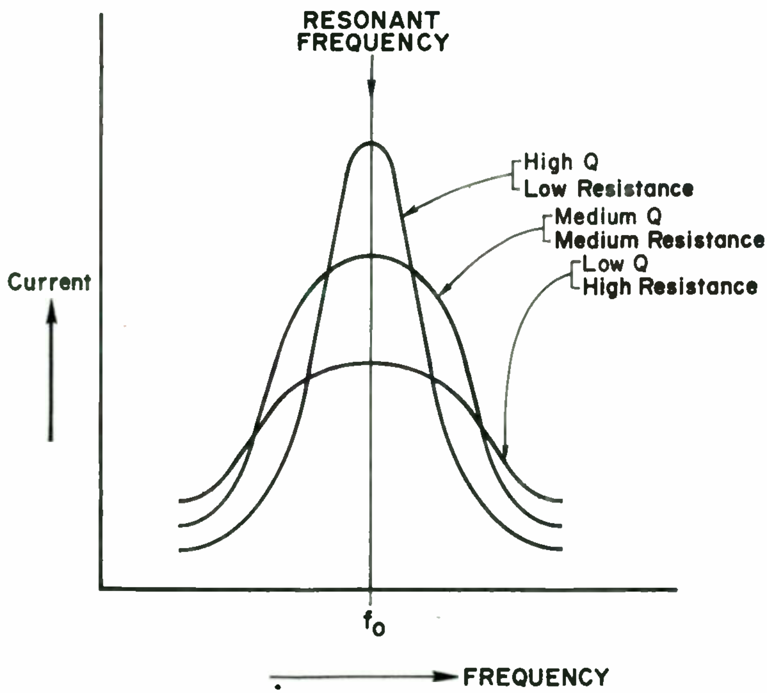


Figure 6 - Resonance curves of a series-tuned circuit vary with the Quality (Q) of the circuit.

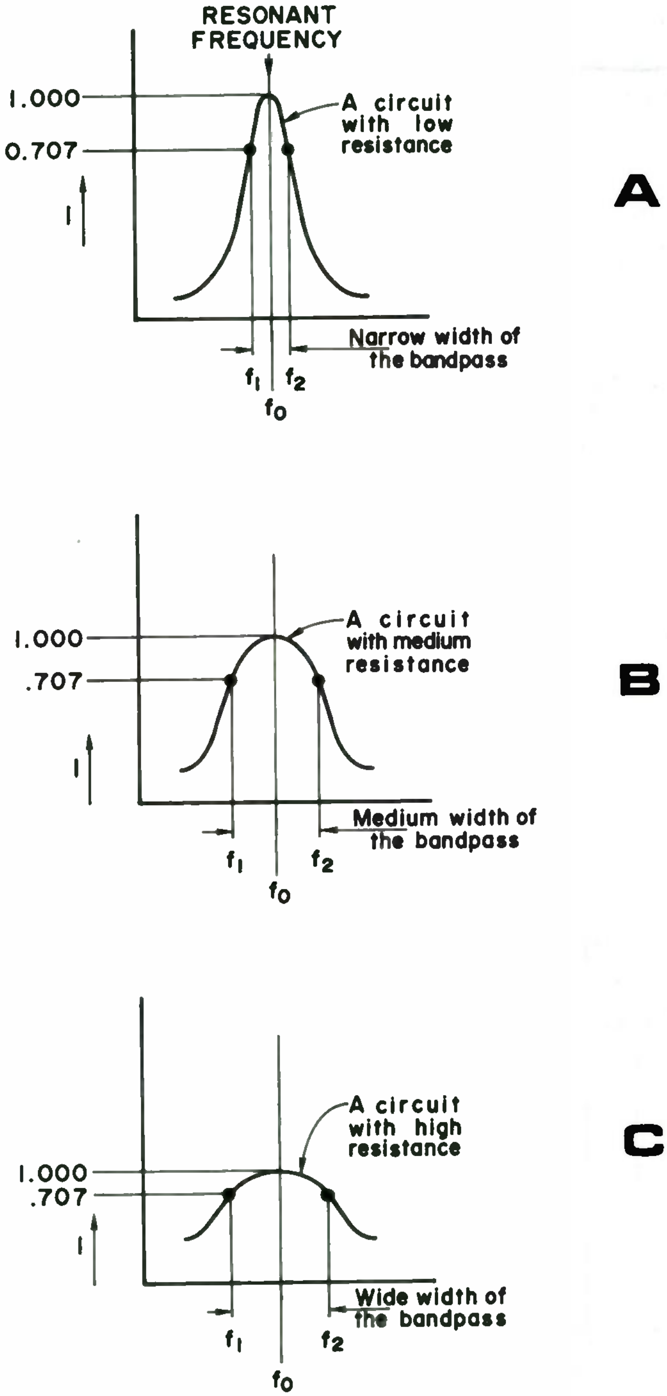


Figure 7 - The width of the bandpass is affected by the resistance of the circuit.

Bandpass

There is a simple method of comparing these curves. Once we know the value of the maximum current developed at the resonant frequency and call it 1.000, we mark off 0.707 of that value on each curve. Where these 0.707 values intersect the waveshapes, the points of the frequencies f_1 and f_2 are established. Figure 7 clearly illustrates that the flatter the curve (Fig. 7C), the greater the number of frequencies that can be "passed" through the tuned circuit. The frequency range from f_1 to f_2 at each curve is known as the *bandpass.*

The curve in Figure 7A has the greatest selectivity because it has only a narrow bandpass; there are only a minimum number of frequencies between f_1 and f_2. Each of the curves at B and C have different bandpass widths; even though it might appear that a tuned circuit with a relatively wide bandpass should not be used, this is not true. Tuned circuits that are represented by curves B and C are important and are used for specific applications, as will be explained later.

PARALLEL RESONANCE

Parallel Circuit Action

A parallel resonant circuit consists of a combination of inductance and capacitance connected in parallel. A small value of resistance (representing the inherent or internal resistance of the two components) may be considered as acting in series with the inductance and capacitance.

A parallel-resonant circuit with losses consists of a combination of inductance, resistance, and capacitance in two parallel branches (Fig. 8). Because the losses of the circuit are generally associated with the inductor (wire), this branch includes a series resistor R in which all the losses are lumped. The other branch consists of a capacitor having negligible loss. At resonance, the same interchange of energy occurs between the capacitor and the inductor that occurs in the series-resonant circuit.

At resonance, the current I_C in the capacitive branch (Fig. 8) is equal to the current I_L in the inductive branch. These currents are 90° out of phase with the applied voltage (one leads by 90° and the other lags by 90°). The vector sum of these two currents is zero because they are equal in magnitude and 180° out of phase. I_t (Fig. 8B) represents the relatively small value of line current needed to overcome the power dissipated in the inherent resistance of L. This small amount of current is supplied by the AC source, shown in Figure 8A, and is the total current drawn by the parallel-resonant circuit. Thus the parallel-resonant circuit has a high input impedance, and the line current is in phase with the applied voltage. This is the condition of unity power factor.

Resonant Frequency

The resonant frequency of a parallel circuit is

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

In this case, f_o is in H_z, L is in henrys, and C is in farads. This is the same as the formula for the series-resonant circuit, because there is an approximate equality in this circuit between the inductive and capacitive reactances.

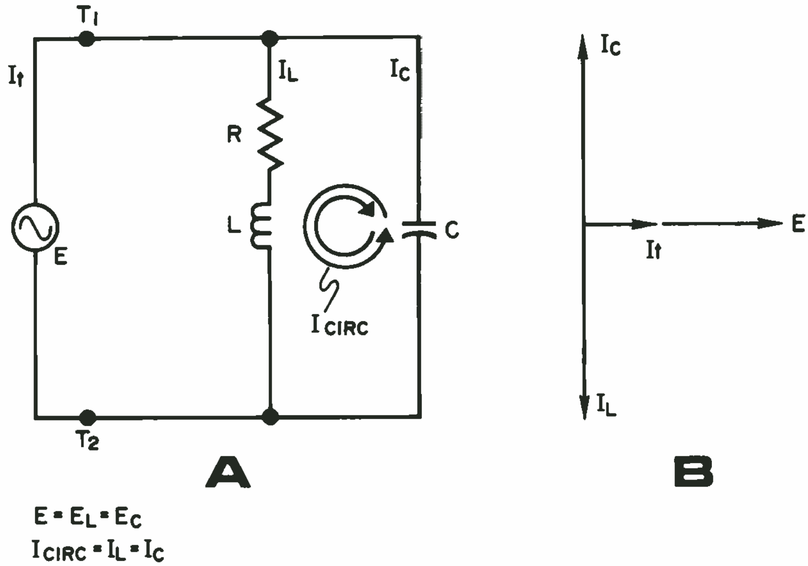


Figure 8 **The circuit conditions existing in a parallel-resonant circuit.**

The parallel circuit is resonant when the currents in the two branches are equal and the power factor of the circuit is unity or 1. In the capacitive branch, the impedance is equal to X_C and the capacitive current $I_C = E/X_C$.

In the inductive branch the impedance Z is approximately equal to the reactance X_L if the resistive losses are low (which they are when coils are properly designed) and the Q of the coil is 10 or higher. In a practical case, the coil current at resonance is $I_L = E/X_L$.

Because the two branch currents I_C and I_L are equal, we can set them equal and obtain

$$\frac{E}{X_C} = \frac{E}{X_L}$$

from which

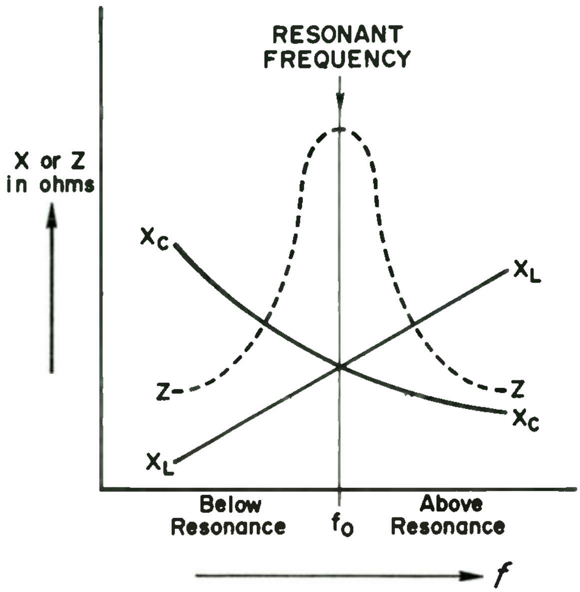
$$X_L = X_C .$$

Thus the inductive reactance and the capacitive reactance are equal in a parallel resonant circuit, just as they are equal in a series resonant circuit.

Circuit Characteristics

The two most important characteristics of a parallel tuned circuit at resonance are: the impedance is at its maximum value, and the current is at its minimum value. If the frequency of the supply voltage is varied both above and below the resonant frequency (f_o), the circuit impedance decreases, which means that the current increases (Fig. 9).

This condition of maximum impedance and minimum current in a parallel-tuned circuit at resonance is opposite to the conditions at resonance for a series-tuned circuit. The curves in Figure 9 should be compared to those in Figure 3. This comparison will show the exact differences.



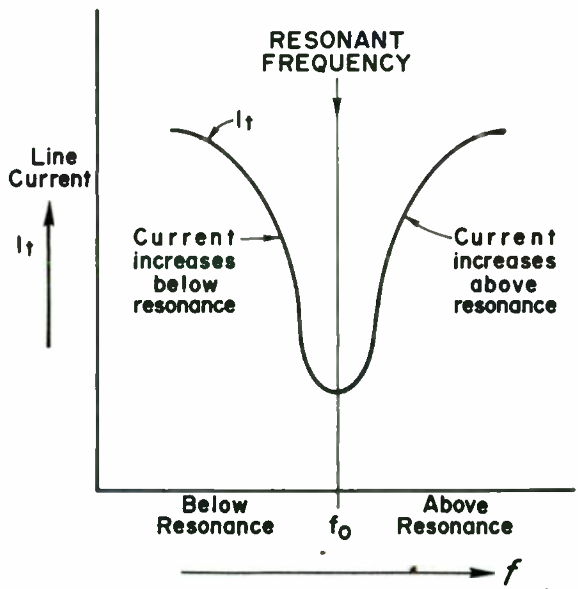


Figure 9 - The impedance of a parallel-tuned circuit is maximum at resonance, while the line current is minimum.

The circulating current I_{CIRC}(Fig. 8) is generally many times larger than the total line current I_t. The line current only supplies the energy that is dissipated in the resistance of the circuit. Since the currents are 180° out of phase (Fig. 2B), the circulating current alternates between the coil and the capacitor and would continue to produce sine waves indefinitely if there were no resistance in the circuit. Consequently, we only need to supply a small amount of line current at the resonant frequency to nudge the circulating current and keep it flowing back and forth between the coil and the capacitor.

Tank Circuit

At resonance, a parallel-tuned circuit has the ability to store electrical energy because of the interaction of the circulating current between the parallel inductance and capacitance. Because of this property of storing energy, parallel resonant circuits are known as *tank circuits*.

The Selectivity and Q of a Parallel Resonant Circuit

The quality (Q) of a parallel resonant circuit determines the selectivity of the parallel-tuned circuit, as it determines the selectivity of the series-tuned resonant circuit. The quality (Q) of the circuit is the same as before: $Q = X_L/R$. The bandpass curves also have the same shape for parallel resonance as they do for series resonance (Fig. 7), and the effect of resistance in the circuit produces selectivity curve shapes (Fig. 6).

Usefulness of Parallel Resonant Circuits

The parallel-resonant circuit is one of the most important circuits used in electronic transmitters, receivers, and frequency-measuring equipment.

The IF transformers of radio and television receivers employ parallel-tuned circuits. These transformers are used at the input and output of each intermediate frequency-amplifier stage for coupling and providing selectivity. They are enclosed in a shield which has openings at the top through which screwdriver adjustments may be made when the set is being aligned.

Parallel-tuned circuits are also used in the driver and power stages of transmitters, as well as in the oscillator stages of transmitters, receivers, and frequency-measuring equipment. The exact use of these circuits will be dealt with specifically in future lessons.

TUNED CIRCUITS

Inductively Coupled

When two separate circuits are *positioned* so that energy from one circuit is coupled to the other circuit by transformer actions, they are said to be inductively coupled (Fig. 10). Mutual inductance is the common property of the two circuits. It is the mutual inductance (M) between the input coil P and the output coil S that determines the amount of voltage induced in the secondary circuit S, from the primary circuit P. The mutual inductance M is expressed in henries and is a measure of how much energy is transferred from an *input* circuit to an *output* circuit.

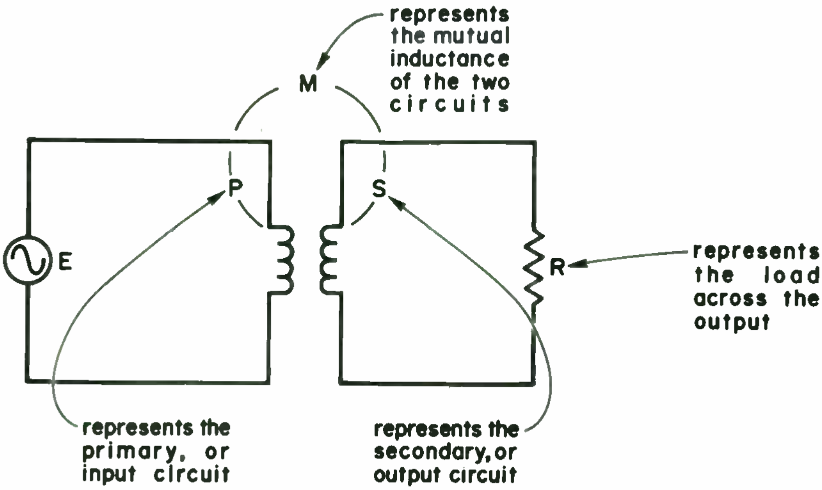


Figure 10 - Coupling between two circuits transfers energy from the primary to the secondary.

The circuit in Figure 10 is also referred to as indirect coupling, magnetic coupling, or mutual-inductive coupling, in addition to being called by the more conventional name, transformer coupling. In every case, the transfer of energy is accomplished by the alternating current of the input circuit flowing through the primary winding and setting up the alternating magnetic field. These magnetic lines of force link with the turns in the secondary winding and induce the voltage that exists at the terminals of this output circuit.

Tuning Methods

A usable tuned circuit is one that allows the frequency of the LC combination to be varied (Fig. 11). This frequency variation is generally accomplished by making the capacitor variable, although some circuits are varied in frequency by adjusting the inductance. A simple circuit like this is sometimes used for tuning, but a more common circuit is one in which the untuned primary is coupled to a secondary that may be tuned to a resonant frequency (Fig. 12). With more turns in the secondary, additional voltage is developed.

The resonance curves of Figure 7 illustrate how the quality (Q) of a circuit determines the selectivity or bandwidth of that circuit. It is assumed that the coil and capacitor in the circuit are not affected by any surrounding components, because this would have an effect on the response curve. Consequently, when a second coil, like the one in the secondary

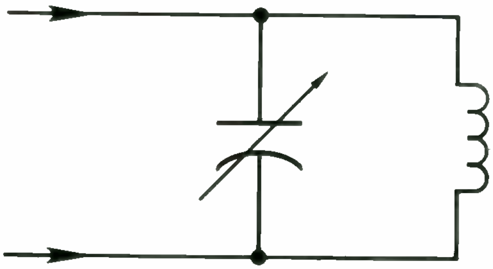


Figure 11 - The frequency of the parallel-tuned circuit is adjusted by the variable capacitor.

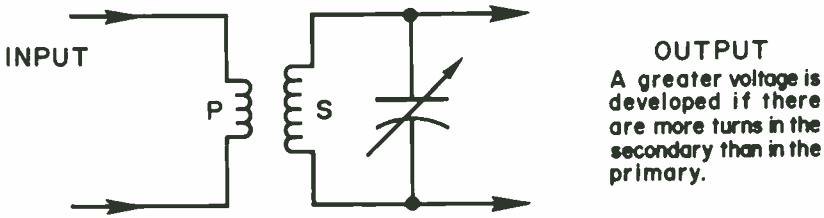


Figure 12 - A coupled circuit that will produce a greater output voltage.

circuit S, is close to the primary coil P, the response curve of the input-output combination depends upon the closeness of the two coils (Fig. 12).

Coupled Circuits

Response curves of IF transformers depend upon the coupling between the coils and the frequency (f_o) to which each circuit is tuned (Fig. 13). When the two circuits are close together, the effect of each one upon the other is stronger than the effect of each by itself. With close coupling (or tight coupling) the familiar double humped response, Figure 13C, is obtained. This last response curve will become broader in frequency response but at the same time the dip in the center will become more pronounced.

TYPES OF TUNED CIRCUITS

Special Circuits

There are many types of tuned circuits; each one has been designed to accomplish a definite electrical function (Fig. 14). The tuned circuits previously described not only perform the function of energy transfer, but also provide some measure of filtering action. There are special circuit designs that have a high degree of filtering action, and by the proper series-parallel combinations of inductance and capacitance they can produce the desired degree of frequency selectivity.

Filter Circuits

Some of the more frequently used types of filters are known as (1) lowpass filters, (2) highpass filters, (3) bandpass filters, and (4) band-reject filters (Fig. 15).

The lowpass filter passes all frequencies below a certain cut-off frequency and opposes all higher frequencies.

The highpass filter passes all frequencies higher than a certain cut-off frequency and opposes all lower frequencies.

The bandpass filter passes all frequencies within a chosen band of frequencies and opposes all frequencies above and below this band width.

The band-reject filter rejects all frequencies within a

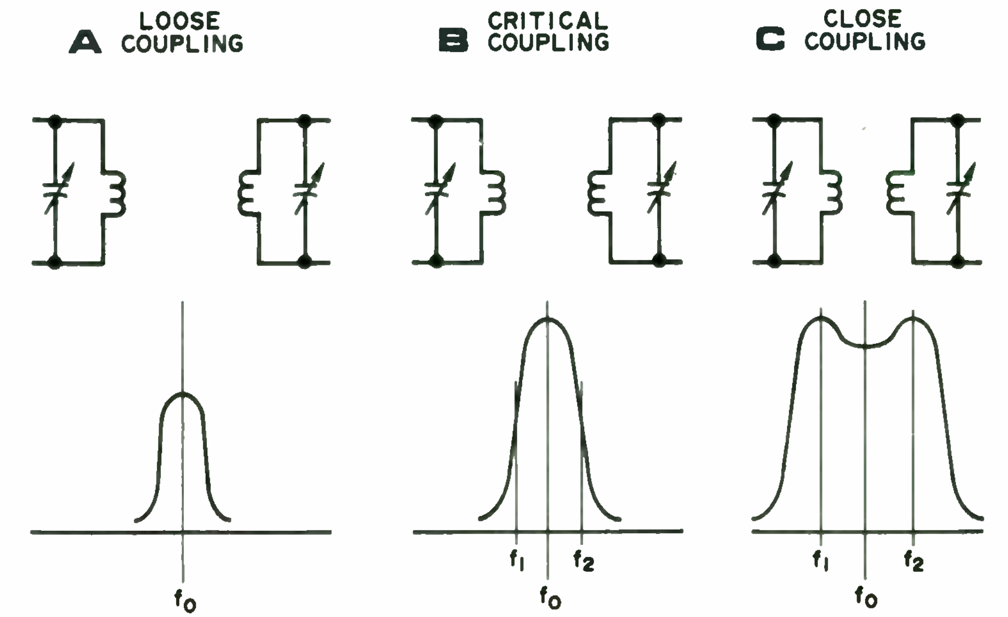


Figure 13 - Response curves that illustrate the effect of different amounts of coupling between two tuned circuits.

chosen band of frequencies and passes all frequencies above and below this band width.

Some filtering action is provided by an individual inductance or capacitance. The opposition to current flow by an inductance is clearly shown in Figure 4B; the curve illustrates how the current decreases as the frequency increases. A capacitor has the opposite effect in a circuit (Fig. 4C); the current flowing in a capacitive circuit increases as the frequency increases.

Attenuation

Neither an inductance nor a capacitance used alone produces sharp frequency cutoff. This cutoff action is also known as *attenuation*. In order to obtain a sharper cut-off, series and parallel combinations of coils and capacitors are both used to improve the sharpness of the attenuating action.

SUMMARY

A tuned circuit consists of inductance and capacitance, with the resistance of the circuit kept as low as possible. When the frequency of the circuit is adjusted to correspond to a selected frequency, the circuit is said to be in *resonance* or at the *resonant frequency*.

The series-tuned circuit is resonant at the frequency at which the inductive reactance equals the capacitive reactance. At this resonant frequency, the impedance is at its minimum value and the current is at its maximum value. The resonant frequency is determined from $f_o = 1 / 2\pi \sqrt{LC}$.

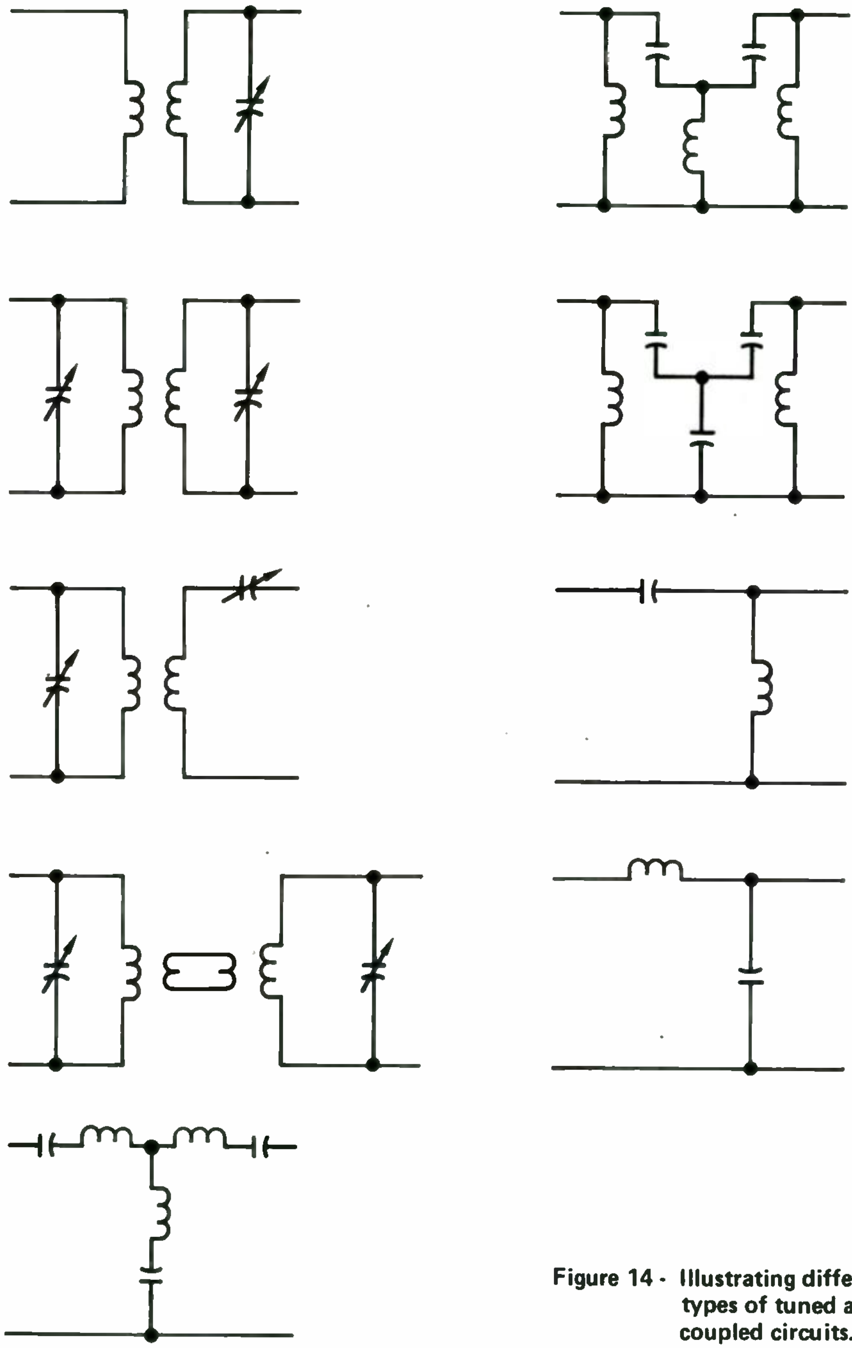


Figure 14 - Illustrating different types of tuned and coupled circuits.

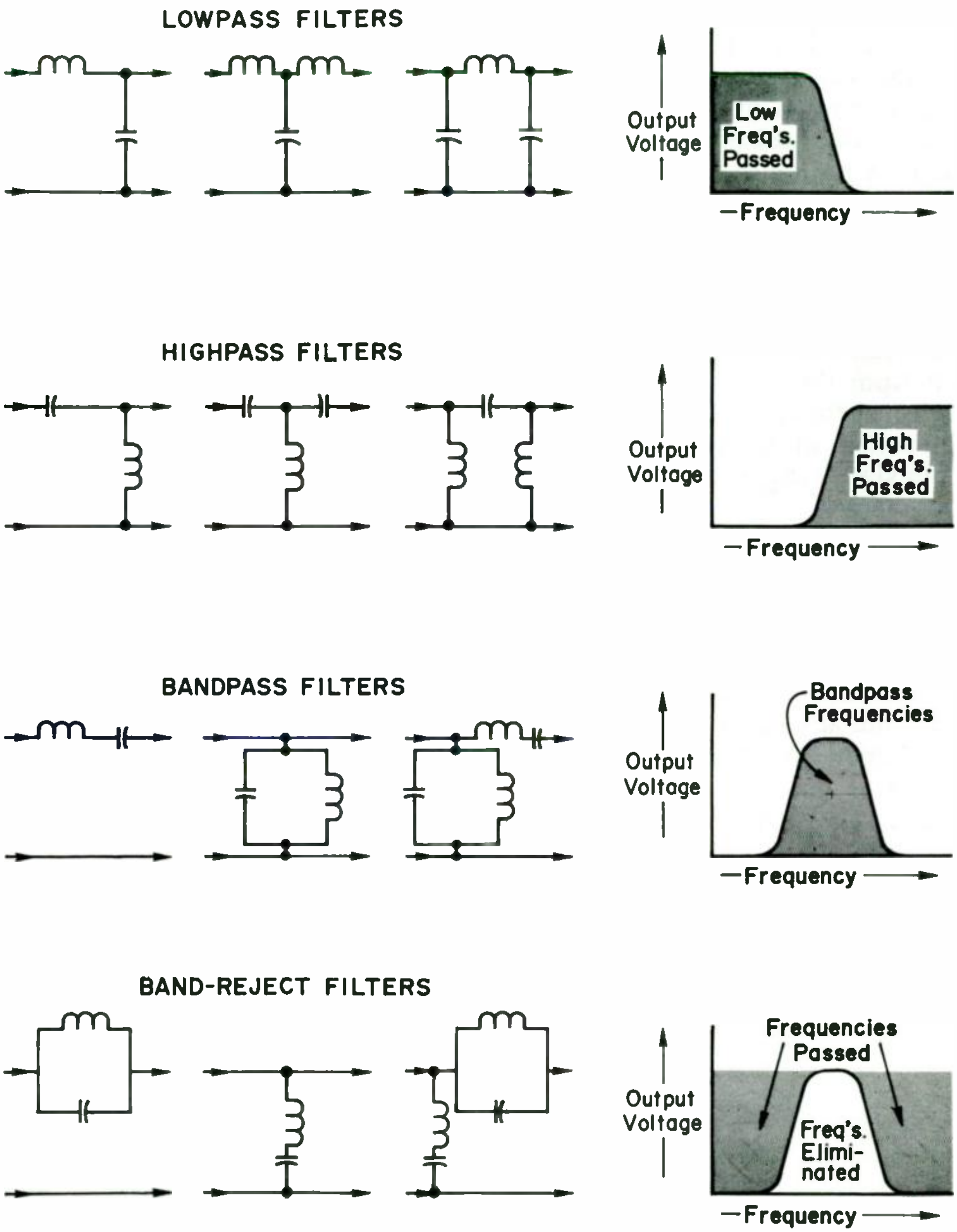


Figure 15 - Representative filter circuits and their characteristic curves.

A resonance curve indicates how quickly the current in a circuit is decreased on either side of the resonant frequency. When the current has decreased to 0.707 of its maximum value, the two frequencies at these points on the resonant curve determine the *width* of the bandpass. A large amount of resistance in a circuit decreases the maximum current value and also widens the bandpass. A minimum resistance produces a circuit with a high degree of selectivity.

The quality (Q) of a circuit is determined from the voltage drop across the coil L or the capacitor C compared to the voltage drop across the resistor R. Thus $Q = E_L/E_R = E_C/E_R$.

The parallel-tuned circuit is also resonant at the frequency at which the inductive reactance is equal to the capacitive reactance. But in this parallel circuit, it is the impedance that is maximum, and the line current that is minimum at resonance. Since there is an interchange of energy between the inductor and the capacitor, there is a large value of circulating current; only a small amount of line current is required to overcome the loss in the resistance of the circuit. This circuit is also called a *tank circuit*.

The resonance curve of a parallel-resonant circuit is similar to the resonance curve of a series-resonant circuit. Resistance in the circuit affects the shape of the resonance curve, the Q of the circuit, and the selectivity, in the same way it affects the series-resonant circuit.

Filter circuits are designed to pass voltages or currents at specific frequencies, while rejecting voltages or currents of all other frequencies. The four major types of filters are lowpass, highpass, bandpass, and band-reject. The lowpass filters pass all frequencies up to the selected frequency and attenuate or reject all higher frequencies. The highpass filters pass high frequencies and reject low frequencies. The bandpass filters allow a select band of frequencies to pass through the circuit and reject frequencies above and below this bandwidth. The band-reject filters attenuate a narrow band of frequencies and pass those above and below the resonance of the filter.

....

TEST

Lesson Number 30

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 52-030-1.

1. A circuit is said to be tuned when
   A. the bandpass is wide.
   B. an AM signal is being tuned.
   C. a circuit includes an inductor and a capacitor, but no resistor.
   D. the frequency of the LCR circuit matches the frequency of the source.

2. A series-tuned circuit is in resonance when
   A. X_L is larger.
   B. X_C is larger.
   C. E_R is smallest.
   D. X_L equals X_C.

3. A resonance curve
   A. is useless.
   B. displays the voltage drops.
   C. only gives information about a series-tuned circuit.
   D. displays the circuit current at different frequencies.

4. In a series-tuned circuit
   A. the IR drop is always low.
   B. the current leads the voltage.
   C. the Q is always low.
   D. the current has the same value through all of the components.

5. In a parallel tuned circuit
   A. the bandpass is always wide.
   B. the Q must be large.
   C. the line current equals the circulating current.
   D. there is a current circulating between the inductor and the capacitor.

6. The quality Q of a tuned circuit is equal to
   A. E_L/E_R
   B. E_R/E_L
   C. E/R
   D. R/XL

7. The selectivity of a circuit is greatest when the response curve is
   A. narrow.
   B. wide.
   C. flat.
   D. medium.

8. A parallel tuned circuit that stores energy is best known as
   A. a tank circuit.
   B. a radiating circuit.
   C. a series circuit.
   D. all of the above.

9. A circuit is tuned when its resonant frequency is
   A. equal to $\frac{1}{2\pi \sqrt{LC}}$
   B. equal to the resonant impedance.
   C. equal to the resonant current value.
   D. none of the above.

10. A bandpass filter
    A. passes all frequencies below a certain cut-off frequency and opposes all higher frequencies.
    B. passes all frequencies higher than a certain frequency.
    C. rejects all frequencies within a chosen band of frequencies.
    D. passes all frequencies within a chosen band of frequencies and opposes all frequencies above and below this bandwidth.

Notes

Notes

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SPARE TIME + EFFORT = PROFITS

Take five to six hours of your spare time each week, add a little effort and you will end up with a nice profit.

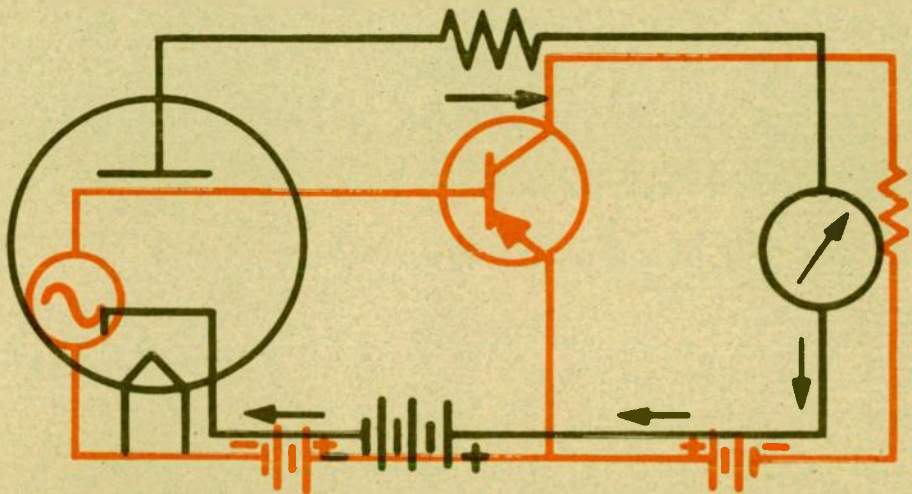
As you gain more practical knowledge you will learn how to handle all the jobs you come up against; whether it be just a simple replacement of a component. . .or a plug-in assembly. . . or servicing and installing complete electronic systems.

Learning "how" takes hard work and study — on your part. We can help you along by making your lessons interesting and enjoyable. So make the effort to learn these basic fundamentals thoroughly — then when you get into actual service and repair work, the effort will pay off handsomely in profits.

S. T. Christensen

LESSON NO. 31

MULTIVIBRATORS



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CONTENTS

MULTIVIBRATORS

INTRODUCTION

In previous lessons, you were introduced to both transistors and vacuum tubes. The primary function of each is their ability to amplify or increase the strength of signals.

In comparing the two devices, you should be aware that transistors are current input devices, whereas vacuum tubes are voltage input devices. The output signals can be either AC or DC current, or they may be the AC or DC voltage developed across a load. This load is either resistive or inductive, and is in series with one of the device's elements; this element can be either the collector or emitter of a transistor, or in the case of a vacuum tube, the plate or cathode.

One of the ways that amplifiers are classified is by their output. Various amplifiers can supply voltage or current at their outputs. Power amplifiers supply both current and voltage. It is a power amplifier that supplies the audio currents that drive a loudspeaker.

In the lesson on transistors, we stated that the term *Beta* indicates the current gain of a transistor. Beta can be further described as forward current gain by interpreting its hybrid symbol. In addition, the circuit configuration can also be indicated with this symbol.

Thus,

HFe = forward current gain of a *common emitter* circuit

HFb = forward current gain of a *common base* circuit

HFc = forward current gain of a *common collector* circuit

The reason for a separate gain figure for each configuration is that each configuration has a different value of forward current gain.

MULTIVIBRATORS

A transistor or vacuum tube multivibrator is a two stage circuit in which each stage has some control over the other. In addition to transistors and vacuum tubes, FET's, tunnel diodes, and four layer devices are sometimes used as the active elements.

A multivibrator has two states. In one state, stage 2 conducts and stage 1

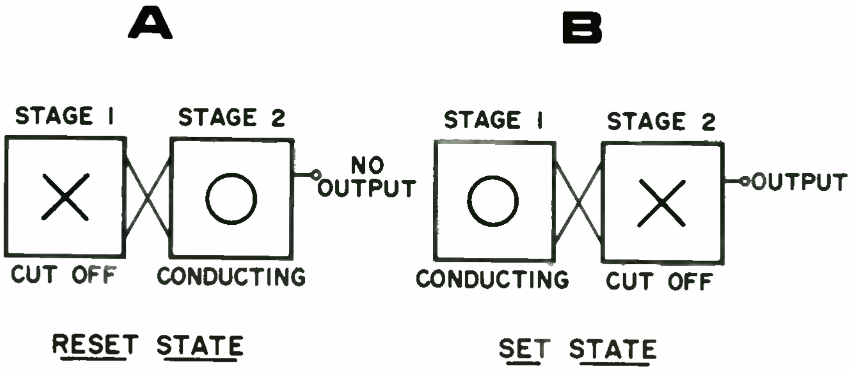


Figure 1 - Set and reset states of a multivibrator.

is cut off as shown in Figure 1A. In Figure 1B, the opposite state exists . . . stage 1 conducts while stage 2 is cut off. A multivibrator in the reset state (Fig. 1A) has no voltage output. However, a voltage output is present when stage 2 is cut off as shown in the set state of Figure 1B.

Multivibrators are generally classified according to their stable states. A *Bistable* multivibrator can remain in either state until triggered, whereas, a *Monostable* multivibrator changes state when triggered and then reverts to rest after a delay period. An *Astable* multivibrator has two unstable states and flips continually from one to the other. It is frequently called a *free running* multivibrator.

Multivibrators have the ability to change states rapidly, which makes them valuable for split second control. The astable or free running multivibrator can be locked to external pulses to produce precise timing functions. In a television set, an astable multivibrator is sometimes used to develop the sweep signals that drive the beam across the face of the CRT in step with sync pulses from the received signal. This electron beam must reproduce more than 15,000 horizontal lines per second, each in its proper sequence. This is possible with the use of multivibrators.

ELECTRONIC SWITCH ELEMENTS

A circuit that can abruptly interrupt or conduct current on command is called a switching circuit. A transistor may be associated with resistors, capacitors, inductors, diodes, or other transistors to perform switching functions. The purpose of this association of components is to receive signals, modify them (usually it amplifies them), and cause some effect. This effect may result in light, sound, or action.

In solid state TV sets, transistors cause a lighted picture to appear on the screens by amplifying and conditioning video signals. The audio circuits produce sound by modifying audio information and presenting it to a speaker. In a remote controlled TV set, the unit is turned on or off, the sound varied, or the channel selector rotated as transistors respond to con-

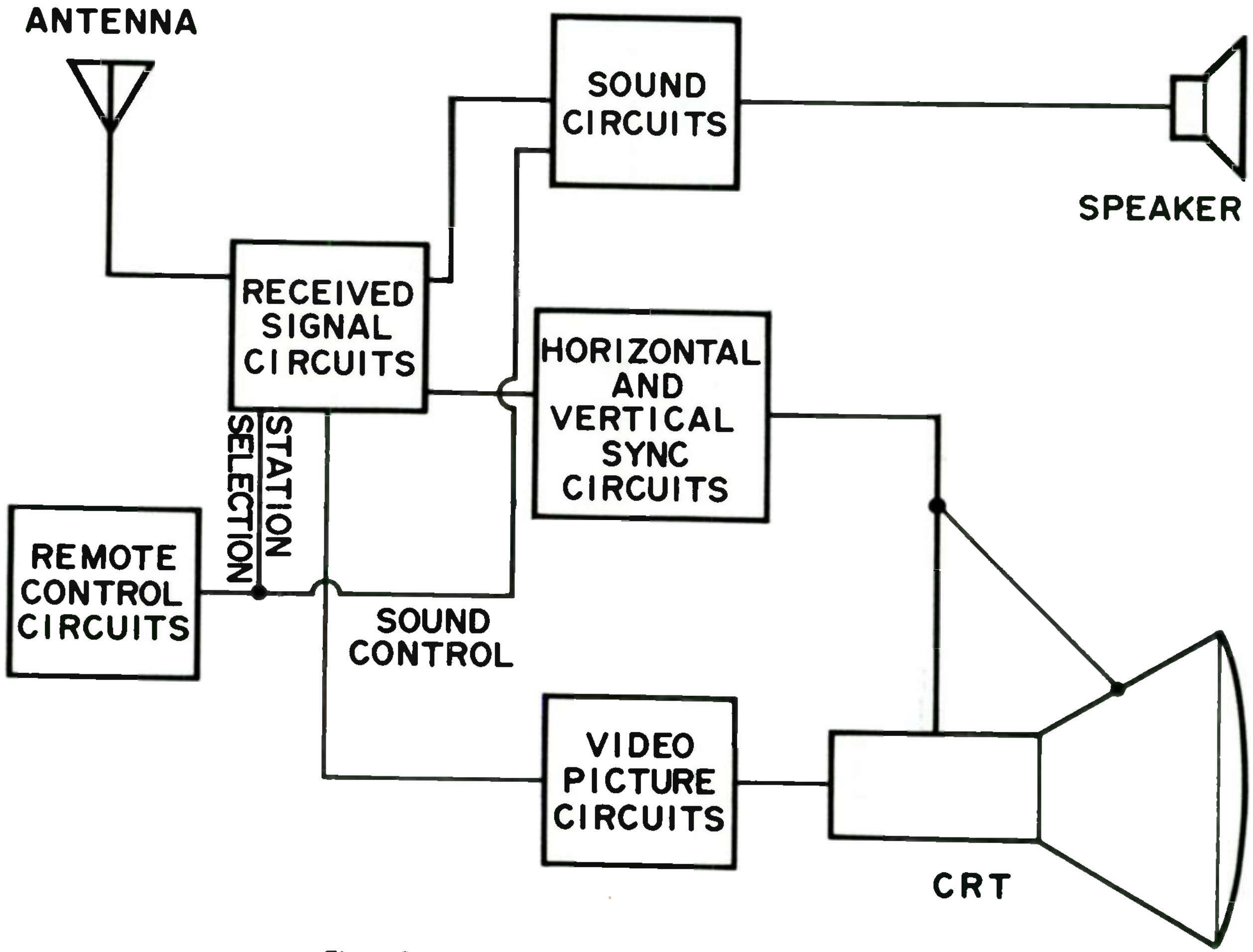


Figure 2 - Block diagram of a remote controlled TV set.

trol signals. A block illustration of a remote controlled TV set is shown in Figure 2. In nearly all of its circuits, some form of electronic switching takes place.

We will now examine electronic switching circuits and their associated components. Solid state circuits will be discussed first. The schematic in Figure 3 illustrates a transistor switching circuit with its associated resistive components. These are:

4

R_L = load resistor

R_B = base bias resistor

R_I = input resistor

R_C = control resistor

R_E = emitter resistor

Not all of these components are used in every circuit application.

A load of some kind is always associated with electronic circuits. This load (most frequently a resistor R_L) serves two functions:

1. It limits the amount of current that can flow through the collector junction and prevents overloading of the transistor which could cause permanent damage.
2. It provides a voltage drop, due to collector current, which may be used to drive other circuits.

Figure 4A shows a common emitter circuit using an NPN transistor. The

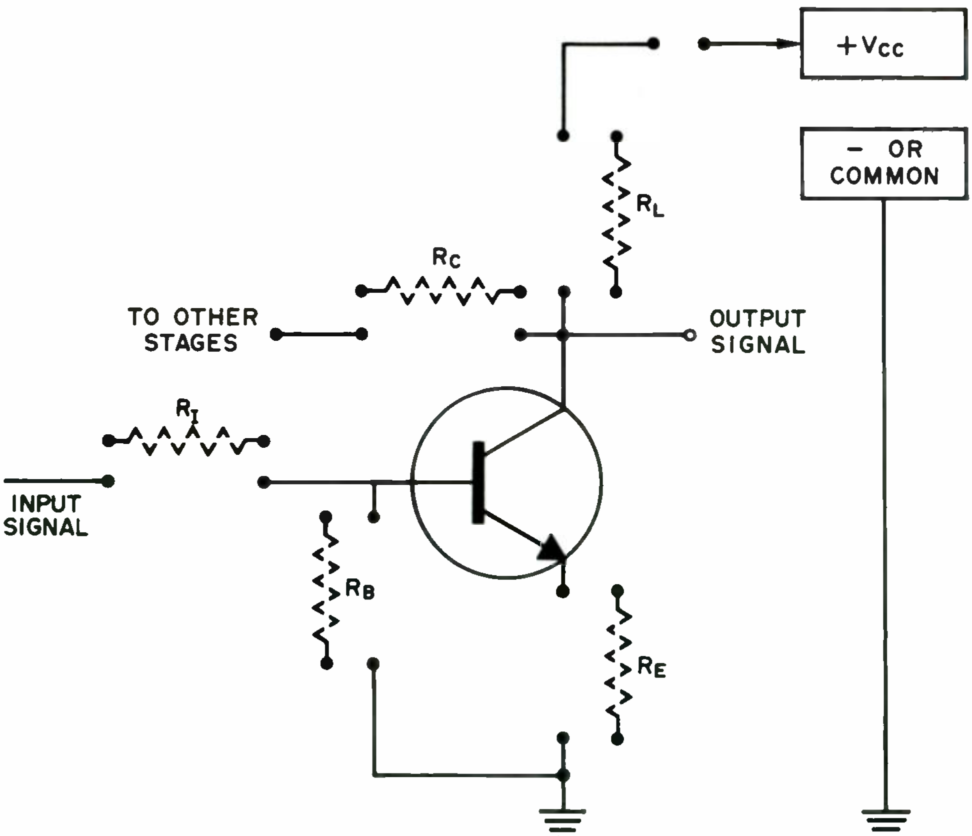


Figure 3 - A basic transistor switch.

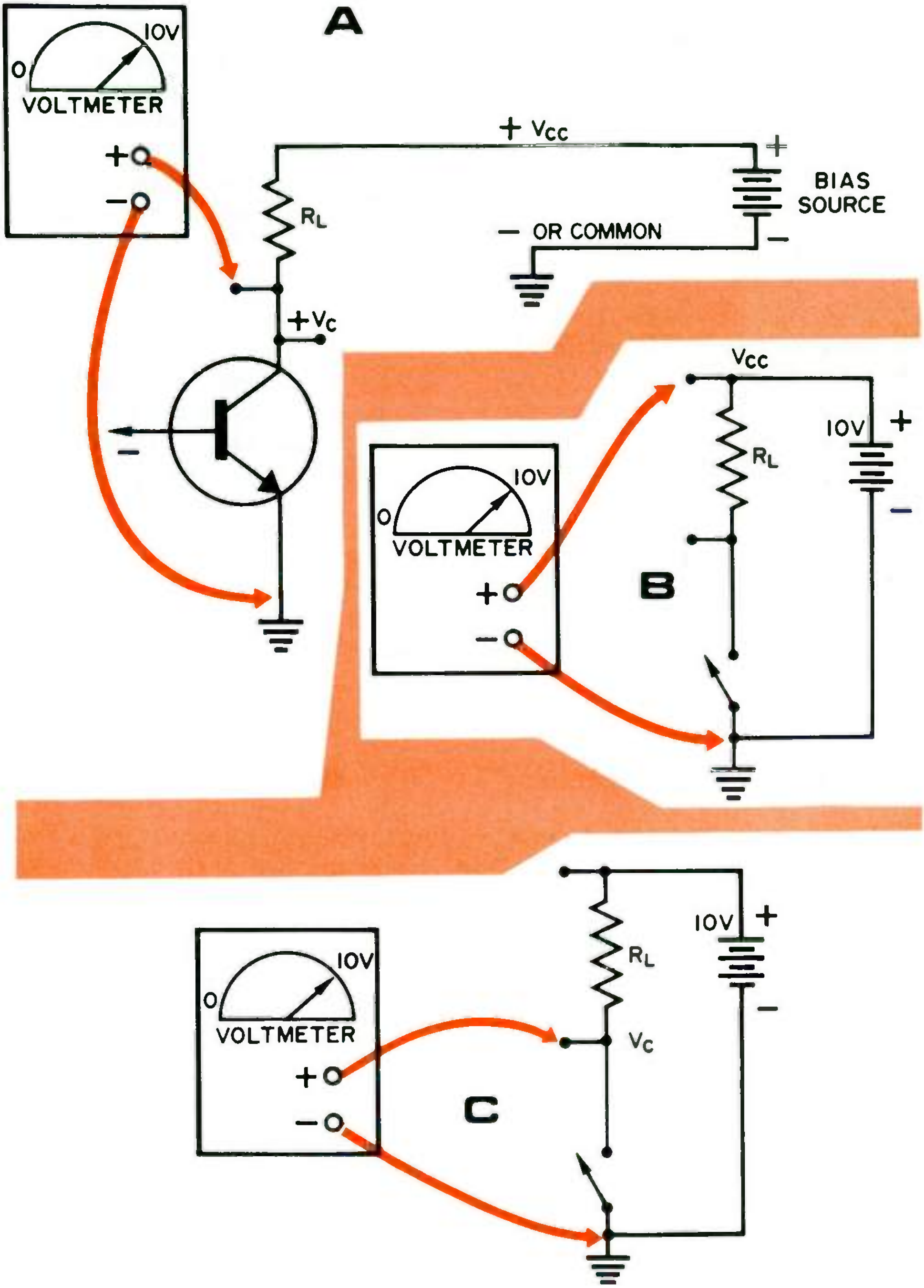


Figure 4 - Mechanical switch analogy of an "open" or "off" transistor switch.

load (R_L) is in place and a collector bias voltage is applied. Observe that this voltage is identified as Vcc. (It is constant in value regardless of the transistor's conduction characteristics.) The voltage that appears at the collector is identified as Vc and varies with collector current.

In Figures 4B and 4C, the transistor is represented as an open switch. The bias supply has been assigned a value of 10 volts. The voltmeter in Figure 4B indicates 10 volts Vcc. In Figure 4C, we also measure 10 volts of Vc. This is because the switch is open and no current is flowing in the load (none of the source voltage is dropped across R_L).

In Figure 5A the input voltage to the base has been raised to some positive value. Positive current flows from base to emitter within the transistor and neutralizes the junction charges. Emitter current flows toward the collector junction and further neutralizes the collector junction charges. Both junctions are forward biased, and a large current flows between the emitter and collector. This current is much larger than the current into the base. Thus, the input current has been increased or amplified in the output or collector circuit.

Figures 5B and 5C show the effects of current flow on the values of Vcc and Vc. In illustration B, we still measure +10 volts Vcc, because the bias supply does not change appreciably with the load. However in illustration C, Vc has dropped to 0 volts. The switch is closed and the total supply voltage is dropped across R_L.

When the current into the base of a transistor is sufficient to neutralize all the junction charges, the transistor is completely forward biased. The junction resistances are almost zero, and only a very small voltage will be dropped across the transistor. This condition is called saturation.

> Saturation occurs when a transistor's junction resistances cannot be further reduced by increasing the input signal current.

Figure 6 illustrates saturating current pulses applied to the base of our NPN transistor. The voltages of these pulses have the same polarity as their current. At the output, the voltage polarity is opposite to the current. When the input voltage and current are at maximum positive, the output current is also at maximum, but the total supply voltage is dropped across R_L, and the collector voltage (Vc) is zero. If the input is reduced to zero, collector current will also decrease to zero. With no current flowing through R_L, no voltage will be dropped across R_L, and Vc will be at its maximum positive value.

The voltage drop across a transistor in a common emitter circuit is opposite or inverted in polarity to the input voltage. Thus, a sine wave voltage, when applied to the input, will be shifted 180° in the output.

An input limit resistor (R_I) is normally included between the signal source and the transistor (Fig. 7). This resistor serves two functions:

1. It limits the amount of base input current to a safe value and prevents permanent

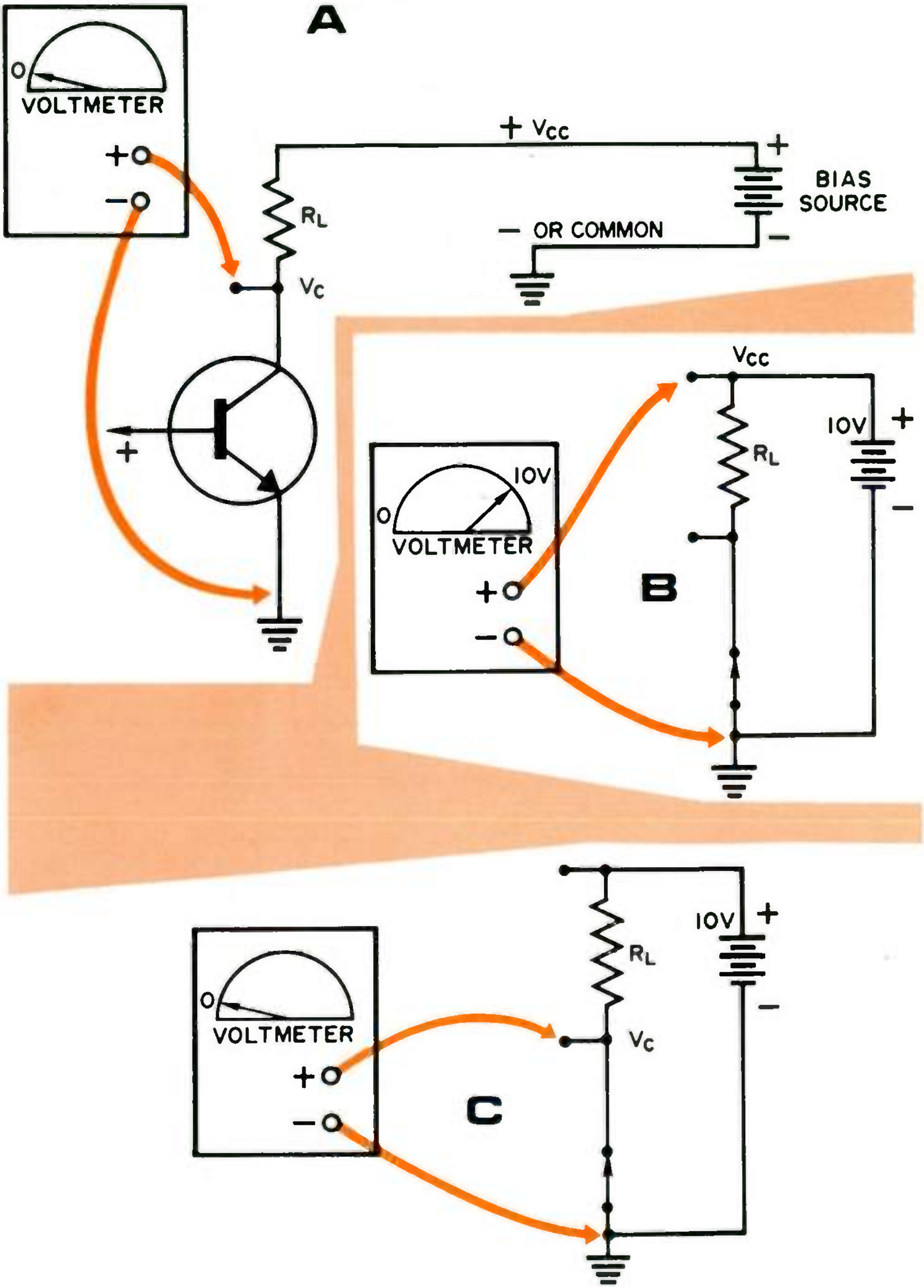


Figure 5 - Mechanical switch analogy of a "closed" or "on" transistor switch.

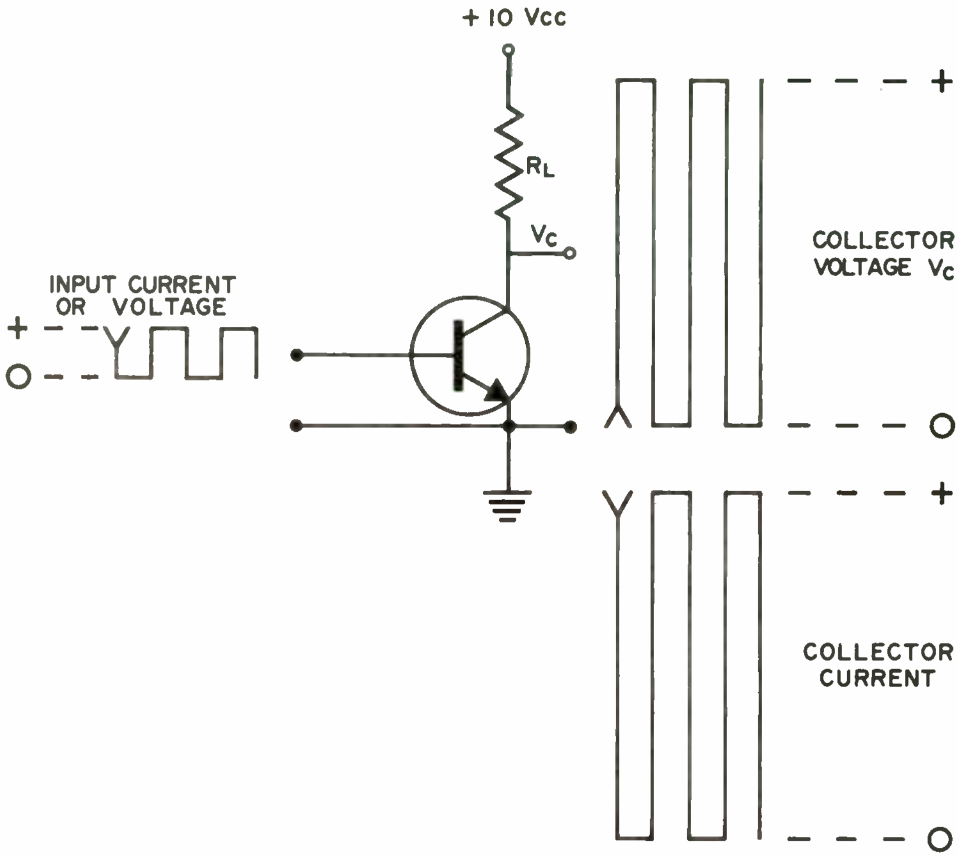


Figure 6 - Output waveform of a transistor switch with a square wave input.

damage to the base-emitter junction.

2. It limits the amount of current that can be drawn from the source and prevents overloading it.

Secondary charge currents are always flowing within the semiconductor material of transistors. These minority currents are mostly due to minority carriers and crystal surface leakage. Minority activity increases with temperature, and in the case of an NPN transistor, the most significant leakage is positive current. These positive current charges move into the base region and act as if a small amount of input current were present. They forward bias the base-emitter junction in proportion to the temperature of the device.

One way to prevent leakage current from forward biasing a transistor is to shunt it around the base-emitter junction. This is accomplished by connecting an external resistor between the base and the emitter leads (Fig. 8).

Figure 9A shows another resistor (R_E) added to the circuit. This resistor also helps to improve the temperature characteristics or *thermal stability* of a

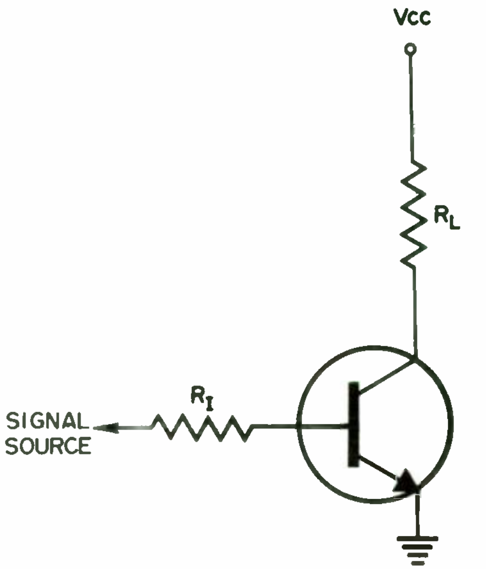


Figure 7 - Resistor RI limits input current and prevents damage to the transistor due to excessive input current.

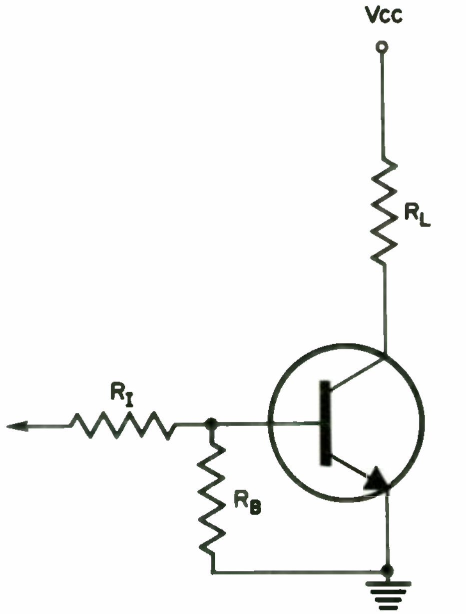


Figure 8 - Resistor RB provides a leakage path for the thermally generated carriers that could turn the transistor on.

transistor. The emitter current through this resistor causes a voltage drop that opposes the forward bias voltage at the base. In addition, the emitter resistor (R_E) serves two other functions:

1. It effectively increases the input resistance of a circuit, thereby, increasing its efficiency.
2. In the case of amplifiers, it aids the circuit in producing an output waveform that is a true reproduction of the input wave shape.

The second function of an emitter resistor will be discussed more thoroughly in the lessons pertaining to audio frequency amplifiers.

Figure 9B shows a diode substituted for R_E. It also includes the auxiliary bias resistor that is occasionally used. This resistor, R_{AUX}, provides bias current. The voltage across the diode will be nearly constant and its magnitude depends upon the kind of semiconductor material in the diode.

Germanium junctions develop approximately .3 volts when forward biased.

Silicon junctions develop approximately .7 volts when forward biased.

Vacuum tubes can also be used effectively as electronic switches. The schematic in Figure 10A is the vacuum tube equivalent of a transistor switching circuit. It has several basic differences one of which is the value of the supply voltage (Ebb). Voltage Ebb is generally 100 volts or more. Another difference is that its input grid voltage

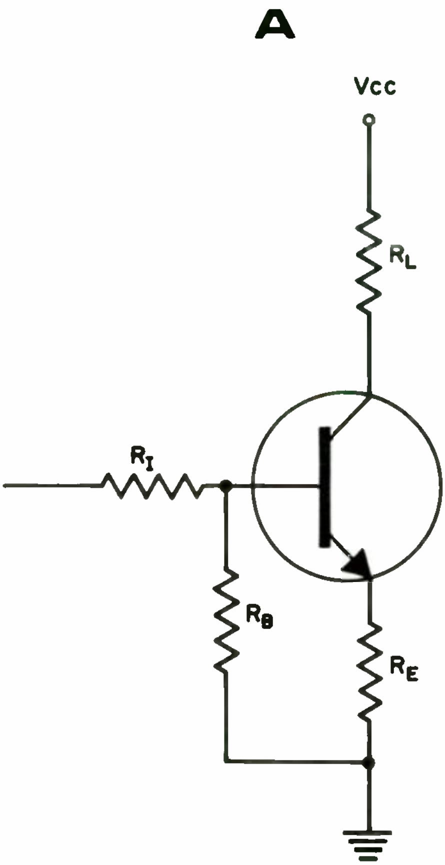


Figure 9A - Thermal stabilization at the emitter with a resistor.

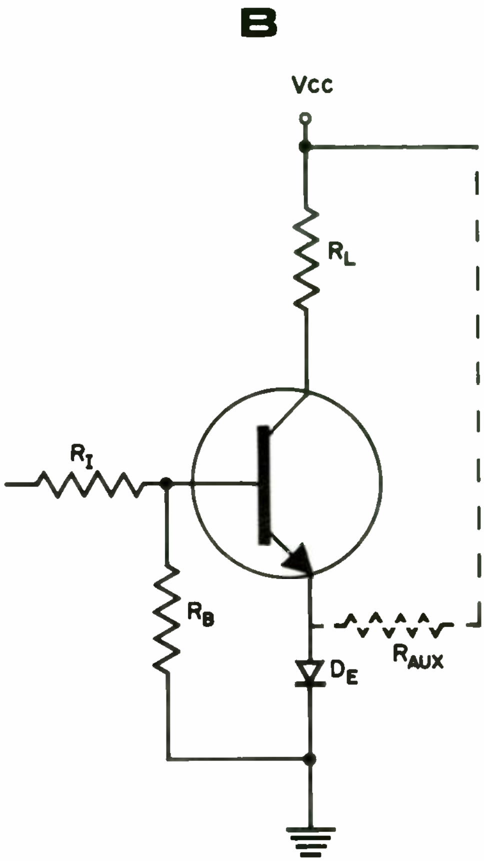


Figure 9B - Thermal stabilization at the emitter with a diode.

is seldom made to exceed the cathode voltage in a positive direction. Vacuum tubes require almost no input current when the grid is maintained at a negative potential with respect to cathode.

In Figure 10B, an alternate grid biasing arrangement is used. The cathode is connected directly to the negative terminal of the power supply and the grid resistor is returned to a separate source that is more negative than the cathode. This maintains the cutoff condition until a less negative potential is applied to the input.

BISTABLE MULTIVIBRATORS (FLIP-FLOP)

In Figure 11, we see a basic transistor bistable multivibrator with its vacuum tube counterpart. A bistable is known in most phases of electronics as a "Flip-Flop." This name is derived from the fact that the circuit can be made to flip to its set state or flop back to its reset state.

Notice that a bistable like all other multivibrators is actually

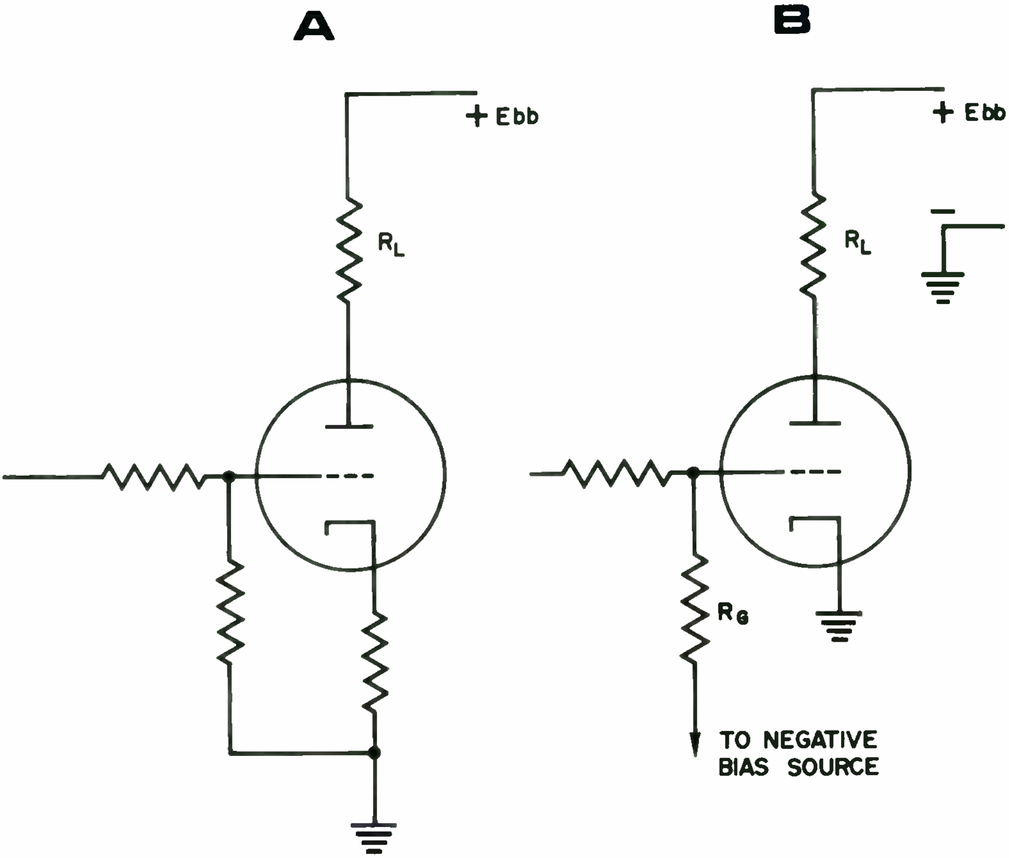


Figure 10 - Basic vacuum tube switches.

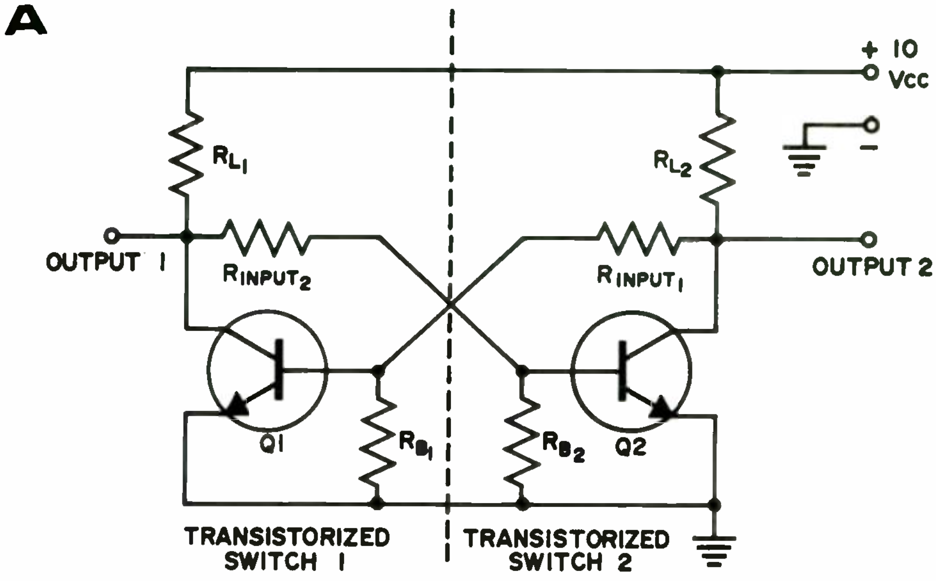
two electronic switching circuits connected together.

In our explanation of circuit operation, we will concentrate on the transistor version for simplicity. Remember that the operation of the two (tubes and transistors) is similar. Transistor circuit descriptions can be applied to tube circuits by substituting the references to transistors (Q) with tubes (V), and by referencing the inputs to voltages, instead of currents.

In Figure 12, we have added N/O (normally open) push button switches from the collector to the common ground at each transistor. In this way, we can simulate a conducting or "on" transistor by closing a switch.

When we actuate switch 1 (the set switch), a path is provided for current flow through R_{L1}. The voltage at Q1's collector drops to zero, and as the current ceases to flow into Q2's base through R_{INPUT2} . . . Q2 turns "off." As collector current ceases to flow through R_{L2}, Q2's collector voltage rises toward the Vcc potential. Two conditions now exist:

1. A positive voltage is present at the output of Q2 or on Q2's collector.



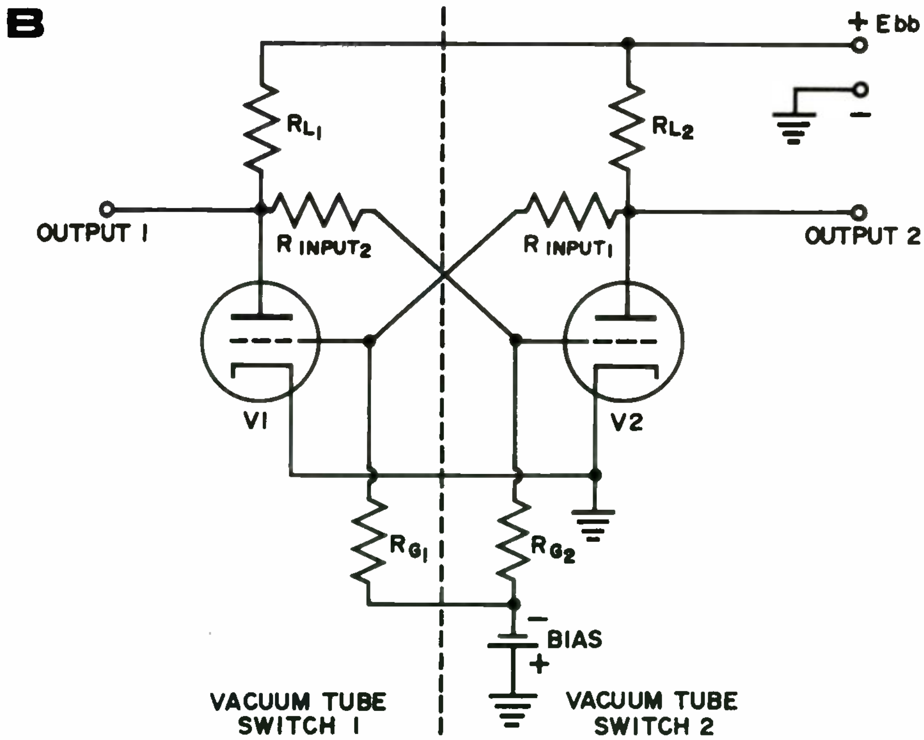


Figure 11 - Basic bistable multivibrators.

2. Current flows through R_{INPUT1} into the base of Q1, turning it "on."

The flip-flop is now set and it will remain in this state until the base current to Q1 is interrupted.

To reverse the state of the circuit we can momentarily close switch 2. This provides a path for current to flow through R_{L2}, in which case the collector voltage at Q2 drops to zero. Base current ceases to flow into Q1; its collector voltage rises and forces current into the base of Q2, turning it on. No output voltage is present from Q2, therefore, the circuit is in a reset state.

Some method other than switch contacts is generally used to trigger multivibrators. One of these methods uses a changing voltage or current that can be coupled into the "on" transistor's base through a resistor. This change of DC level is frequently called a *gate current* or *gate voltage.*

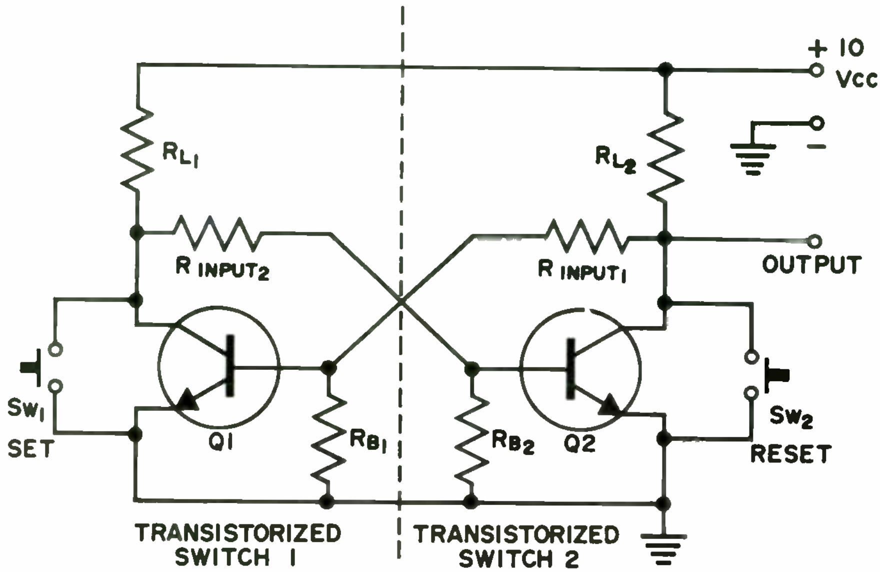
The flip-flop pictured in Figure 13 is an RS type or a set-reset circuit. Its output level changes are shown in the illustrations with the input gate levels. Notice that there are four input pulses for two level changes in the output. This illustrates one important use for a flip-flop; that is, its use as a divider stage in computers or industrial counting equipment.

In Figure 13, the negative going set current into the base of Q2 opposes the positive holding current from the collector of Q1 which is flowing through R_{INPUT2}. The current into the base of Q2 drops to near zero and Q2 turns off. Q1 is turned on and remains on until the reset current pulse arrives and opposes its base holding current.

The changing portion of a gate or pulse can also be used to trigger a multivibrator. This method is called AC triggering, and the current pulses are usually steered in one direction through a diode. Figure 14 illustrates diode capacitor triggering networks. A voltage pulse is applied to plate 1 of the coupling capacitor, and the force is coupled through the capacitor causing electrons to flow out of plate 2 through the diode and into the base of the transistor. This negative current opposes the base holding current of the "on" transistor causing it to turn off. There is one fallacy, however, in the trigger networks of Figure 14. Negative current can flow from plate 2 of the capacitor through the diode, but electrons can not return because of the directional characteristic of the diode. Eventually plate 2 becomes deficient in electrons, and a positive potential exists. Since plate 2 lacks sufficient electrons to supply current, the network fails to function. This can be overcome through the use of a recovery resistor connected between plate 2 and a negative source.

Figure 15 illustrates where this resistor is usually inserted. Both arrows in Figure 15A illustrate recovery current flow. The broken arrow indicates current flow when the trigger pulse is present. The solid arrow indicates the electron flow into plate 2 of the capacitor that occurs between pulses. Figure 15B shows how the network is connected into one side of a flip-flop.

A



B

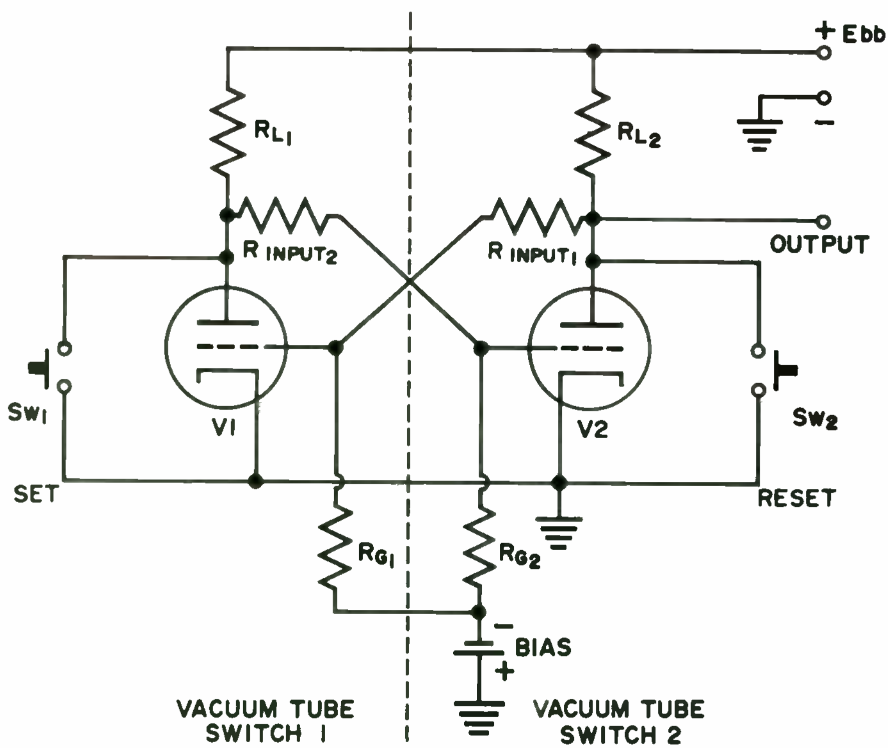


Figure 12 - Bistable multivibrators with mechanical switches for set and reset functions.

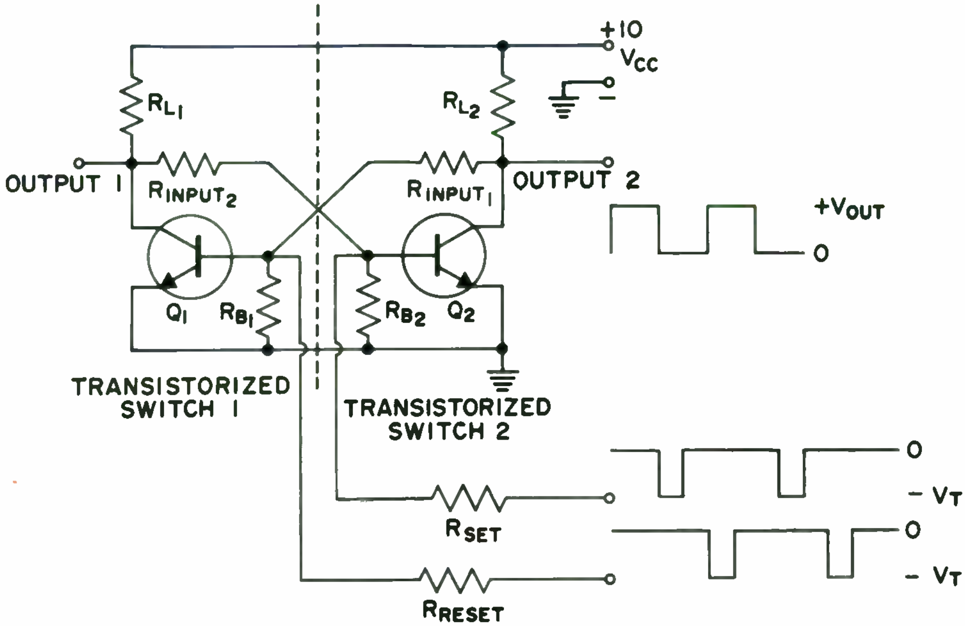


Figure 13 - A level or gate voltage used to set and reset a flip-flop.

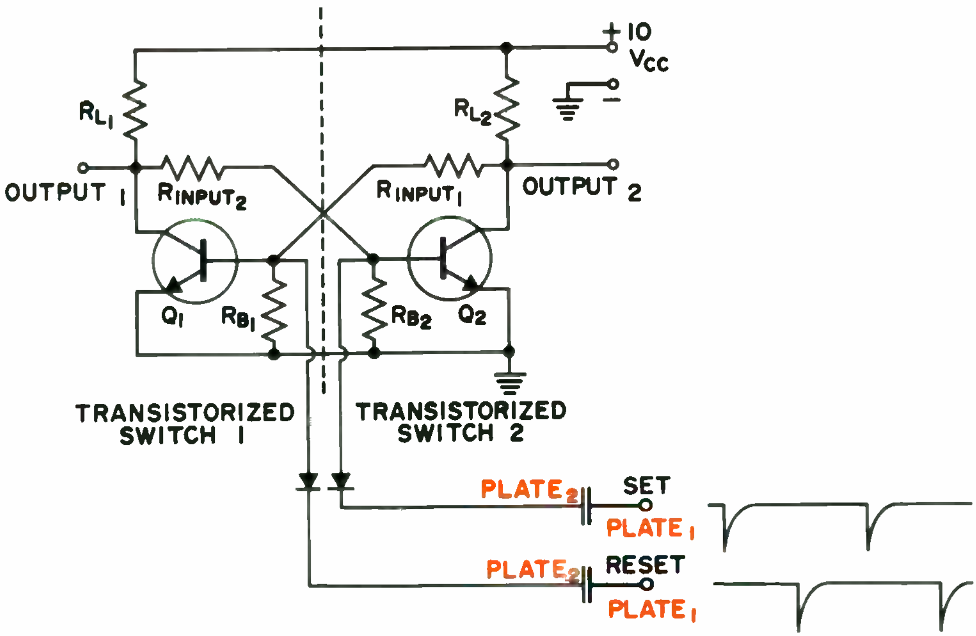


Figure 14 - Steered pulses set and reset a flip-flop.

The schematic in Figure 16 illustrates a preferred network configuration. The recovery resistors (R_R) are connected to their associated transistor's collector. The negative charge is replenished when the collector goes negative after the transistor turns on. This method prevents multiple pulses or noise on the trigger line from falsely triggering the circuit. R_R and C constitute an RC network with a charge time constant. A time interval must pass after each trigger function before the circuit has regained sufficient electrons to respond to the next trigger pulse.

Figure 17 illustrates triggering of a toggle input flip-flop. This system requires only one trigger line. Since alternate sides of the network are negative or enabled, alternate input pulses will trigger first one side then the other.

Emitter triggering can be used by including a common emitter resistor (Fig. 18). This method is less popular than base triggering.

Another method, collector triggering, is shown in Figure 19. Collector triggering is used less often than base triggering because of its high power requirements. The circuit in Figure 19 uses a diode (D3) for recovery although a resistor could be used. Recovery current flows into plate 2 of the capacitor during the positive going portion of the trigger pulse.

Until now, the transistor circuits shown have all used NPN devices. These can be easily duplicated with PNP devices by reversing the polarities of the bias supply and the input trigger pulses. The schematic in Figure 20 illustrates a toggle flip-flop using PNP transistors. Notice that Vcc is negative in polarity.

DELAY TIMES

Specific amounts of time are required for all the actions to take place when a transistor is turned on or off. These can all be grouped and called delay times.

In turning a transistor on, the input must rise to a potential sufficient to overcome the potential hill voltage at the junction. After forward bias current begins to flow, additional time must pass before the charges that have back biased the junctions are neutralized.

When an "on" transistor is turned off, it must be cleared of the charges that have caused its input junction to be forward biased. This action also causes a delay in time.

An additional time delay may be encountered in triggering networks. Time is required for charges on the input capacitors to be neutralized. Capacitors and associated recovery resistors represent a time constant. This limits the frequency at which the network can be effectively pulsed.

Figure 21 illustrates additions and modifications which can be made to a multivibrator to speed up its operation. Diodes D3 and D4 have been installed in place of the recovery resistors. Observe the polarity of these

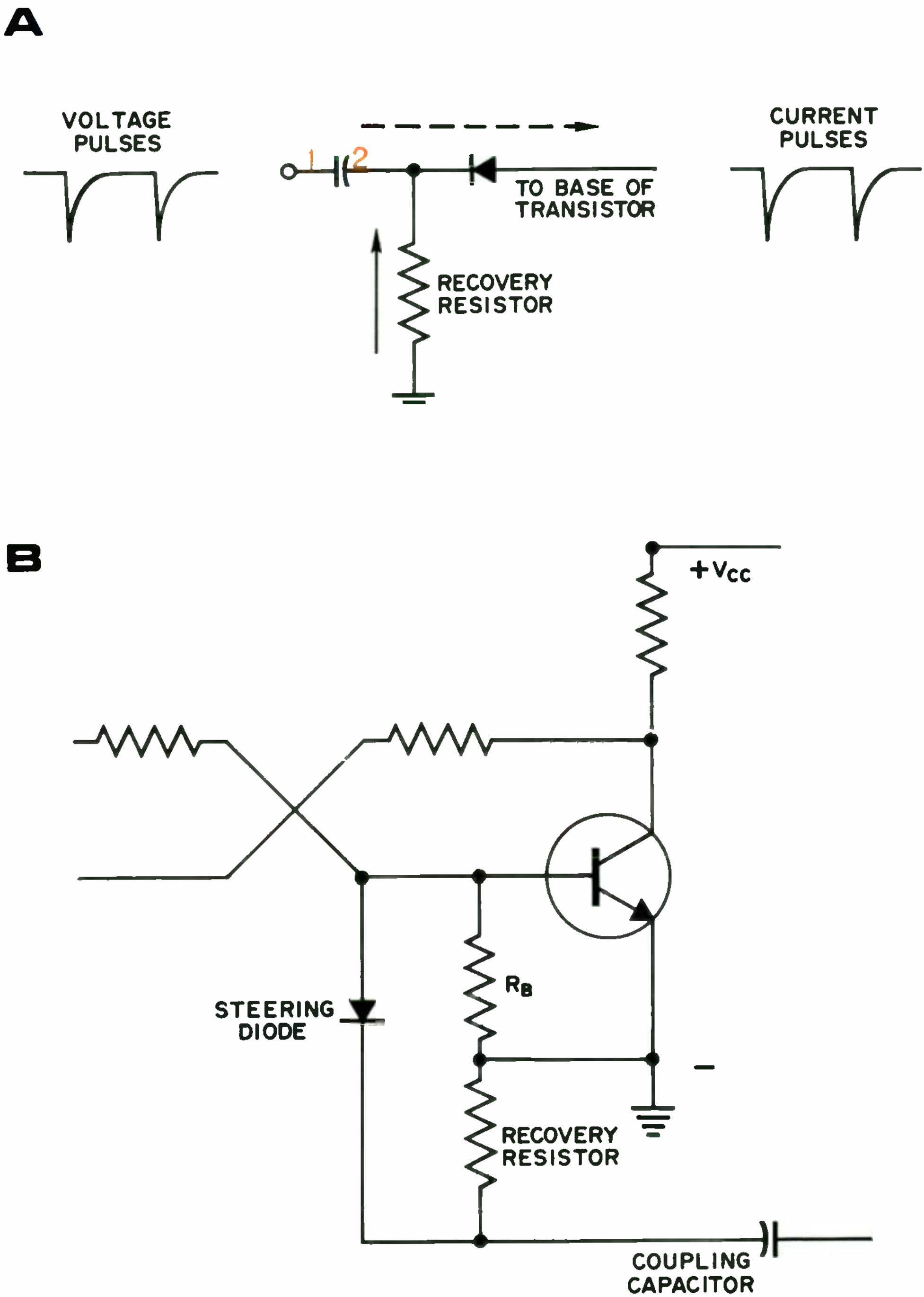


Figure 15 - Pulse steering network with recovery resistor.

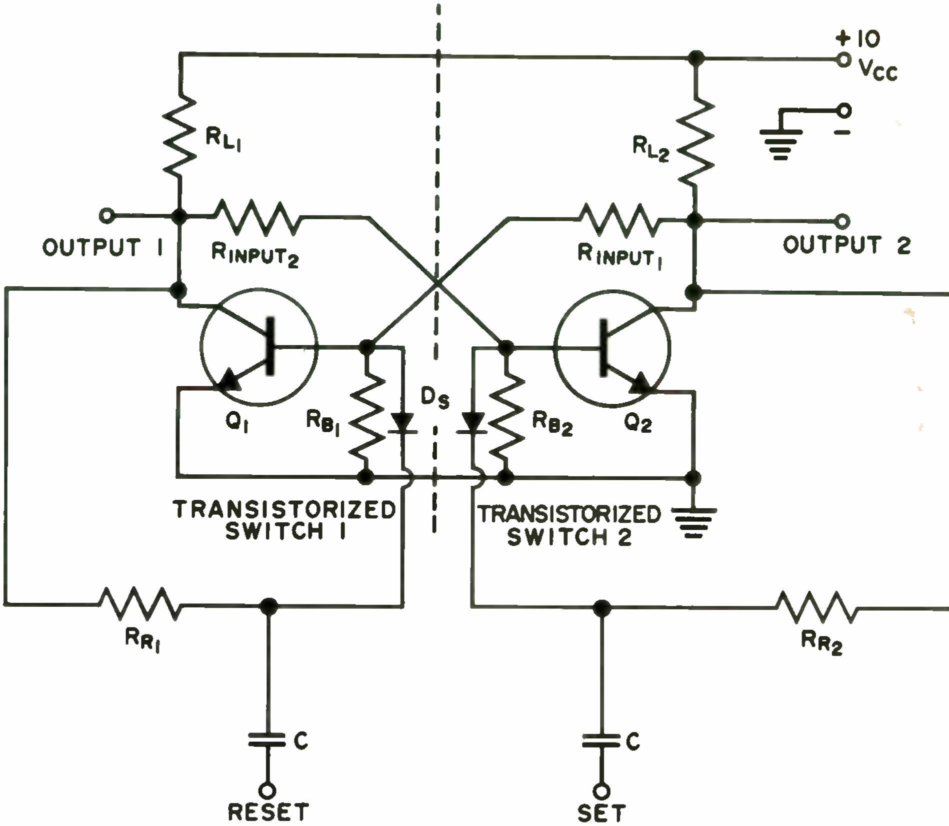


Figure 16 - Flip-flop with pulse steering networks.

diodes. It is such that they allow negative current to return to the capacitors and neutralize the positive charges that result after the network has been subjected to a negative pulse. Since the forward resistance of the recovery diodes is very small, the time constant resulting from them (in association with the capacitance C) is relatively short. The network is neutralized relatively fast and is fully recovered even when trigger pulses arrive in rapid succession.

The schematic of Figure 21 also shows the addition of two capacitors, C3 and C4. They are connected to shunt the base input resistors. These capacitors act as instantaneous storage for charges from the collector and base regions when either is changing state. They neutralize through their respective base input resistor during the time when no action is occurring in the transistor. Since these capacitors provide a place for charges to collect, they speed up the transition from *on* to *off* or from *off* to *on*. Because of their effect, they are frequently referred to by engineers and technicians as "speed up capacitors."

ASTABLE MULTIVIBRATORS (FREE-RUNNING)

An astable or free running multivibrator has no stable state. It is constantly changing from state 1 to state

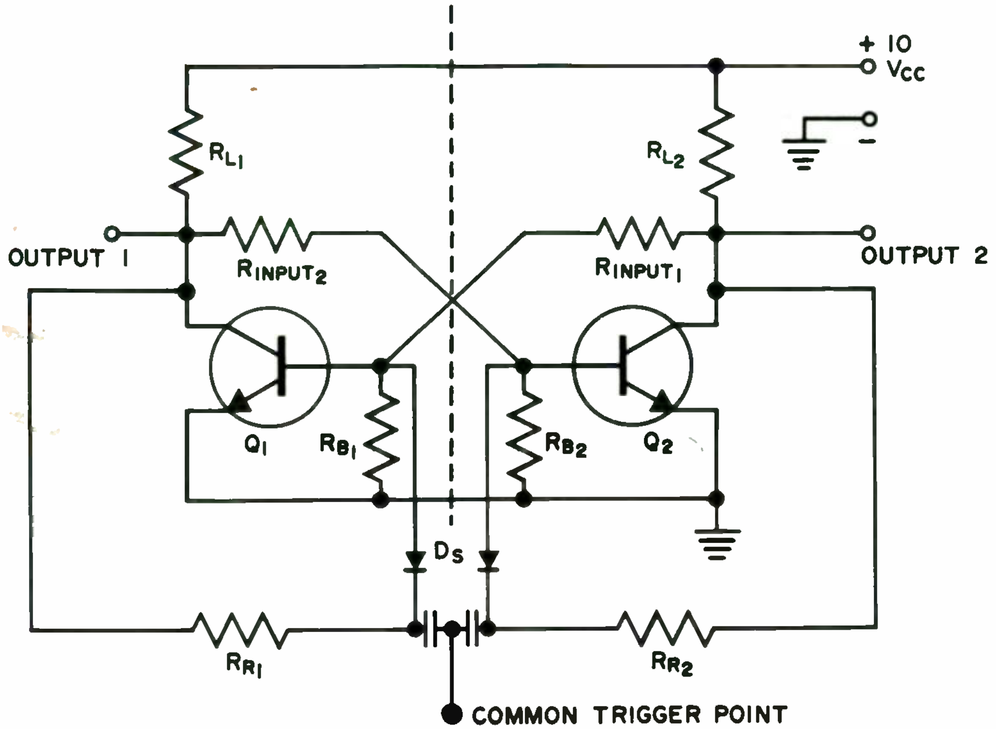


Figure 17 - Toggle input.

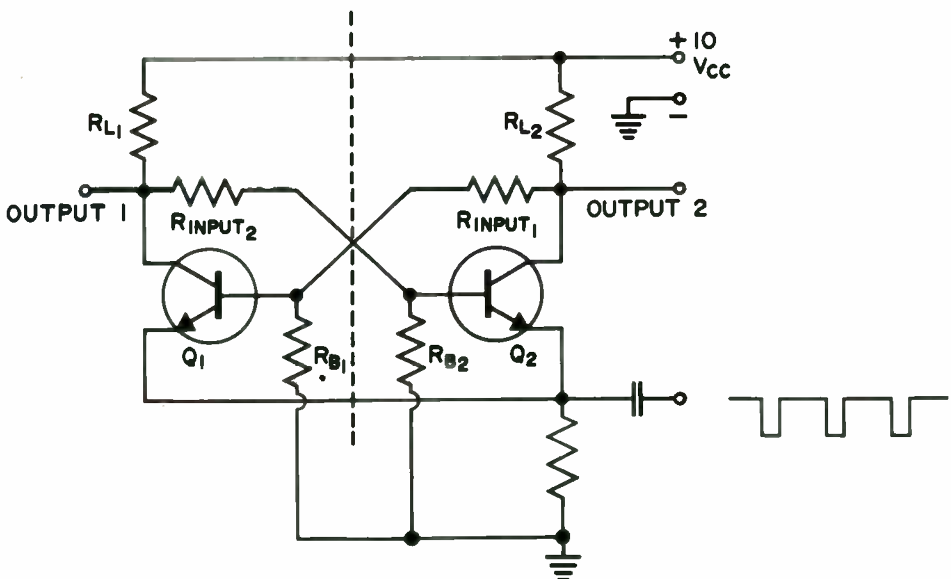


Figure 18 - Emitter triggering.

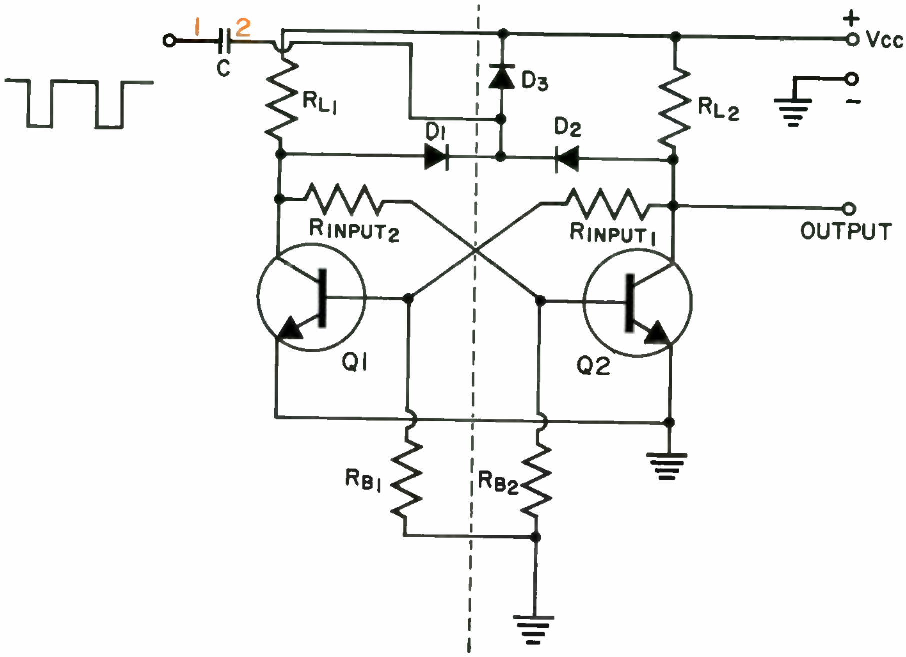


Figure 19 - Collector triggering.

2 and back. Figure 22A represents a practical free running multivibrator using NPN transistors. Figure 22B is an astable multivibrator using triode vacuum tubes.

The basic difference between an astable and a bistable multivibrator is the method used to cross couple the two stages. Notice in Figure 22 that capacitors C_{T1} and C_{T2} have replaced the base input resistors used in bistables.

The capacitors (C_{T1}, C_{T2}) in an astable multivibrator couple only the *changing* portion of the collector voltage into the base of the opposite transistor. Since the DC voltage at the collector is isolated from the opposite transistor's base, holding current can never flow and the circuit can never stabilize in either state.

The animated diagram in Figure 23A illustrates the action in a basic astable multivibrator that is ready to change state.

1. The current through Q2 has stabilized.
2. The charge on plate 2 of C1 is no longer changing.
3. Since the force on plate 2 of C1 is not changing, its charge has no effect on plate 1.
4. Negative charges flow out of the base area of Q1 through R_{B1} to ground.
5. Negative charges begin to flow into the base area of Q2, neutralizing the positive charges that have caused it to be forward biased.

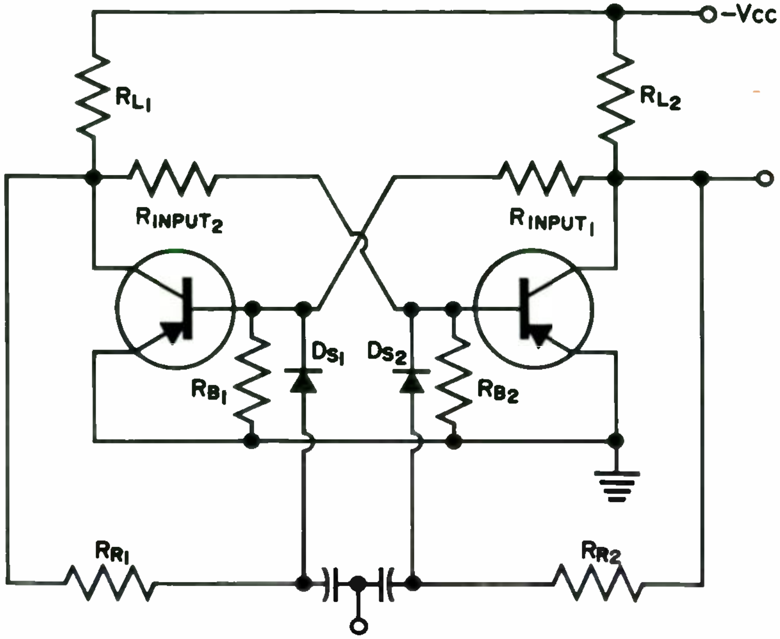


Figure 20 - Flip-flop with PNP transistors.

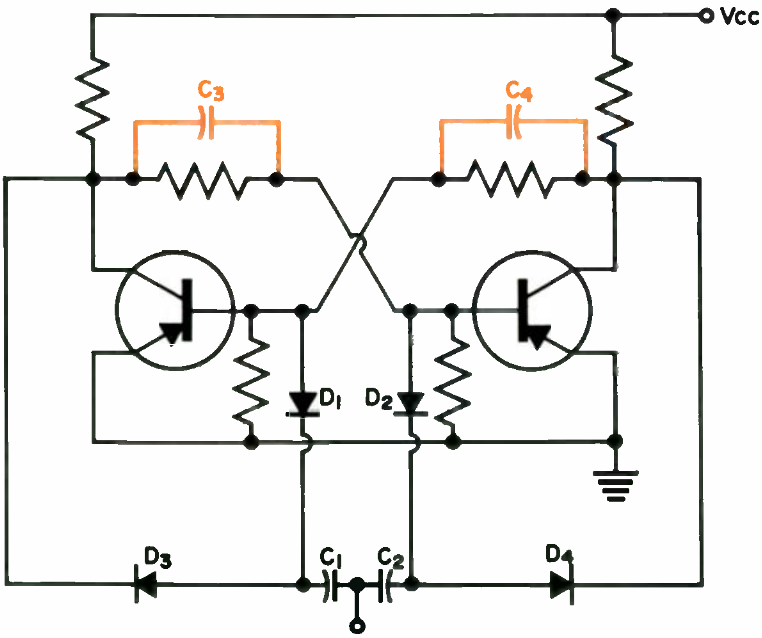


Figure 21 - High speed flip-flop showing speed up components.

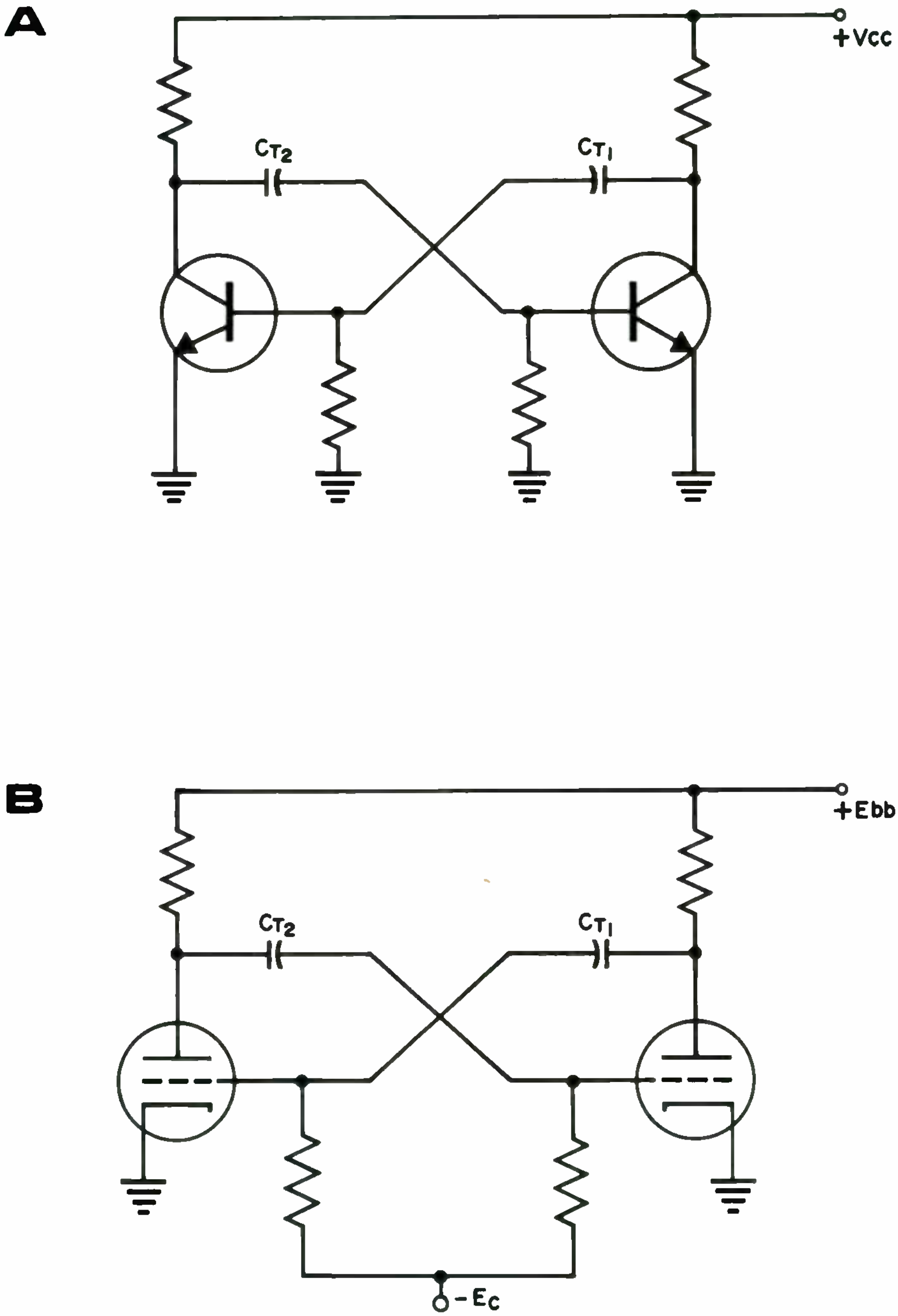


Figure 22 - Basic astable multivibrators.

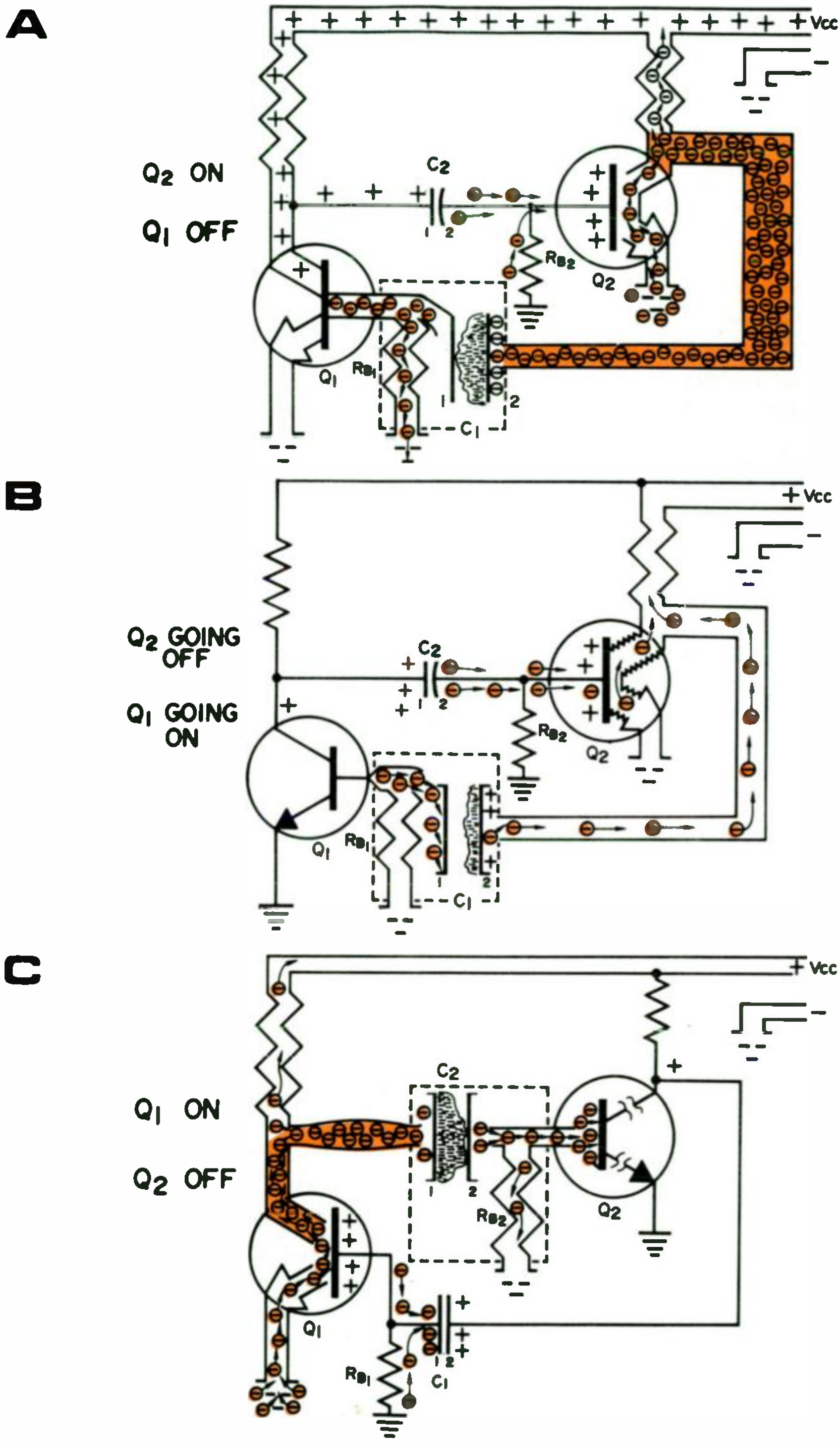


Figure 23 - Charges associated with the operation of astable multivibrators.

In Figure 23B, the charges on C1 and C2 and the bases of Q1 and Q2 are beginning to redistribute.

1. Negative charges flow into Q2's base turning it off.
2. Negative charges flow from C1 plate 2 charging it positive.
3. The positive going charge on C1 plate 2 causes plate 1 to attract current from the base of Q1. This forward biases Q1 and it begins to turn on.
4. As Q1 turns on it forces negative charges into C2 plate 1; plate 2 forces negative charges into the base of Q2 turning it off.
5. In turning off, Q2 suddenly charges C2 positive. The sudden change on C2 causes increased current to flow into the base of Q1 driving it deep into saturation.

Figure 23C illustrates the completion of charge distribution.

1. Q2 is completely turned off.
2. Q1 is completely turned on and its forward current is beginning to diminish.
3. The negative base charge on Q2 is beginning to leak off through R_{B2}.
4. The circuit is stabilizing in preparation for its reverse transition.

Figure 24A illustrates the negative charge increasing on plate 1 of C1 as negative current flows through the emitter-base junction and into this capacitor. Eventually, a surplus of negative charges collects on plate 1. It is these negative charges that rapidly reverse bias the emitter-base junction and force Q1 into cut off when the transistors change state.

Figure 24B shows the charge movement from plate 2 of C2. These negative charges not only flow into the base of Q2, they also flow through R_{B2} to power supply negative or ground. Eventually, plate 2 of C2 becomes deficient in negative charges, and becomes positive. It is this positive force that attracts charges through the emitter-base junction of Q2 and rapidly forward biases it. When the circuit changes state, the charges on C2 reverse.

The time that an astable multivibrator remains in either state is determined by the amount of time required for its RC networks to recover. This time is determined by the RC time constants of R_{B1}/C1 and R_{B2}/C2 (Fig. 24C). It is the time constant of these networks that determines the frequency of the square wave generated by the circuit.

For precise control of the frequency of repetition rate of a multivibrator, a synchronizing (sync) pulse is generally used. A *pulse synced* astable multivibrator is usually adjusted to operate at a slightly lower frequency than the sync pulse repetition rate. The incoming sync pulse then forces turn-off of the "on" transistor. Occasionally the pulse is steered to force the "off" transistor into conduction. Figure 25A shows a commonly used sync input network with an RC network and a steering diode.

Figure 25 shows the unsynced output in the absence of the sync

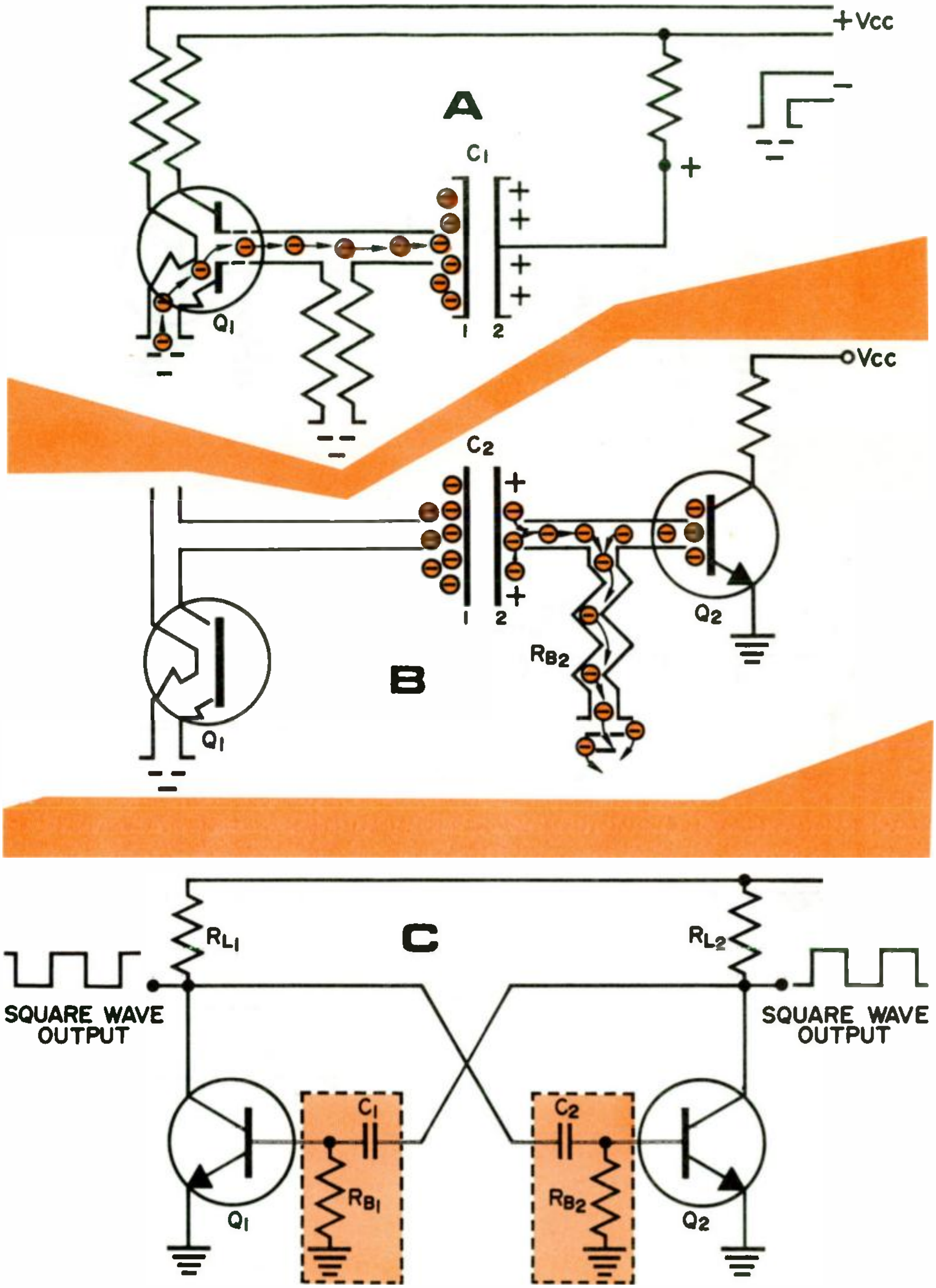


Figure 24 - (A) Base current flow charging C1. (B) C2 discharging through RB2. (C) Timing networks C1 & RB1 and C2 & RB2.

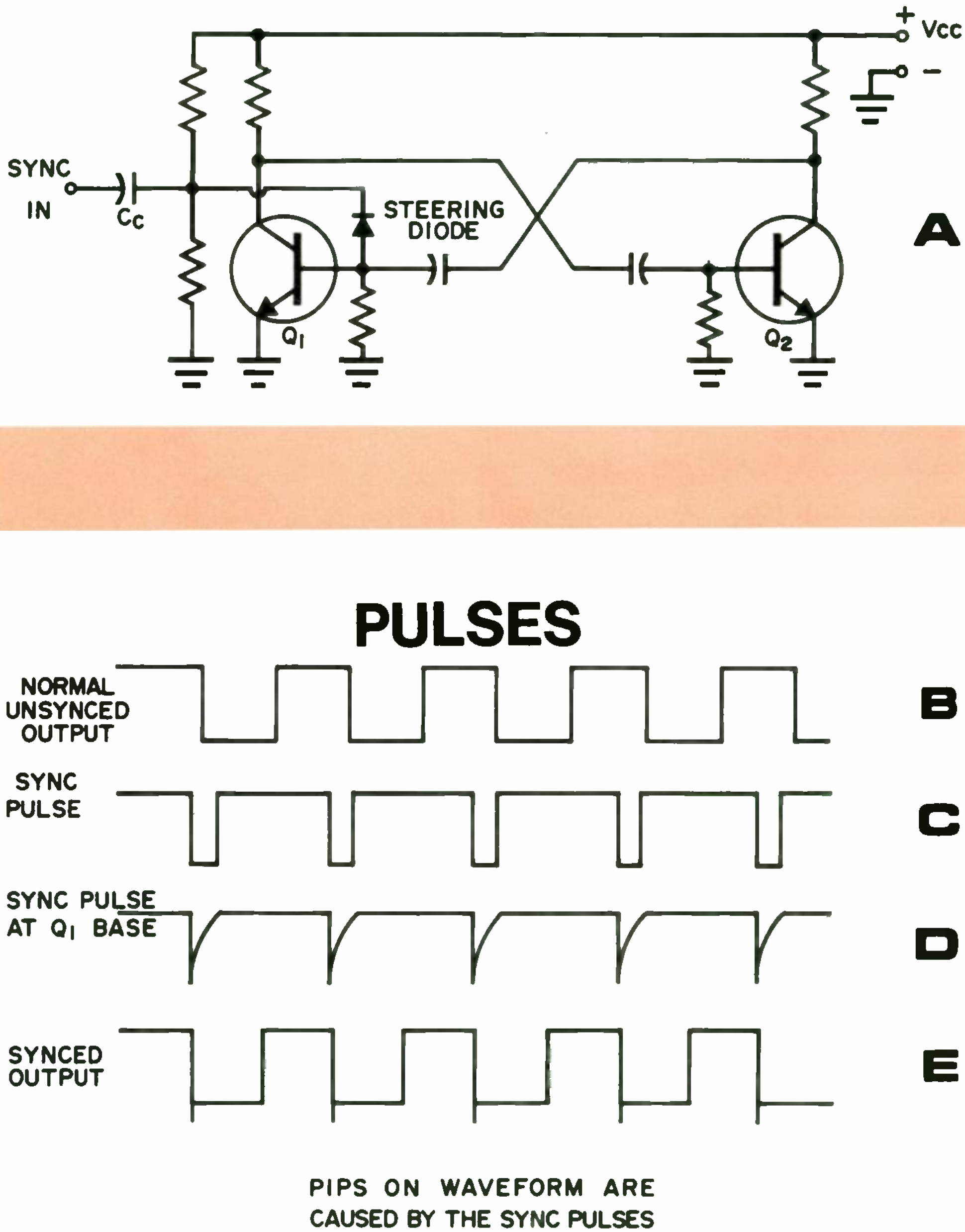


Figure 25 - (A) Pulse synced astable multivibrator. (B through E) Pulse relationships.

pulses at B. The sync pulses fed into coupling capacitor C_C are shown at C. The differentiated pulses at the base of Q1 are pictured at D. The corrected rate of the multivibrator at E is due to the influence of the sync pulses.

MONOSTABLE MULTIVIBRATORS (ONE-SHOTS)

The monostable or one shot multivibrator (unlike the previously described types) has one stable state and one unstable state. Its primary purpose is for pulse delay and timing.

The schematic in Figure 26A illustrates a monostable multivibrator using NPN transistors. The coupling from Q2 collector to Q1 base is through R_I and is DC coupling. This transistor is normally held on by current flow through R_{L2} and R_I. The collector of Q1 is AC coupled to the base of Q2 through C_T. Capacitor C_T keeps the DC voltage at the collector of Q1 from appearing on the base of Q2. Capacitor C_T passes only a change of potential into the base of Q2; not the DC potential.

When a negative trigger pulse appears at the trigger in point, current is steered into the base of Q1 turning it off. The collector potential of Q1 rises in a positive direction. The change in potential on plate 1 of capacitor C_T causes current to flow through the base-emitter junction of Q2 into plate 2. This current turns on Q2, which remains on until the charge across C_T leaks off through resistor R_{B2}. The time required for the charge to dissipate is determined by the time constant of C_T and R_{B2}.

A vacuum tube version of a one-shot multivibrator is shown in Figure 26B. There are only slight differences in configuration between it and the transistor circuit. Operation of the two circuits is basically the same.

A more reliable circuit for precise control is shown in Figure 27. An additional clamping resistor R_{CL} provides current to keep Q2 turned on. Since Q2 is on, its collector potential is zero, and holding current ceases to flow into the base of Q1. Transistor Q1 is in it's "off" state.

In comparing Figure 27 and Figure 26A, we notice that the trigger pulse is applied to Q2 instead of Q1 (Fig. 27). In Figure 27 transistor Q2 is the "on" transistor. (Transistor Q1 is the "off" transistor.) If a negative going output signal is required from the one shot in Figure 27, it can be taken from the collector of Q1.

SCHMITT TRIGGERS

A transistorized Schmitt trigger is shown in Figure 28A. A Schmitt trigger circuit is an emitter coupled multivibrator circuit (cathode coupled when vacuum tubes are used). It can be used to trigger every other opposite-polarity pulse, or it will trigger on a change in DC level. It is most often used to convert sine waves to square waves, or to convert random height pulses to pulses of a similar amplitude.

In Figure 28A the collector of Q1 is connected to the base of Q2 through resistor R_{I2} which is shunted by speed-up capacitor C_{I2}. Feedback to Q1 is provided by the common emitter resistor R_E. With Q2 conduct-

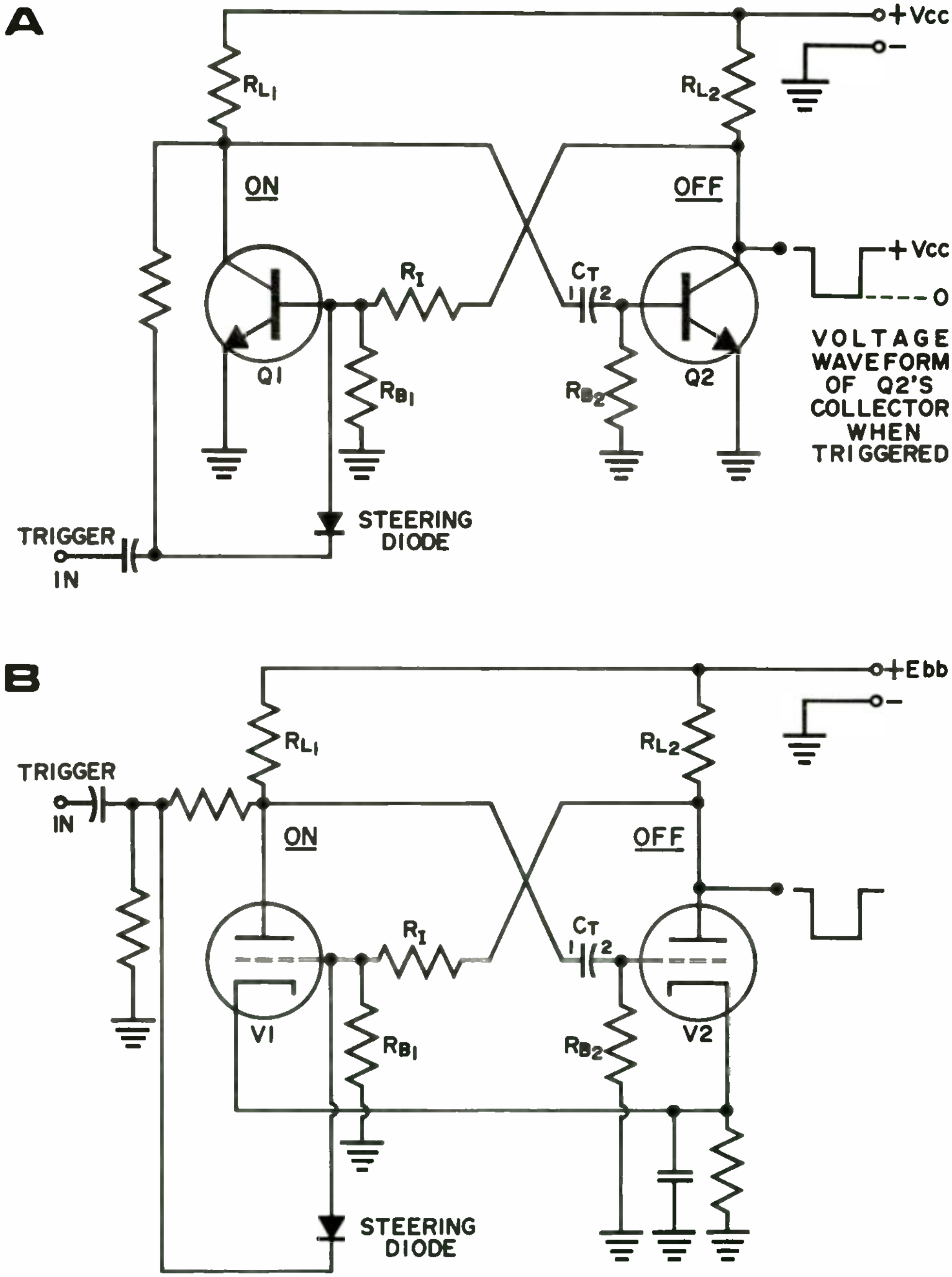


Figure 26 - Comparison between (A) a transistorized one shot multivibrator and (B) a vacuum tube one shot multivibrator.

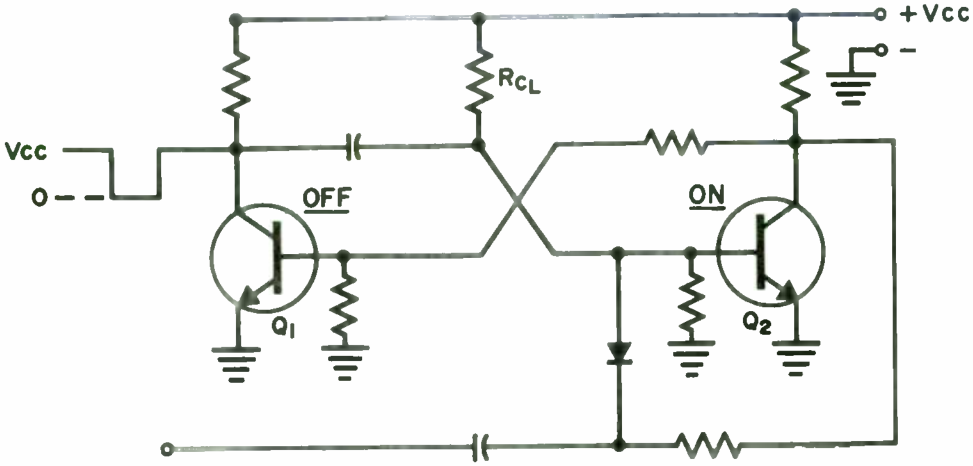


Figure 27 - Monostable multivibrator modified for more precise operation.

ing, a positive voltage appears at the emitter of Q2 and Q1 due to the current flow through R_E. This voltage holds Q1 completely cut off, because

> a positive voltage at the emitter of an NPN transistor has the same effect as a negative voltage at the base.

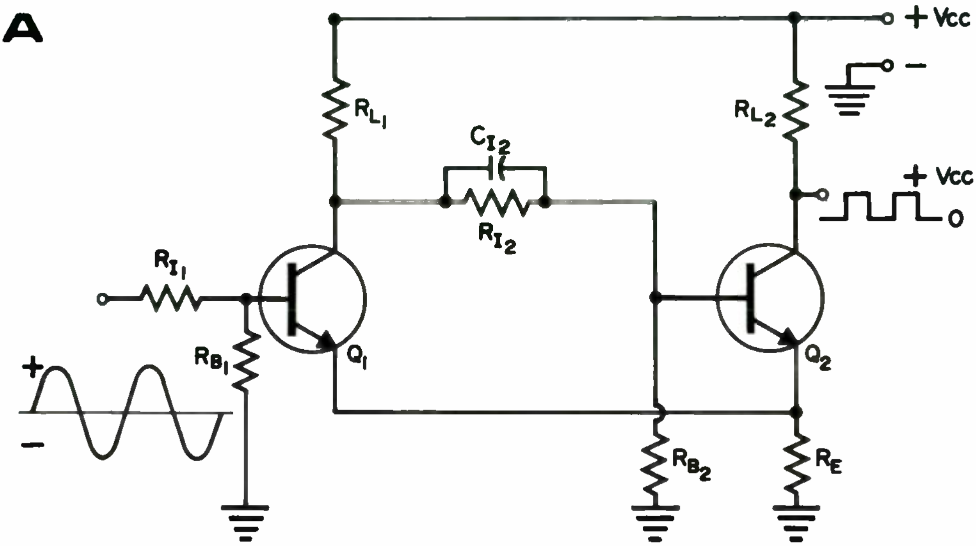
With Q1 not conducting, its collector voltage approaches Vcc and provides holding current into the base of Q2 through R_{12}.

When the sine wave applied to the input of Q1 rises to a positive value sufficient to turn on Q1, the holding current to Q2 is interrupted and it turns off. The voltage developed across R_E back biases Q2's base-emitter junction and prevents it from turning on. The sine wave voltage drops to a negative value and Q1 ceases to conduct. The voltage across R_E drops and begins to flow into the base of Q2, as the voltage at the collector of Q1 returns to Vcc potential. The voltage across R_E rises sharply and completes the turn off of Q1. The resulting waveform at the output is a square wave because of the almost instantaneous transition of the circuit.

The circuit of Figure 28B is biased through resistor R_I for bistable operation. Transistor Q1 is turned on by a positive input pulse and turned off by a negative pulse. Transistor Q2 turns on and off in opposition to Q1. The regenerative action due to R_E causes the transition to be almost instantaneous.

The Schmitt trigger circuit in Figure 29 is used to equalize pulses. The input pulses may be random in amplitude. At some voltage called the *threshold level*, Q1 will turn on and Q2 will turn off producing an output level nearly equal to Vcc. Any input pulse with an amplitude greater than threshold level will produce an output pulse equal in amplitude to all other output pulses.

A



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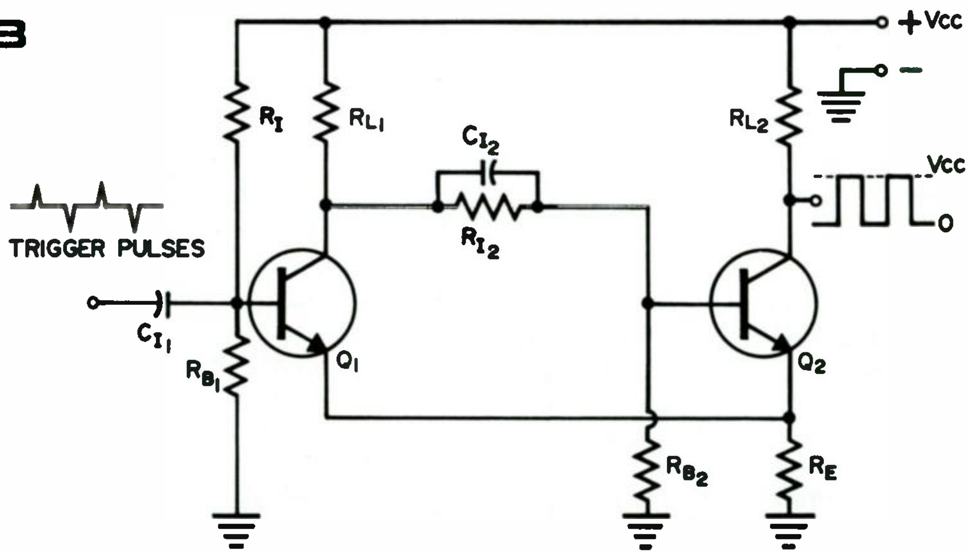

Figure 28 - Schmitt triggers.

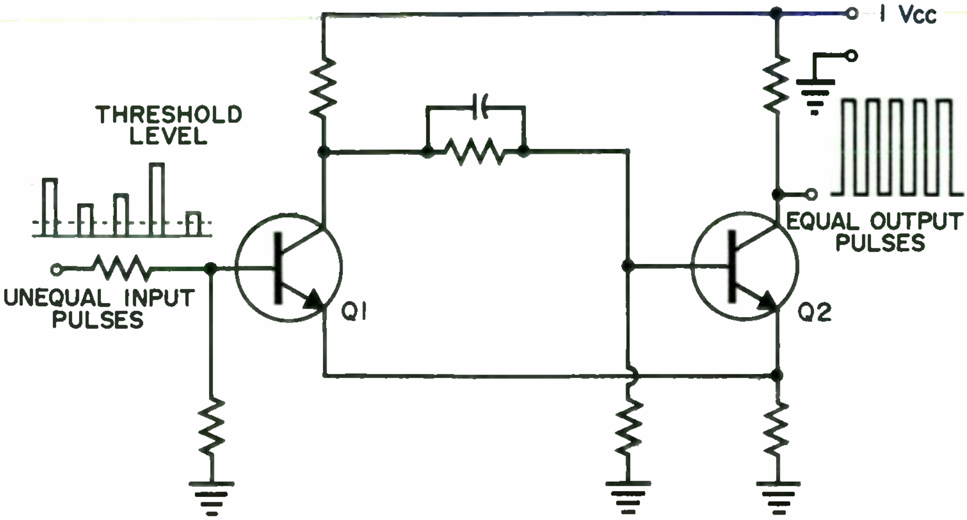

Figure 29 - A schmitt trigger equalizes random height pulses.

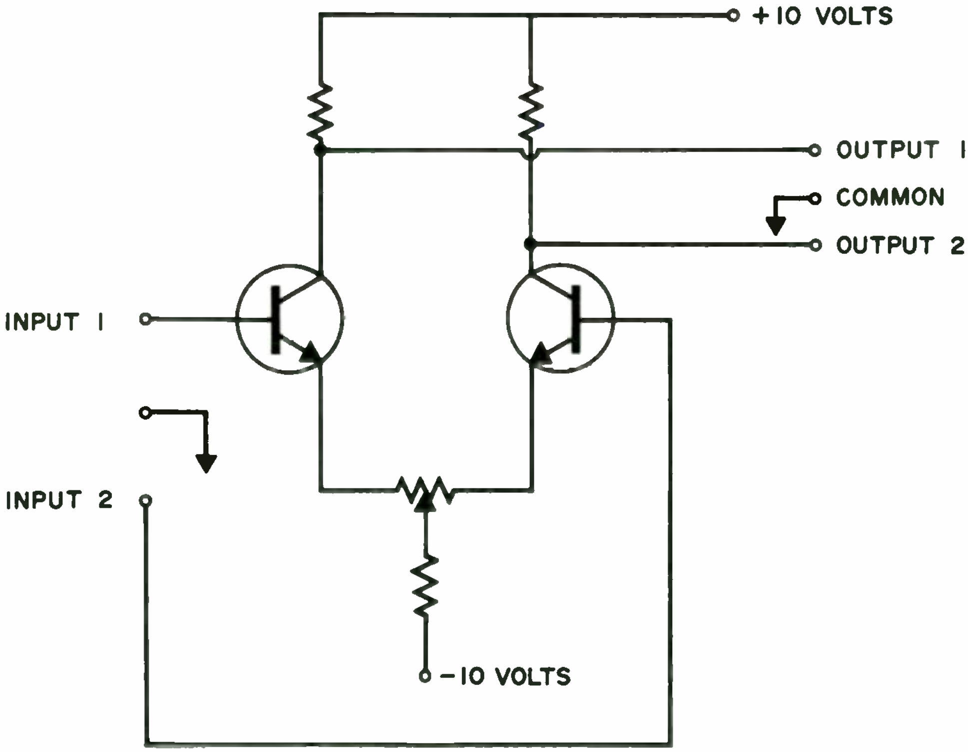

Figure 30 - Basic differential amplifier.

DIFFERENTIAL AMPLIFIERS

The differential amplifier is not a multivibrator, but it is often associated with them in industrial instruments. Differential amplifiers are also known as *difference amplifiers* and are used to amplify small DC voltages. Well designed differential amplifiers are capable of detecting small DC voltage in the presence of AC interference signals of much greater magnitude.

The schematic in Figure 30 is the basic representation of a single stage common emitter differential amplifier. Unlike conventional amplifiers, it has three input terminals and three output terminals rather than two. In addition, it usually has three power supply terminals. In Figure 30, we observe a +10 volt source, a- 10 volt source, and a common terminal.

These amplifiers are particularly useful for determining temperatures by amplifying the small output voltages of thermocouples and presenting them to metering or read out devices. The circuit in Figure 31 is a basic differential voltmeter. It is used not to measure the value of a voltage, but instead to measure the difference between two voltages.

If voltages 1 and 2 are applied to inputs 1 and 2 of the metering circuit of Figure 31, the meter will indicate the potential difference between them. Suppose voltage 1 is positive with respect to voltage 2. Q1 will conduct

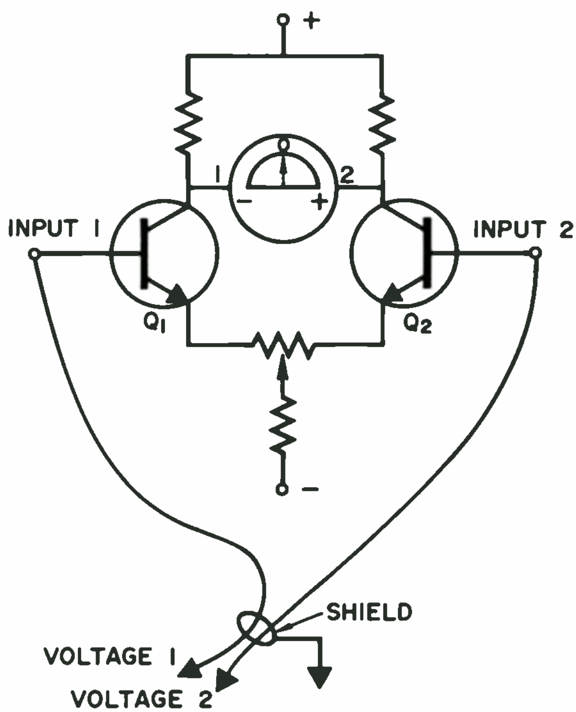

Figure 31 - Differential voltmeter.

more collector current than Q2, and its collector voltage will be more negative than Q2's. Therefore, terminal 2 of the meter will be more positive than terminal 1, and current will flow through the meter deflecting the needle to the right (toward +). This indicates that voltage 1 is positive with respect to voltage 2.

Let us suppose that voltage 1 is negative with respect to voltage 2. Q2 conducts more heavily than Q1 making terminal 2 of the meter more negative than terminal 1. Current flows through the meter from terminal 2 to terminal 1 causing the needle to deflect left (toward –). This indicates that input voltage 1 is more negative than voltage 2.

Another condition is that both voltage 1 and voltage 2 become equally more positive. In this case, if both voltages are referenced to the common terminal of the amplifier, both Q1 and Q2 will conduct more heavily. The voltages at terminals 1 and 2 of the meter become more negative, but since there is no voltage difference between them, the meter indicates zero.

A similar condition exists if both inputs are driven equally negative. The two transistors will both conduct less heavily and the meter will indicate zero difference voltage.

Differential amplifiers can become quite complex with the addition of more stages to provide greater amplification. Sophisticated stabilization techniques are employed to prevent drift and improve amplifier precision. An explanation of these techniques requires advanced mathematical concepts beyond the scope of this course.

PULSE SHAPING

The pulses from multivibrators must frequently be modified to some other shape for specific applications. This generally involves either integration or differentiation of pulses.

Differentiating Networks

Figure 32 shows an RC network and its effect on a square wave pulse. The capacitor charges and discharges exponentially causing an exponential voltage at the output due to the current through R. It rises sharply and then drops rapidly toward zero at an exponential rate. These pulses are used to control circuits whose operation

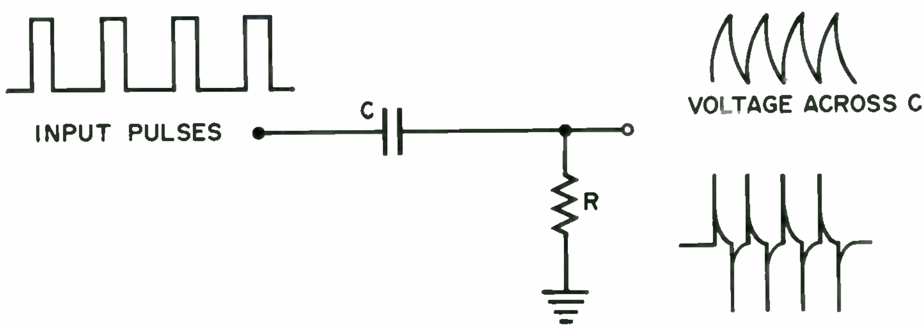

Figure 32 - A differentiating network.

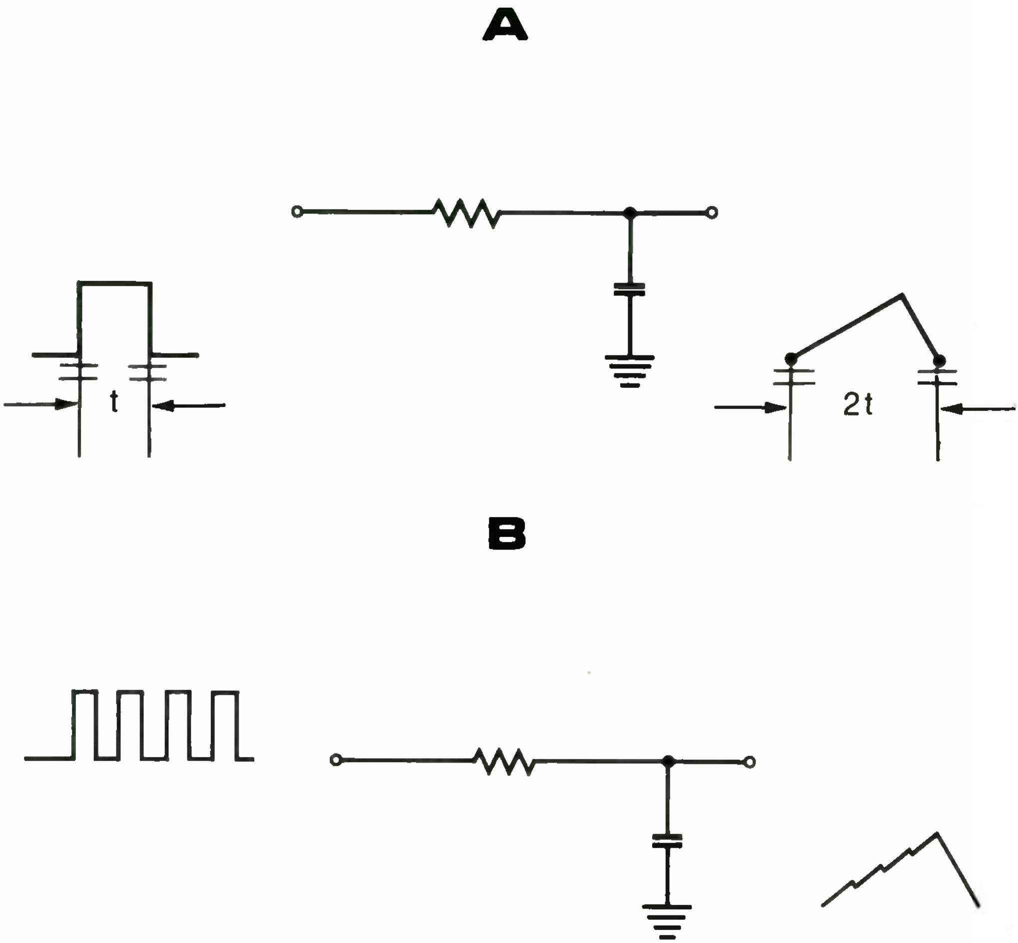

Figure 33 - Integrating networks

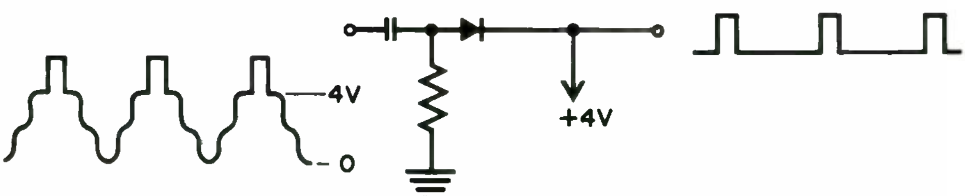

Figure 34 - A sync clipper.

would be impaired by longer duration pulses.

Integrating Networks

The network in Figure 33A is used to convert a square wave to a triangular wave. The RC time constant is made long, relative to the pulse repetition rate. On the leading edge of the input pulse the capacitor begins to charge. The capacitor continues to charge until the pulse begins its downward swing. The capacitor then begins to discharge. The output pulse width is twice that of the input pulse.

The integrating network in Figure 33B also has a long time constant. When input pulses are closely grouped, C charges to a higher level during each pulse. The result is a sawtooth shaped pulse whose length is equal to, or greater than, the length of the total input pulse group.

Pulse Clipping

Sync pulses must be removed from the incoming signal to a television receiver without destroying other information. This can be accomplished by using a clamped or back biased diode. Figure 34 shows a video waveform being applied to a diode sync separator. The sync pulses in this particular case begin their rise from a positive 4 volt level. The diode is back biased by applying 4 volts positive to its cathode. The anode must exceed this 4 volts before the diode can conduct. Only the sync pulses exceed this potential; therefore, they are the only portion of the signal that will be passed by the diode.

SUMMARY

A multivibrator has two states. These are the set and reset states. Multivibrators are generally classified by their stable states. The active devices used for multivibrators may be transistors or vacuum tubes.

The bistable multivibrator can remain in either state until triggered by a sync pulse. For this reason the bistable multivibrator is also known as a "flip-flop". A monostable multivibrator changes state when triggered and reverts to a rest state after a delay period. An astable multivibrator has two unstable states and continually changes from one to the other. It is frequently called a free running multivibrator.

For precise control of the frequency of a multivibrator, synchronizing pulses are used. If the multivibrator is in synchronization with the sync pulses, the sync pulses have no effect on the output. If, however, they are out of sync, the sync pulses trigger the multivibrator to bring it into frequency lock with the sync pulses.

TEST

Lesson Number 31

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 52-031-1.

1. The term HFe describes the forward current gain of a transistor in a
   - A. common-base circuit.
   - B. common-emitter circuit.
   - C. common-collector circuit.
   - D. none of the above.

2. A multivibrator is a circuit that has two states. Its general circuit configuration is that of two interconnected
   - A. SCR's.
   - B. FET's.
   - C. tunnel diodes.
   - D. electronic switches.

3. There are three general types of multivibrators:
   - A. monostable, unstable, free running
   - B. astable, free running, monostable
   - C. one shot, monostable, bistable
   - D. astable, bistable, monostable

4. The load resistor associated with electronic circuitry is identified as:
   A. R_E
   B. R_L
   C. R_B
   D. R_I

5. A bistable multivibrator has ________ stable states.
   A. no
   B. one
   C. two
   D. four

6. An astable multivibrator is also called a
   A. flip-flop.
   B. one shot multivibrator.
   C. free running multivibrator.
   D. triggered flip-flop.

7. A monostable multivibrator is also called a
   A. flip-flop.
   B. one shot multivibrator.
   C. free running multivibrator.
   D. schmitt trigger.

8. The circuit most often used to convert sine waves to square waves is the
   A. flip-flop.
   B. one shot.
   C. Schmitt trigger.
   D. differential amp.

9. The circuit used to determine the difference between two voltages is the
   A. flip-flop.
   B. one shot.
   C. Schmitt trigger.
   D. differential amp.

10. One network used to shape pulses is the differentiating network; another is a/an
   A. difference amp.
   B. flip-flop multivibrator.
   C. integrating network.
   D. steering network.

Notes

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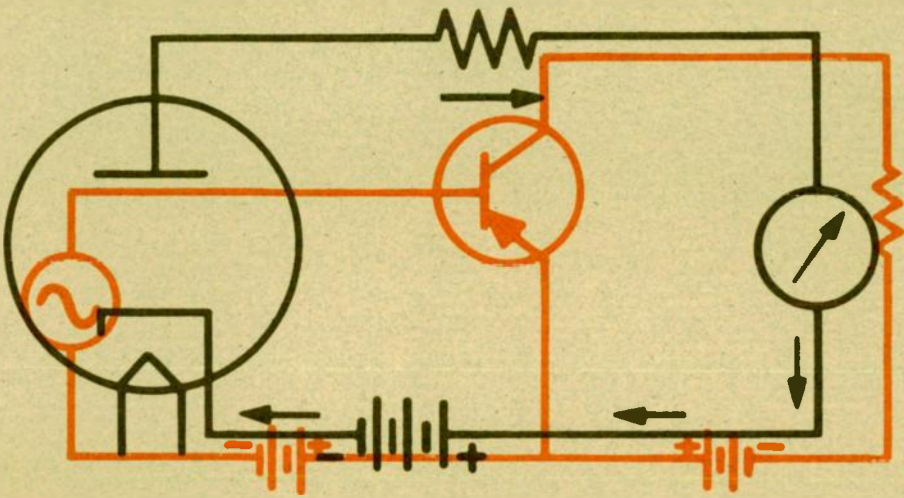
LESSON NO. 32

OSCILLATORS



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CONTENTS

OSCILLATORS

DEFINITION

Most dictionaries define a repeated back and forth motion as *oscillation.* In electronics this term is also used and any device that causes an action of this type is called an *oscillator.* An AC generator is self-contained to give an external AC signal to some other piece of equipment. It is common to have the repairman or technician refer to either the oscillator or the AC generator as one and the same. For our purposes, we will call the unit that generates an AC signal an oscillator.

A parallel circuit of inductance and capacitance is the key part of an electronic oscillator circuit (Fig. 1). If the capacitor is given a voltage or if the coil is given a current, an AC current is generated. The AC current does not continue indefinitely because there is resistance in the wire making up the inductor. This resistance will cause the AC current to die out.

The circuit in Figure 1 has a tendency to generate AC current. Figure 2 shows a capacitor in a charged state. The top plate of the capacitor has an excess of electrons. When the switch is closed (Fig. 3) the coil is connected across the capacitor. This allows a path for the capacitor to discharge. Note that when the switch is closed, both the capacitor and the inductor have the same voltage. The

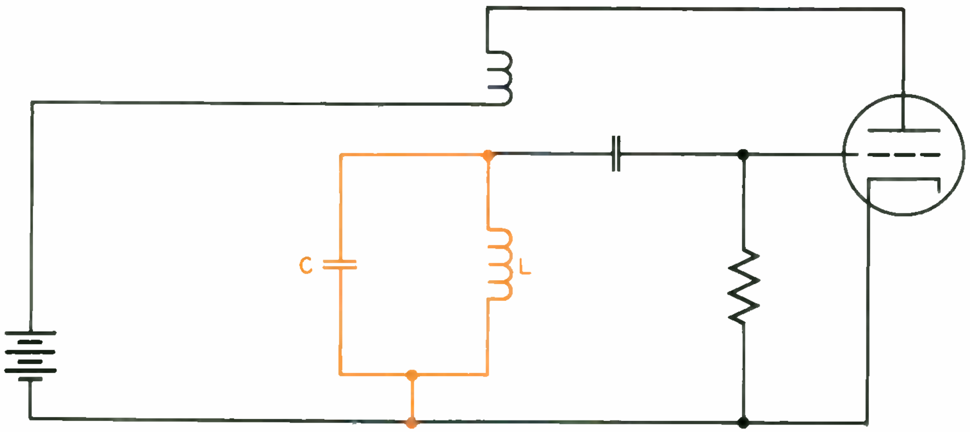


Figure 1 - A parallel LC circuit as the key part of an oscillator.

capacitor acts as a voltage source at this instant.

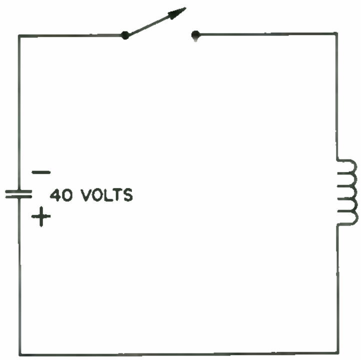


Figure 2 - A capacitor about to be discharged through an inductor.

The charged capacitor produces a current flow through the inductor (Fig. 3A). This current flow produces a magnetic field around the inductor. The inductor is effectively storing energy in the magnetic field. When the capacitor is completely discharged, the potential difference between its plates is zero. The magnetic field around the inductor begins to collapse (Fig. 3B), inducing a voltage into the inductor. This induced voltage of the inductor sets up a current flow in the direction indicated in Figure 3B. This action begins to charge the capacitor with a different polarity. After a period of time the magnetic field around the inductor has collapsed completely and the capacitor is in a fully charged state with the bottom plate negative in polarity.

The capacitor now discharges producing a current flow through the inductor (Fig. 3C). Again a magnetic field is set up around the inductor to store the energy. When the capacitor

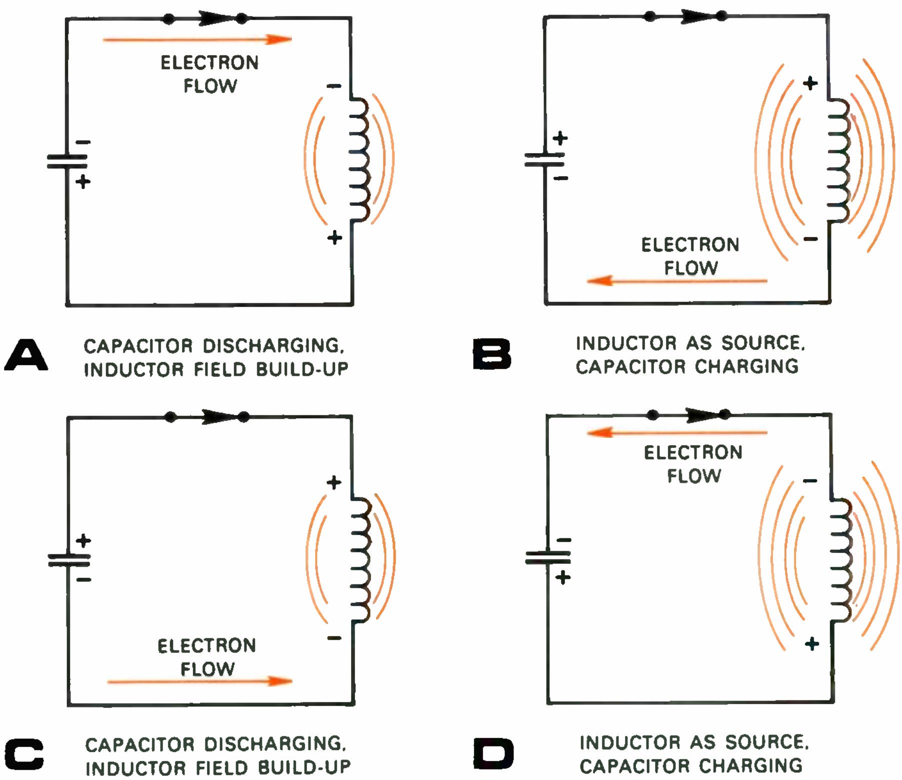


Figure 3 - The basic tank circuit.

is fully discharged, the magnetic field around the inductor is maximum. The magnetic field around the inductor collapses, inducing a voltage into the inductor. This induced voltage produces a current flow in a direction that will charge the capacitor (Fig. 3D).

After a period of time the magnetic field around the inductor is collapsed completely and the capacitor is again in a fully charged state with its original polarity. The original action is then repeated.

This is a basic tank circuit which is the basic oscillator. The repetition rate or frequency of oscillation is determined by the values of inductance and capacitance in the tank circuit. This is known as the resonant frequency and is determined by the formula

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

In the ideal tank circuit the oscillation would continue indefinitely. An ideal tank circuit would have absolutely no losses.

All conductors have a certain amount of inherent resistance which varies with the size and length of the conductor. Therefore, the inductor and capacitor contain a certain amount of inherent resistance known as the *effective resistance* (R_{eff}) of the circuit. As current flows through this resistance, power is dissipated in the form of heat ($P=I^2R$). After a period of time the tank circuit would expend the energy that was originally stored in the capacitor and oscillation would cease.

The capacitor is the simplest device that can be employed to utilize as an oscillator. The charging and discharging of the plates is a result of some oscillating signal that causes the apparent current flow of an AC signal. It does not matter if the signal (generated by the oscillator) is a square wave, a sine wave, or if the signals are pulsating DC or AC. Any of the signals in Figure 4 may be caused by some type of device that is triggered electronically and that amplifies and reamplifies the signals by means of tuned circuits. Whether the oscillator is capable of producing a continuous number of frequencies or only one frequency, it is termed an *oscillator*. *Variable oscillator*, *fixed oscillator*, *crystal controlled oscillator*, *tuned oscillator*, or *spurious oscillations* are terms that mean an AC signal of some sort is being produced by oscillation. While some oscillations are required for a particular circuit, there are also oscillations that are not wanted or needed. A typical unwanted oscillation is called *speaker feedback* and is familiar to anyone who has listened to a public address (PA) system and heard it squeal. The squeal is caused by pointing the microphone at the loudspeaker. The

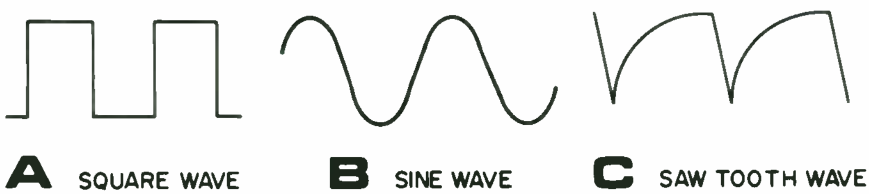


Figure 4 - Oscillator output signals.

output of the loudspeaker is fed directly to the microphone. The signal is amplified and again applied to the loudspeaker. The cycle continues and the output is a loud squeal. The amplifier is effectively operating as an oscillator. Similarly, this is the way oscillators in electronic equipment generate desired signals.

While the waveforms shown in Figure 4 have a neat appearance, it must be understood that we are always dealing in time and that a perfect wave is impossible to produce. The *square wave* shows an amplitude that is constant at its peaks. It takes time, even if a millionth of a millionth of a second, for the amplitude to move from the top to the bottom of the curve. The oscillator produces a required signal or type of wave, but it is not perfect. If we think of the square wave as switching from one direction to the other with the peaks being constant, the vertical lines should be slanted for the time it takes the wave to reach the other peak (Fig. 5). The *sine wave* is a mathematical computation based on trigonometric functions where the sine evaluation is plotted graphically. Hence, the name *sine wave*. The saw tooth wave is similar to the charging and discharging of a capacitor. There is always the parameter of time. All changes take time.

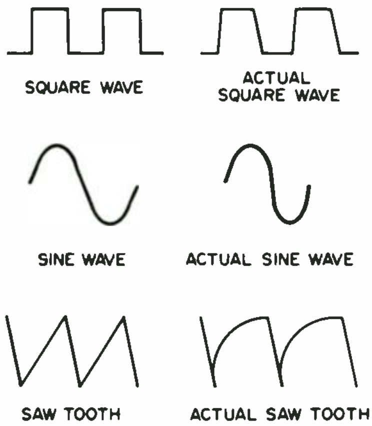


Figure 5 - Perfect and practical AC signals.

FEEDBACK

As previously explained, a loudspeaker can feed its signal back to the microphone that originally fed the signal through the amplifier to the loudspeaker. Usually, an oscillator depends on this feedback principle. A signal is started through a transistor or tube, amplified, and then *fed back* to the original input until it amplifies itself to the desired signal. The feeding back of this signal is termed *feedback.*

Various methods are used to produce feedback. The object is to feed back a portion of what is being amplified and cause this continuous feeding-back to occur at a given frequency. Eventually, a maximum point of amplification is reached. The oscillator continues its operation because of this selective feedback. This device amplifies phase relationships so that it does not cancel out the wanted signal. (The feedback signal must be in phase with the input signal of the device). The circuit components determine the frequency and the amount of amplification. The input signal is always 180 degrees *out-of-phase* with the output signal. The feedback signal must be changed by some means to be *in phase* with the input signal.

Of the two types of feedback, negative and positive (Fig. 6), this lesson is concerned with *positive* (in phase) feedback.

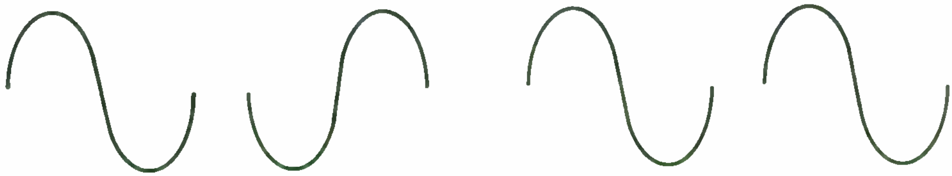


Figure 6 - Positive and negative feedback phase relationships.

Signal feedback is a natural occurrence that is created the moment voltages are applied to the oscillator (which is controlled by circuit components).

The desired frequency of the oscillator is determined by circuit component values that are tuned to a specific frequency. Due to feedback each frequency build-up helps create a signal that will be established through the frequency-determining, circuit parts. Decreasing the capacitance or the inductance will *increase* the frequency of the AC that is generated by an oscillating circuit. The discharge action is more rapid with a smaller capacitor and/or a smaller coil. Increasing the henrys of a coil or the farads of a capacitor will decrease the frequency because fewer cycles are completed in one second. In AM radio receivers, oscillators having a frequency of 1,000,000 to 2,000,000 hertz are used. In FM radio receivers, oscillators having a frequency of 90,000,000 to 110,000,000 hertz are used. Two million (2,000,000) hertz (Hz) is the same as 2,000 kilohertz (kHz) or 2 megahertz (MHz).

A *signal generator* is a piece of test equipment which produces an AC signal output. The frequency and the amplitude of AC voltage can be adjusted at the output. These adjustments are made on the front panel knobs. The circuits found in a signal generator include at least one oscillator circuit. Signal generators provide a signal that can be substituted for the signal from an AM radio, FM radio, or TV station. Thus, connections from a signal generator can be made to the various circuits of the receiver for testing purposes.

HARTLEY OSCILLATOR

The method of frequency determination and the method of positive feedback are defined by type. The Hartley Oscillator (Fig. 7) is recognized by its feedback method. The feedback signal is obtained by a tap from the tuned circuit coil. The position of the feedback point determines the amount of feedback.

In Figure 7A, L and C3 make up a tank circuit tuned to the desired frequency. The coil is tapped for AC ground potential, causing the input and output signals to be in phase. The vacuum tube oscillator has the grid and plate connected to the opposite

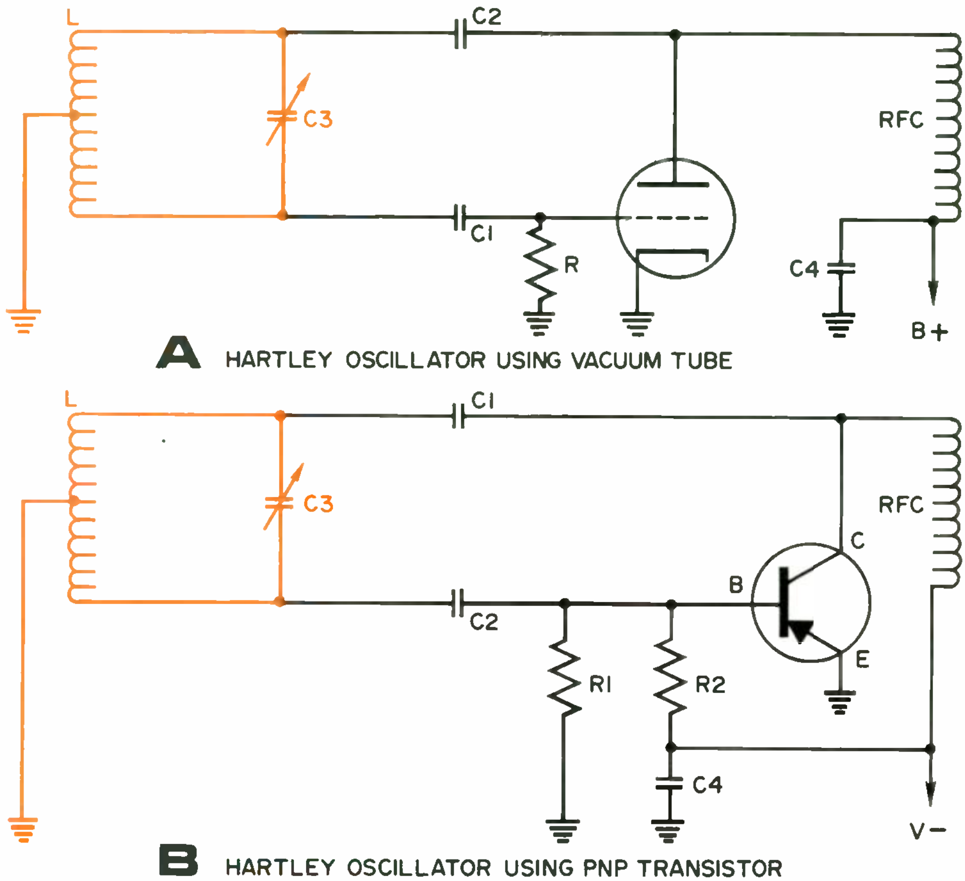


Figure 7 - A Hartley oscillator circuit.

ends of the coil and the cathode is connected to the tap. The tap is at an RF neutral potential while the balance of the coil increases to each end with respect to the tap. This places the output and the input in phase. The signals rise and decrease simultaneously. The configuration of the PNP transistor circuit (Fig. 7B) shows the same principle. An NPN transistor may be used in place of a PNP transistor if the polarity of V is reversed.

In the tube oscillator (Fig. 7A), resistor R and capacitor C1 are used to obtain grid bias. R is the *grid leak resistor*. The grid attracts electrons with respect to the cathode during the positive portion of the cycle. This flow of electrons through R causes a voltage drop across R. This drop causes the grid to become negative (bias). While C1 blocks the DC, it should have low reactance at the desired frequency. Due to its conventional arrangement, the tube acts as an amplifier. C2 and C4 have low reactances at the operating frequency. C2 blocks DC from the tank and grid circuits. The RFC (radio frequency choke) passes very little AC current.

Thus, all the AC current from the tube plate is concentrated into L and C3 via C2.

Few parts are required to make an electronic AC generator. Basically, an amplifier tube or transistor is combined with a tank circuit. The circuit connections provide the necessary feedback so that the AC current in the tank is not damped. Both grid and plate are connected to a similar type of resonant circuit, as shown in Figure 7A (L and C3). The plate goes to L and C3 via C2. The grid goes to L and C3 via C1. If the tank impedance of the oscillator is approximately 1,000 ohms, the reactance of the radio frequency choke would be approximately 10,000 ohms.

To check the functioning of an oscillator, measure the DC voltage passing from the grid to the cathode. The voltage in a circuit of this type is negative and will range from −1 to approximately −5 volts. This DC grid voltage is also called *bias voltage*. This checking method, however, does not check the frequency of the oscillator.

The transistor oscillator (Fig. 7B) is similar to the vacuum tube oscillator (Fig. 7A). The transistor oscillator is biased slightly forward to cause the starting of collector and base currents. This forward biasing is caused by R1 and R2. C1 and C2 pass the AC signal while stopping the DC signal from becoming shorted to ground. C4 has a low reactance and it is called a *by-pass capacitor*. The radio frequency choke (RFC) passes very little AC current in this oscillator.

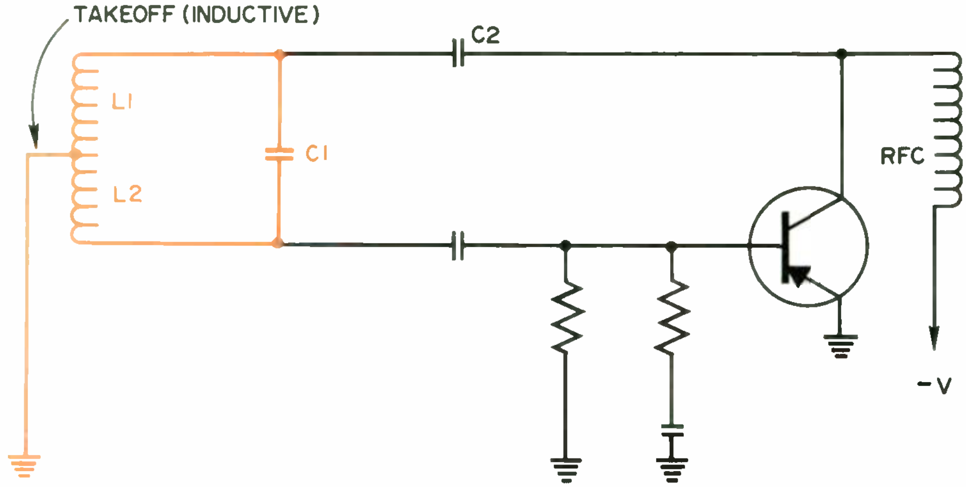
While either part of the tank circuit may be tuned, the capacitor is shown as tunable. Both L and C3, however, may be fixed or tunable.

COLPITTS OSCILLATOR

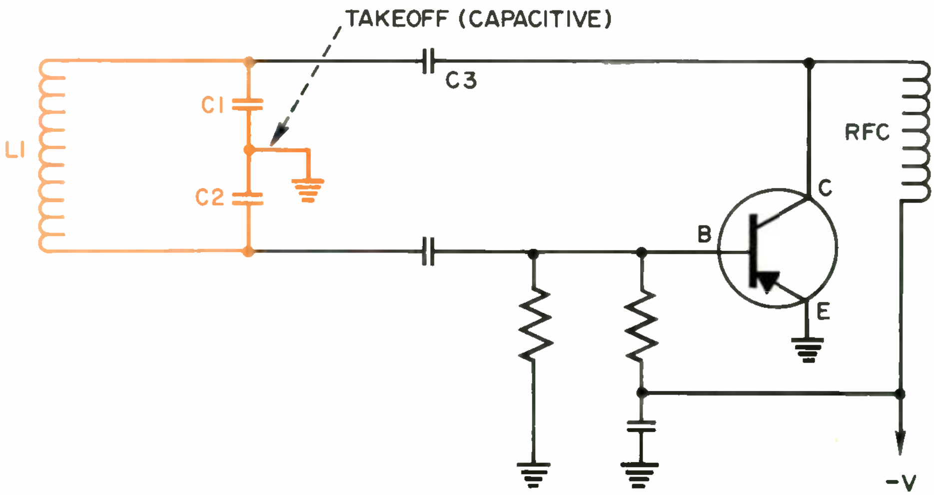
The Colpitts Oscillator is similar to the Hartley Oscillator. The main difference between them is that in the Colpitts Oscillator the feedback take off is from the capacitor side of the tank circuit (Fig. 8).

The collector current starts and ends at the emitter. The AC current from the collector goes into three branches. One branch is the radio frequency choke. This amount of AC current is small and is not useful. In Figure 8A, the AC collector currents pass through C2. From C2, one current passes through L1 to the emitter (ground). The other current passes through C1 and L2 to the emitter (ground). Figure 9A is a re-drawn version of a portion of Figure 8A showing the tank circuit. L1 is in parallel with a series circuit made up of L2 and C1.

Similarly, the collector load for the Colpitts Oscillator shown in Figure 8B can be re-drawn (Fig. 9B). Capacitors C2 in Figure 9A and C3 in Figure 9B have two names: coupling and blocking capacitors. *Coupling capacitors* refers to low reactance to AC currents. If the impedance of the parallel circuit in Figure 9A (L1, L2, and C1) is approximately 1,000 ohms, then the reactance of C2 would be approximately 100 ohms or less. *Blocking capacitor* refers to the inability of DC current to pass through a capacitor. The collector DC current passes through the RFC only (Fig. 8).



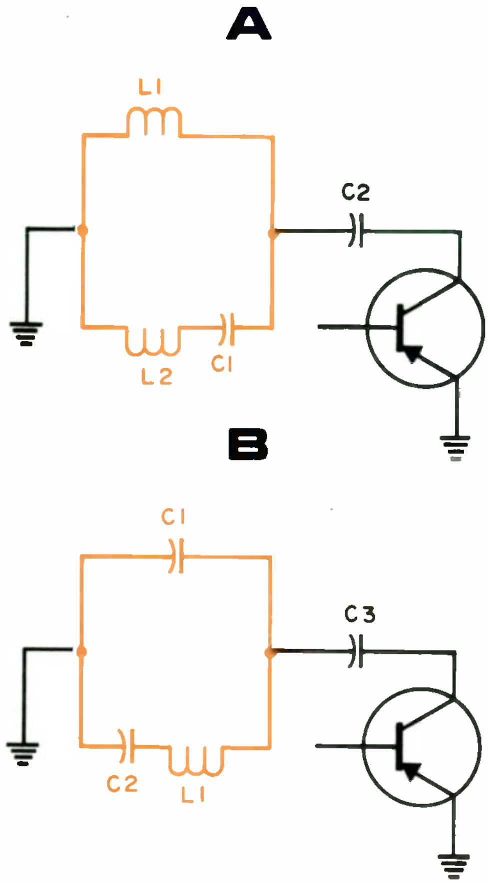
A HARTLEY OSCILLATOR



B COLPITTS OSCILLATOR

Figure 8 - A comparison of a Hartley oscillator circuit with a Colpitts oscillator circuit.

The collector currents of transistors and the plate currents of tubes are always pulsating DC. Pulsating DC is made up of two parts. One part is pure DC; the other is pure AC. With time and practice in circuit reading, you will become proficient in recognizing the direction of the collector currents of transistors and the plate currents of vacuum tubes. If the collector load is shorted, a malfunction exists. Voltage is not produced by the current and the circuit is inoperative. An ohmmeter is used to determine whether the coils and/or the capacitors are shorted.



HARTLEY OSCILLATOR
COLLECTOR LOAD
IMPEDANCE

COLPITTS OSCILLATOR
COLLECTOR LOAD
IMPEDANCE

Figure 9 - Collector loads for Hartley and Colpitts oscillators.

TUNED-GRID TUNED-PLATE OSCILLATOR

Every amplifying device has a small amount of built-in capacitance. In tubes, for example, this capacitance exists between the elements. The same type of capacitance exists between the layers or elements of a transistor. In an oscillator, this capacitance is used to the advantage of the oscillator. In an amplifier, however, it is an unwanted source of feedback and can cause unwanted oscillations. The tuned-grid tuned-plate oscillator makes use of the inter-electrode capacitance for a feedback path. Wherever two conductors exist in close proximity, there is always capacitance. An example of this is the individual windings of a coil. The capacitive values of a tank circuit are influenced by this built-in capacitance when the value of the actual resonant capacitor is determined. Less actual capacity is necessary since there is already some capacity present between the turns of the coil.

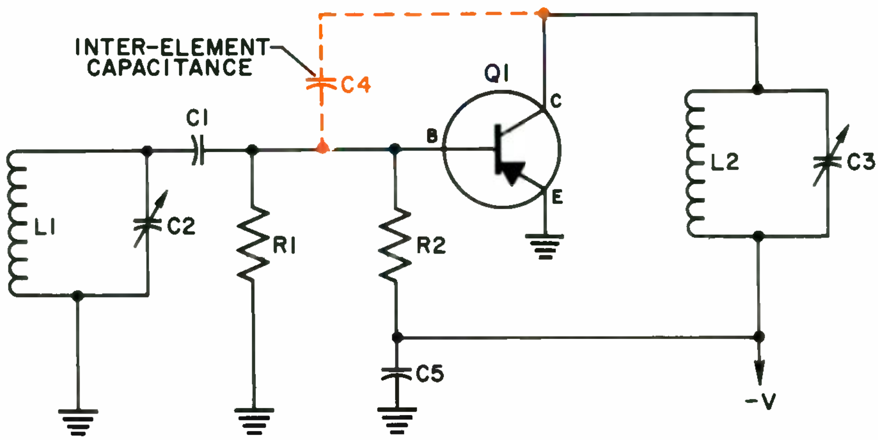


Figure 10 - A tuned-input,tuned-output oscillator.

The tuned-grid, tuned-plate oscillator, also called the tuned-input, tuned-output oscillator (Fig. 10) is rarely used. It operates in a manner similar to the crystal controlled oscillator that will be studied later. Again, the tank circuit controls the oscillator's frequency. There is no coupling between the coils. L1 and C2 form the input tank circuit which is RF coupled to the base of Q1 through C1 which blocks DC. The output tank circuit (L2 and C3) serves as a part of the collector's inter-electrode load impedance. Inter-element capacitor (C4) feeds some of the collector current to the input resonant circuit of L1 and C2. C4 is not an added capacitor; it is the *inter-element capacity* between the transistor's base and collector. C5 is a *by-pass capacitor.* It has a low reactance at the operating frequency.

R1 and R2 (Fig. 10) are part of the base-to-emitter DC circuit. Figure 11 shows the DC electron flow in the base-to-emitter circuit. R1 is parallel to the internal resistance from base to emitter. (In transistors, electrons always flow against the arrow shown on the emitter lead.) The electrons pass upward through R2. At the top of R2, they split into two branches. One branch goes to the left through R1. The other branch goes to the right through the base-to-emitter *internal resistance.* The electrons, coming out of the emitter and the bottom of R1,

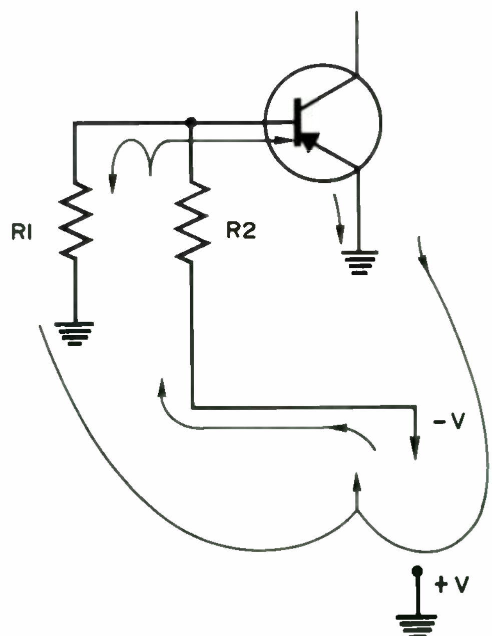


Figure 11 - DC electron flow in a base to emitter circuit.

join together at the +V terminal since all three points (R1, R2, +V) are common (ground). This circuit is a *biasing circuit.* The word bias refers to the DC conditions that exist between a transistor's base and emitter or between a tube's grid and cathode. Normally, this bias voltage is less than one volt between a transistor's base and emitter.

If R1 in Figure 11 were open, it would no longer serve as a branch in parallel with the base-to-emitter internal resistance. This makes the bias current passing through the transistor increase, since all the current from R2 passes into the base of the *transistor.* The increased base current causes the collector current to increase. This increase in collector current causes the transistor to heat up. (In a tube, plate current causes this heating process.) The collector current is always many times larger than the base current. In small transistors, the heat generated is not noticeable even though it may be enough to damage the transistor.

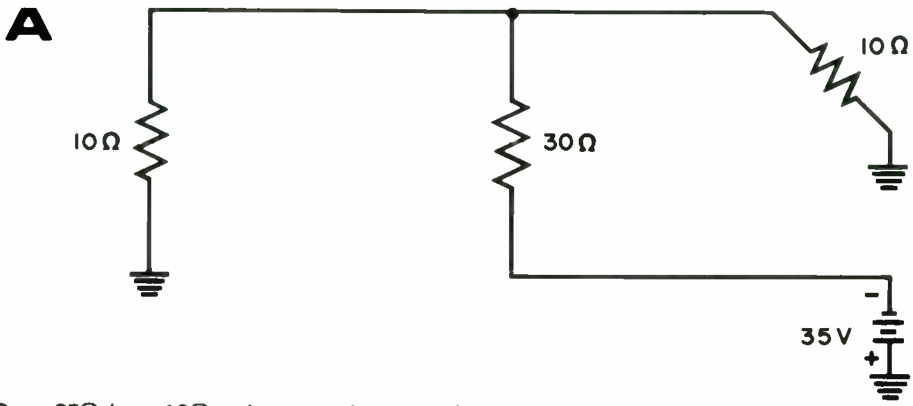
In Figure 11, the transistor base-biasing circuit is emphasized. When the electrons leave the negative terminal of the DC voltage source −V they must return to the positive terminal of V (+V). After passing through R2, the electrons divide into two branches. They come together again at the positive terminal of V. R1 is parallel to the transistor's internal resistance from the base-to-emitter. If R1 opens, the base current increases. *Base current* is the base-to-emitter current. Normally no current flows between the base and the collector.

Figure 12 shows how an open R1 (Fig. 11) causes the base current to increase. The 10 ohm resistor (drawn at an angle) represents the base-to-emitter resistance of the transistor. The actual base-to-emitter resistance of most transistors usually is much larger than 10 ohms. Simple values are used here to demonstrate the general action. In Figure 12A, the base current is 0.5 ampere. In Figure 12B, the base current has increased to 0.875 ampere because the resistor is now open and the circuit has been changed. In this circuit, the total current decreases when the resistor is open. The transistor base current, however, is the total current in this circuit *only* when the resistor is open. Practically speaking, the open resistor represents a poor solder joint, a broken resistor lead wire, or a broken resistor.

The *tuned-plate tuned-grid* type of tube oscillator is called the *TPTG.* It is one of the oldest known oscillator circuits. The transistor equivalent is called the *TBTC* for *tuned-base tuned-collector.* The transistor equivalent, however, is usually referred to as the *tuned-input tuned-output* oscillator. In the vacuum tube type, triodes are used because tetrodes and pentodes have very little capacity between the input (grid) and the output (plate). This is due to the tube elements between the grid and the plate acting as shields.

ARMSTRONG OSCILLATOR

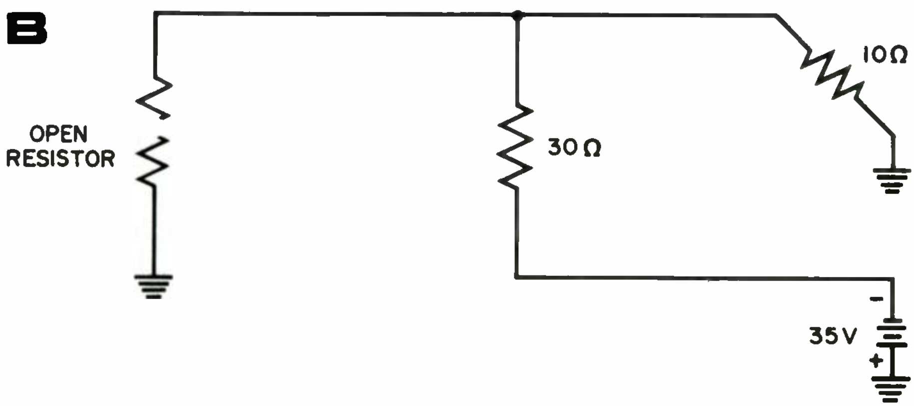
The action of one inductor influencing another inductor by having a current flow through it is called *transformer action.* A variation of the tuned-input tuned-output oscillator is



R_T = 35Ω (two 10Ω resistors are in parallel)

I_T = 1 Amp.

Current through each 10Ω resistor is 0.5 Amp.



R_T = 40Ω (one 10Ω resistor is open)

I_T = 35/40 = 0.875 Amp.

Current through the resistor representing the base to emitter resistance has increased from 0.5 Amp. to 0.875 Amp.

Figure 12 - The effect of an open resistor on transitor bias current.

devised by inductively coupling the input to the output. (This is called *tickler coil action.*) In this case, only one circuit is tuned: the grid circuit. The direction of the windings will determine in phase or out-of-phase operation. Note that in Figure 13A the tank circuit is isolated from the DC source. In addition the RF is coupled to the base by C1.

In the design of the tube-type Armstrong Oscillator of Figure 13B, the DC is isolated from the grid, without disturbing the RF coupling, through C2. The necessary bias for the grid is developed on the positive portion of the signal cycle by C2. When observing the tube-type schematic of the Armstrong Oscillator, note that the values of C1, C2, and C3 show both the desired and the undesired paths of RF. To retain the oscillation for further use and to prevent any of it from passing into the power supply, the oscillation is coupled to another circuit.

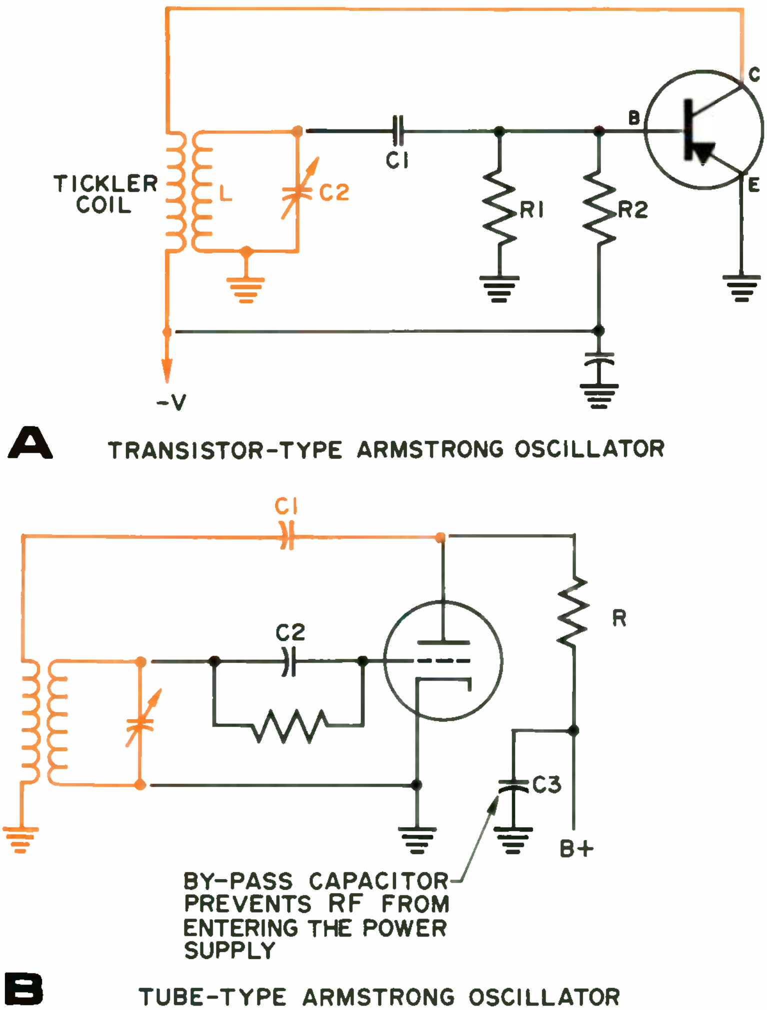


Figure 13 - Armstrong oscillators.

It was stated earlier that forward biasing is needed to start the transistor oscillator. In a vacuum tube, the oscillating current flows when zero bias occurs. Because the grid is at zero voltage potential (with respect to the cathode), current flows to the plate and through the plate circuit. That, combined with inherent, or natural, random variations, tends to trigger the circuit. The amount of feedback determines how much bias there is to be developed. If the circuit is not oscillating there is an absence of AC output. With no AC output, tube bias is not developed. A DC voltmeter connected from grid-to-cathode, or across C2 will indicate zero volts.

The wrong phase in the feedback network will also cause the oscillator to have no AC output. The incorrect phase might occur when replacing a transformer and accidentally reversing the leads of the primary or secondary windings of the transformer. This will not occur if an *identical* replacement transformer is available. Substitute transformers usually have differences in construction and lead placement.

The Armstrong Oscillator is one of the most frequently used oscillator circuits. The Armstrong Oscillator's circuit is easily recognized because a resistor is used instead of a radio frequency choke (Fig. 13B). It would seem that an RFC might perform better than a resistor because it has a much lower resistance to DC. Also an RFC would be more efficient for DC, since a smaller supply voltage could be used. However, the disadvantages exceed the advantages. The RFC may be unintentionally coupled to other coils or transformers mounted nearby. This unintentional coupling would cause poor receiver performance. Also the RFC may be affected by the magnetic fields of nearby coils or transformers. When a RF coil or RF transformer is replaced, it must be positioned exactly as the original coil or transformer. Changing the position increases the chance of an unintentional coupling.

An RFC may have a reactance of 20,000 ohms and still have a DC resistance of approximately 50 ohms. A resistor having a resistance of 20,000 ohms would have the same resistance for AC as for DC. A serviceman would not be required to measure or calculate the reactances of coils and transformers. He would be required to measure the resistance of coil or transformer windings in order to establish whether they are open or shorted. Frequently, the normal resistances of coils and transformers are printed on the schematic.

RF AND AF OSCILLATOR

The radio frequency range deals with the tuning of the oscillator circuit by the use of L and C. The audio range deals with the use of R and C to determine the frequency. Mathematical formulas show that time is equal to the product of the resistance and capacitance. This *time factor* or RC time constant can occur at an audio rate. This time constant is used to advantage in audio frequency oscillators.

Since time and phase are directly related, simple phase shifts cause time delays. Combinations of RC circuits can accomplish the phase shift more easily than more complicated circuits. We are able to use three parallel circuits with a 60-degree phase shift in each circuit. Adding the circuits together will cause a 180-degree phase shift. While the combination of the three circuits cause a 180-degree shift, the phase shift takes place only at a specific frequency, dependent upon the capacitive reactance. The type of audio oscillator in Figure 14 is used in test equipment (not in radio or television receivers). Usually, separate audio oscillators are not used as test equipment circuits because most RF signal generators have an audio output of approximately 400 hertz. This 400-hertz AC signal will adequately test all the AF portions of radio and TV receivers.

Frequencies above 20,000 hertz are considered to be radio frequencies. Frequencies below 20,000 hertz are considered to be audio frequencies. TV receivers contain an oscillator that controls the sweep of the beam across the width of the CRT. This oscillator is called the *horizontal oscillator*. TV receivers also use an oscillator to control the height of the picture. This is called the *vertical oscillator*. Even though the vertical and horizontal oscillators of a TV receiver are not meant for the human ear, they are operated in the audio range and must be considered as audio frequency oscillators.

CRYSTAL OSCILLATOR

With the exception of a crystal used for the input tank circuit, the crystal oscillator in Figure 16 is identical to the tuned-grid tuned-plate oscillator. The crystal is a specially ground quartz crystal that has been cut to a particular axis of its grain. This type of cut is called *surface grinding*. The crystal is held in place by two plates

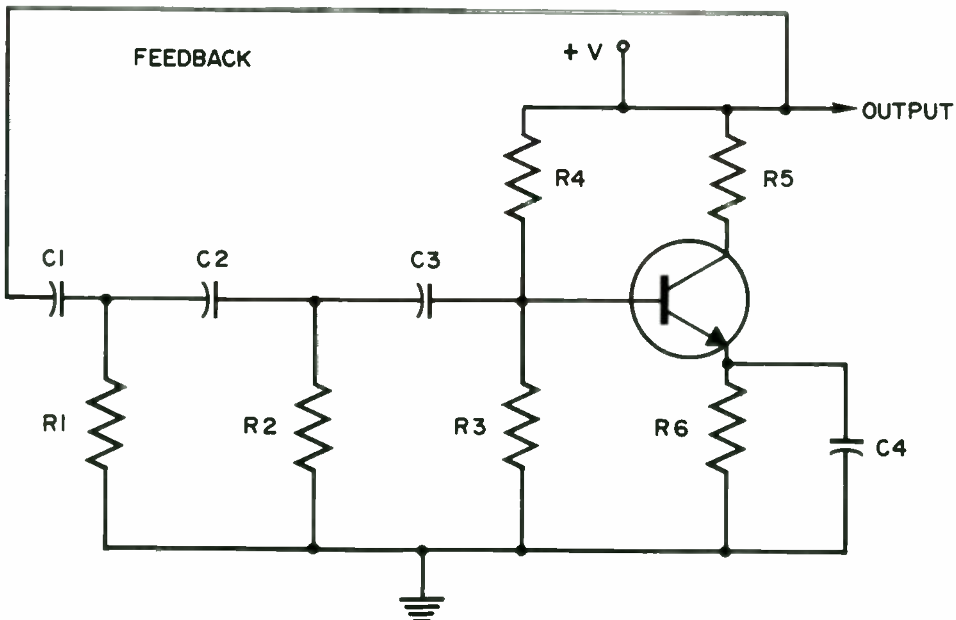


Figure 14 - An audio oscillator using resistors and capacitors instead of a resonant circuit.

that receive the vibrations or oscillations of the crystal. Because of its construction and circuit reaction, a crystal may be expressed symbolically as a tank circuit (Fig. 15).

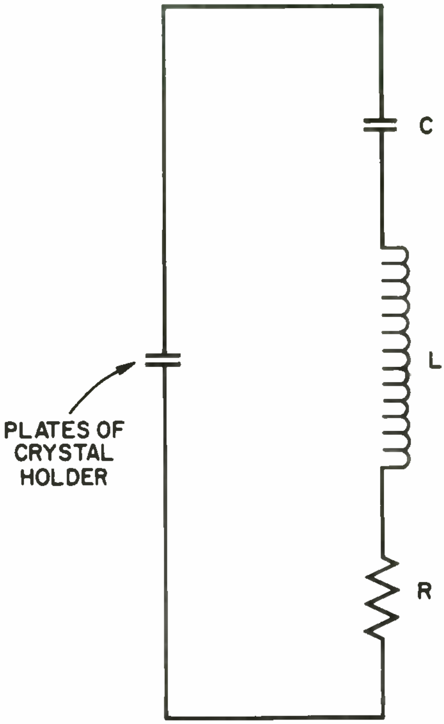


Figure 15 - An equivalent circuit of a quartz crystal.

The inter-element or inter-electrode capacitance of the tube is used for the feedback network just as in the TPTG Oscillator. Some variations may exist due to the use of a shunt or series-fed plate voltage. The DC plate current path in Figure 16A is described below:

1. cathode to plate
2. plate to L
3. through L to B +
4. through DC source, plus to minus (ground)
5. ground to cathode

The DC plate current path in Figure 16B is described below:

1. cathode to plate
2. plate to RFC
3. through RFC to B +
4. through DC source, plus to minus (ground)
5. ground to cathode

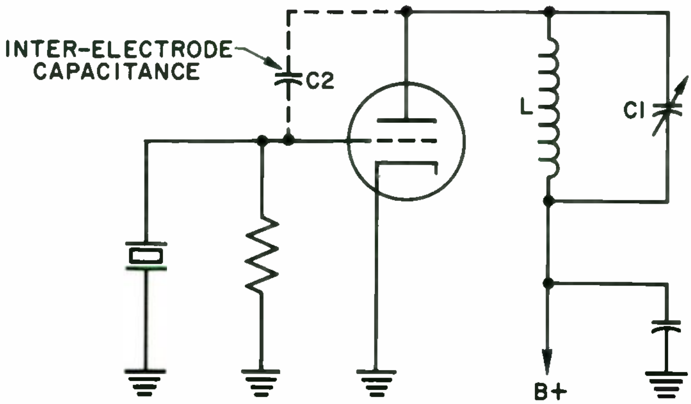
There is no DC current through the tank coil in Figure 16B. This complicates the circuitry by creating the need for two extra components. (C1, the blocking condenser, and RFC). The feedback paths in Figure 16A and Figure 16B are identical. The feedback passes through the inter-electrode capacitance between the grid and the plate.

Some signal generators use crystal oscillators. In these generators, a crystal can be plugged into a socket on the front panel. To obtain a different frequency, another crystal can be plugged in. This is the only way that the frequency of a crystal oscillator can be changed. Varying C1 in Figure 16A, or C2 in Figure 16B, will not vary the frequency of the output AC. Only the output voltage will vary when these capacitors are adjusted.

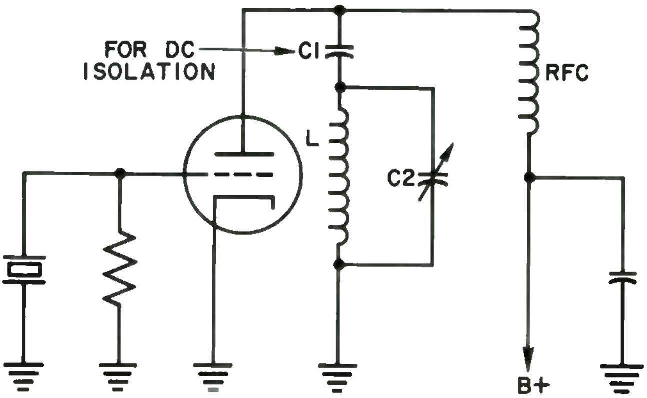
FET OSCILLATOR

Field Effect Transistors display characteristics similar to tubes because they are voltage dependent. (Regular transistors are current dependent). Therefore, these circuits are similar to those with tubes. The three elements of a FET have special names (Fig. 17).

G represents gate
S represents source
D represents drain



A SERIES-FED CRYSTAL CONTROLLED OSCILLATOR



B SHUNT-FED CRYSTAL CONTROLLED OSCILLATOR

Figure 16 - Crystal oscillators.

The FET is like a pentode in operation. In a pentode, the screen voltage is held constant so that only the grid voltage controls the plate current. In a triode, the plate voltage also controls the plate current. This is not true for a pentode. In a pentode, there are three grids between the plate and the cathode; the *control* grid, the *screen* grid, and the *suppressor* grid. These three grids shield the plate voltage from the cathode region.

The special way that the FET is constructed makes the drain current dependent on the gate voltage only. (In a transistor, the collector current depends on the base current. Theoretically, the base voltage does change, but it is not enough to measure.) The large internal resistance from gate to source makes the FET unusual. This internal resistance is many MEGOHMS. In transistors, the internal resistance from base to emitter is only

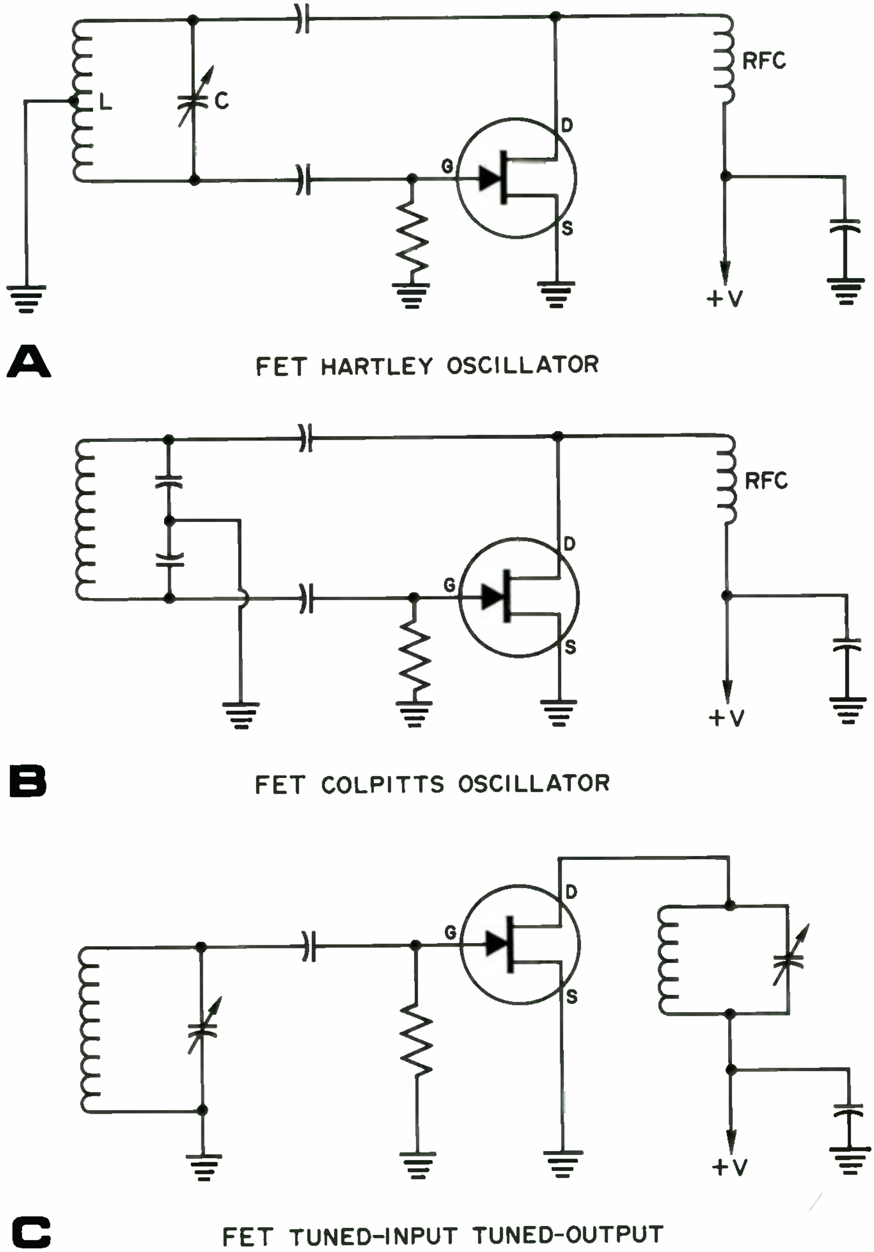


Figure 17 - FET oscillator circuits.

several thousand ohms. Thus, the FET is used where the losses due to resistance must be as small as possible. This indicates large resistances because the current and losses are low when parallel resistances are large.

ELECTRON COUPLED OSCILLATOR

The Electron Coupled Oscillator is called an ECO. A vacuum tube is used in this type oscillator. It uses either a tetrode or a pentode, because both of these tubes have screen grids. The screen grid is used as the plate of this oscillator. Any one of the tube oscillator circuits already studied in this lesson can be used. This includes Figures 7A, 13B and 16.

The screen grid of a tetrode or pentode intercepts approximately one-tenth the electrons that are moving towards it from the cathode. The remainder of the electrons continue to move toward the plate and become the plate current. Therefore, if an oscillator circuit is using a screen grid as the plate, the remainder of the electrons do not require circuitry such as coils, condensers, or resistors to couple the signal to the oscillator output. Thus, the circuitry requiring the output voltage from the oscillator can be connected to the plate of the tetrode or pentode. This is *electron coupling*.

Most coupling from one circuit to another circuit requires additional parts. In an ECO, coupling is accomplished via the electron stream (common to the screen grid and the plate). Figure 18 shows a crystal-controlled, crystal oscillator of the ECO type. (Sometimes, the word *xtal* is used instead of the word crystal). Compare Figure 18 with Figure 16A. Note the close similarities between the screen grid circuit of Figure 18 and the plate circuit of Figure 16A. The AC plate load may be a resistor, the primary of a transformer, or some other resonant circuit. The plate current, passing through the AC load, produces a useful AC voltage.

FREQUENCY STABILIZATION

Most oscillators have an AC output, where the frequency is determined by the inductance and the capacitance of a resonant circuit. If the inductance of the tank circuit is changed, the frequency of the AC output is changed. Similarly, if the capacitance of the tuning capacitor is changed, the frequency of the oscillator's AC

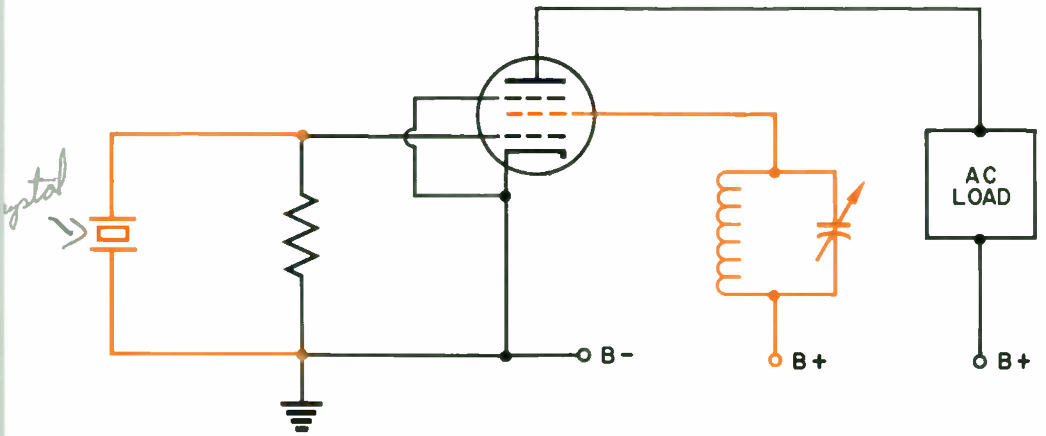


Figure 18 - An electron coupled oscillator (ECO).

output is different. The AC output of an oscillator has two characteristics; the strength of output (volts) and the frequency of output (hertz or cycles per second). Both of these characteristics should remain fairly constant when the oscillator is operating, otherwise the operation of the receiver containing the oscillator circuit might be affected. Usually the strength of the AC output remains fairly constant. This is particularly true over short periods of time. The frequency of the oscillator's AC output, however, will often change over long periods of time. This undesired change in frequency is called *frequency drift.*

In electronic circuits, the value of most parts can be changed considerably and yet not affect the operation of the circuit. This is not true in oscillator circuits. Almost every component in the oscillator circuit has some effect on the output frequency even though the main determining factor is the L and C (inductance and capacitance) of the resonant circuit.

When a receiver is turned on, the temperature of the parts increases slightly for about five or ten minutes. The exact physical size of a capacitor and an inductor has a direct bearing on the electrical value of the receiver's parts. Thus, when a receiver is warming up, all of the coils and condensers are somewhat changed in electrical value. This change is small, but it has a noticeable effect on the frequency of the oscillator circuits. Since a different frequency changes the operation of the receiver, the manufacturers sometimes use parts that will oppose one another during warm-up. For example, if the inductance of a tank circuit's inductor increases, a capacitor that has a decrease in capacity during warm-up is used. If the decrease of one is close to the increase of the other, no noticeable change in the oscillator frequency results. This type of capacitor is called a *negative temperature coefficient capacitor.* When an oscillator circuit is being serviced, it is wise to use identical replacement parts whenever possible.

The fine-tuning control of a TV receiver is a small, variable capacitor or inductor. It is a part of an oscillator's resonant circuit. In some TV receivers, the fine-tuning control requires adjustment during the receiver warm-up period. This adjustment overcomes the drift of the oscillator.

Efforts on the part of the receiver manufacturer to keep the frequency of oscillator circuits constant is known as *frequency stabilization.* Frequency stabilization uses special parts and circuits. A perfect oscillator, however, has never been built. All oscillators drift a little. When repairs are performed on RF oscillator circuits, care should be taken to retain the original construction. This is especially true with respect to the length of leads and to the exact position of a replacement part.

INDIRECT FREQUENCY GENERATION

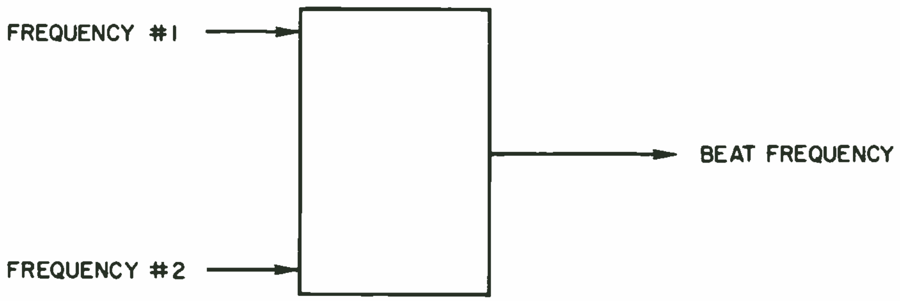
Direct frequency generation involves an oscillator circuit. Three possible means to determine the frequency are available, through the use of:

a. an LC tank circuit.
b. a quartz crystal.
c. an R and C at low frequencies.

It has been found that there is another way to generate a desired frequency. By using two frequencies and the proper circuits, a new frequency can be generated. This new frequency is the difference between the two original frequencies (Fig. 19).

This method of generating a new frequency is one of our most useful ideas in the design of modern receivers. The difference frequency is referred to as the *beat frequency*. The process of combining two AC signals to get a third AC signal is called *heterodyning*. (Hetero comes from the Greek word meaning a mixture.) Heterodyning refers to the two input signals. Because they are different, the combination is thought of as a mixture.

When the output of a circuit is the difference frequency, the circuit is called a *detector* or a *mixer*. The circuit can be quite simple. It may use a diode, a resistor, and a capacitor. In principle, it is similar in operation to a half-wave rectifier or power supply.



FREQUENCY #1	FREQUENCY #2	FREQUENCY #3
1000 kHz	1200 kHz	200 kHz
1400 kHz	1900 kHz	500 kHz
600 kHz	1050 kHz	450 kHz
700 kHz	1155 kHz	455 kHz
600 kHz	1055 kHz	455 kHz
800 kHz	900 kHz	100 kHz
42 MHz	45 MHz	3 MHz

TABLE 2 – DIFFERENCE FREQUENCIES

Figure 19 - Examples of the generation of difference frequencies.

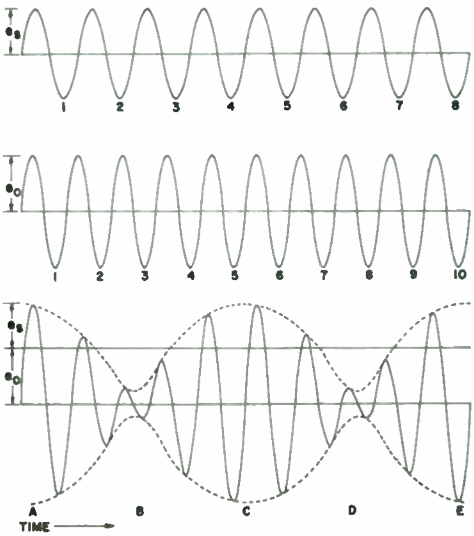


Figure 20 - The result of the addition of two unlike frequencies.

When two frequencies combine to generate a different frequency, two AC voltages combine to generate a third AC voltage. In Figure 20, the top AC voltage has a frequency of 8 hertz. The next AC voltage has a frequency of 10 hertz. The result of the two AC voltages combined fluctuates in amplitude. The fluctuation is at a rate of 2 hertz. At the instant that the two input AC voltages begin, they are *in phase*. When the first has completed exactly two cycles, the second has completed exactly two and a half cycles. Now, they are *out-of-phase*. Their sum has a low value. When the first has completed exactly four cycles, the second has completed exactly five cycles. Now, they are in phase again because both positive alternations occur at the same time. Their sum has a large value. This rise and fall of the sum is called the *beat frequency* or the *difference frequency*. If the sum voltage is fed into a detector, there is a simple AC at the output, because the detector utilizes only the top or bottom half of the sum AC voltage. The detector output is the top or bottom dotted line. Both of these dotted lines are AC at the difference frequency. Essentially, a capacitor in the detector circuit will connect either the positive peaks or the negative peaks of the sum.

The use of the heterodyne method of generating a difference frequency requires only a moderate amount of parts. Sometimes, the detector section uses an amplifying tube such as a triode or pentode. Then, the beat frequency is generated and amplified. A transistor may also be used for this purpose.

USE OF OSCILLATORS IN RECEIVERS

Many years ago, oscillators were not used as a part of receivers. The processing of the signal received by the antenna from the radio station was simple (Fig. 21A). After being amplified several times by RF amplifiers, the AC signal from the radio station was fed to the demodulator portion of the receiver. The RF amplifiers used tuned circuits as plate load impedances so that only one station was passed at any one time. RF amplifiers, then did two things:

a. amplify the strength of the station signal, and
b. pass only one station signal at a time.

The ability of tuned or resonant circuits to pass only one radio station at a time is called *selectivity*. If there is not enough selectivity, more than one station is heard at the same time. If there is too much selectivity, only

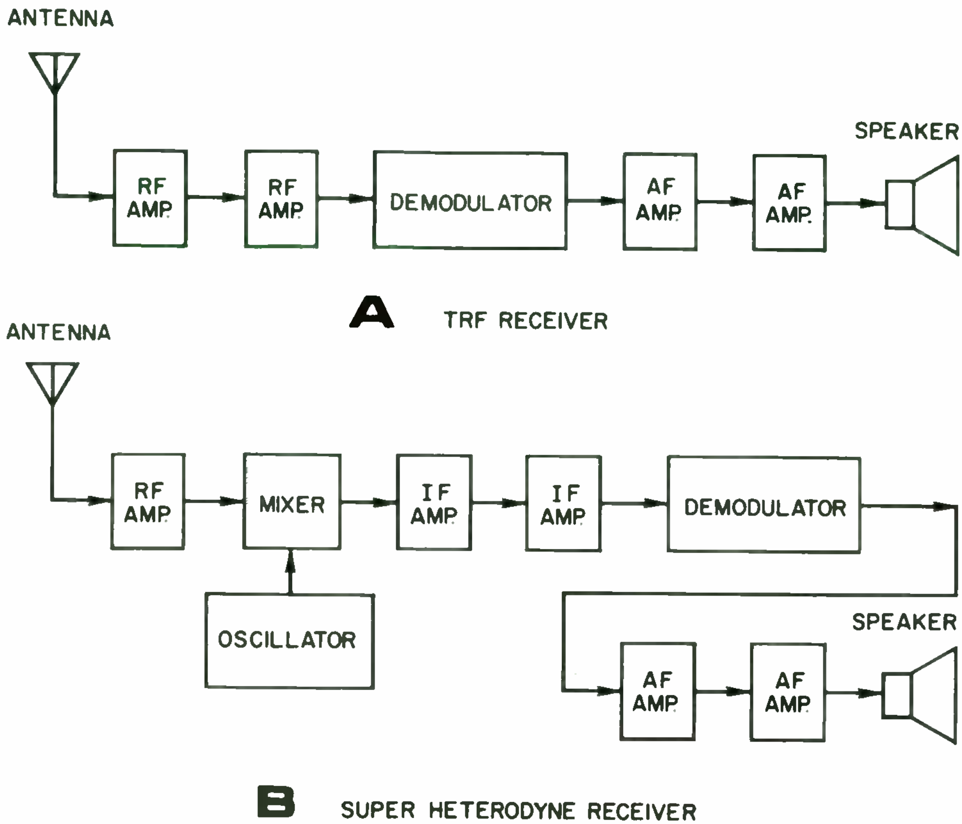


Figure 21 - Basic types of receivers.

one station is heard, but, it sounds unnatural because the higher audio frequencies are lost. The manufacturers attempted to obtain the proper amount of selectivity by the selection of parts values. (The word *bandwidth* is often used to describe selectivity. If the bandwidth is too wide, there is not enough of selectivity.)

The signal at the output of the demodulator section was the same as the microphone signal at the radio station. If this small signal were fed to a speaker, the result would be inaudible. That is why at least two audio frequency amplifiers are used.

A receiver of this type is known as a *TRF receiver* or a *tuned radio frequency receiver* because tuned circuits were always used in each RF amplifier. The amplification and selectivity in the RF amplifiers, however, was not the same for all stations. There was a tendency for the amplification to be greater for radio stations operating at a higher frequency. This resulted in the possibility that the RF amplifiers would operate as oscillators since some of the output always managed to get back into the input circuit. This was undesirable, but it couldn't be eliminated entirely at that time.

The RF portion of a receiver of this type had less selectivity (more bandwidth) at higher station frequencies. This resulted in several stations being heard at the same time. One type of RF amplifier cannot be expected to operate in exactly the same manner for different station frequencies. Thus, the amplification and the selectivity would vary when different stations were tuned. Receivers of this type were used for many years, but they are no longer being built.

Modern day radio receivers are similar to the block diagram shown in Figure 21B. Note: there is an oscillator portion and the mixer portion has two inputs. The action in Figure 21B is identical to that demonstrated in Figure 19. The difference frequency is called the *Intermediate Frequency* (IF). The difference frequency is always the same regardless of what station is tuned in. This is made possible by changing the oscillator frequency when tuning to a different station.

In the fifth example in Figure 19, frequency #1 corresponds to the station frequency and frequency #2 corresponds to the oscillator frequency. The difference frequency is the IF. In the fourth example of Figure 19, the station frequency is 700 kilohertz. If the oscillator frequency is increased by 100 kilohertz (1155 kilohertz), the difference is the same as in example five. AM radio receivers use an IF of 455 kilohertz. When tuning in a station at 900 kilohertz, the oscillator frequency is 1355 kilohertz. When tuning in a station at 1100 kilohertz, the oscillator frequency is 1555 kilohertz.

IF amplifiers are specialized amplifiers. They can be excellent amplifiers at 455 kilohertz and relatively poor amplifiers at other frequencies. IF's are not used for other frequencies because the output of the mixer section is always 455 kilohertz. The amount of amplification of the IF amplifiers does not change. The selectivity remains constant because the signal is always amplified at the same frequency. A receiver that uses an oscillator *and* IF amplifiers is known as a *superheterodyne receiver.*

Close study of Figure 21B shows how any radio station frequency can be changed to a fixed frequency. All that is needed is a change of the oscillator frequency each time a new station is tuned in. Sometimes, the RF amplifier section is omitted. In this case the antenna feeds the mixer directly. Some low priced receivers will have only one IF amplifier stage.

The oscillator in a radio, TV or FM receiver, used as described above, is usually called a local oscillator. Whenever stations are changed, the frequency of the local oscillator is changed. This is usually done with a variable capacitor, although, in some cases variable coils are used.

SUMMARY

An oscillator is an electronic circuit having no external input. The output is alternating current. In most oscillators, the frequency is determined by the amount of inductance and capacitance in the resonant circuit. Using smaller value coils and capacitors results in higher frequencies. Radio receivers usually use oscillators. The frequency of radio receiver oscillators varies from approximately 1,000 to 2,000 kilohertz.

The heart of the oscillator is the resonant circuit. The resonant circuit is also called a tank circuit. All resonant circuits tend to oscillate. A tank circuit in conjunction with a tube or transistor generates continuous oscillations.

There are a great number of oscillator circuits. Many of them are variations or modifications of several basic circuits. The Hartley and the Colpitts oscillators are very similar. Figure 9 emphasizes how the resonant circuit acts as a collector load impedance. All amplifiers have load impedances so that an AC current can produce an AC voltage. An oscillator resembles an amplifier circuit, but an oscillator supplies its own input signal to the base or grid. An amplifier receives a signal from some other section of the receiver.

A tuned-input tuned-output oscillator uses two resonant circuits. Interelement capacity acts to provide the feedback necessary for oscillation. The Armstrong Oscillator uses one tuned circuit. A transformer is used to provide the feedback from the output (collector or plate) to the input (base or grid).

A slice of quartz behaves like an LC circuit. A crystal can be used to replace a resonant circuit in some oscillators. Crystal oscillators are not used for RF frequencies above 20 megahertz. At higher frequencies, it is necessary to use very thin slices of quartz (which are very fragile and crack easily).

Figure 11 showed the base to emitter circuit of a transistor. This type of circuit is very common in transistor amplifiers. Many defects cause abnormal DC voltages to appear in the circuits. Understanding the DC paths of these circuits makes it easier to find the cause of a DC voltage that is too high or too low. Voltages are measured more often than currents because it is more convenient to measure voltage (There is no need to unsolder). To measure current, however, the current meter must be placed in series with a component or circuit. This requires the unsoldering of at least one point of a circuit. Unsoldering is usually not done because it is time consuming.

Figure 19 introduced the idea of two frequencies being heterodyned (added) to generate a beat or difference frequency. Some signal generators operate on the heterodyne principle. All modern receivers use the heterodyne principle. These receivers are called *superhets.* In a superheterodyne receiver, the difference frequency is called the intermediate frequency. The IF frequency in most AM radio receivers is 455 kilohertz.

When a receiver oscillator is not operating, the receiver is completely inoperative because no IF frequency is produced. There is no output from the IF amplifiers because the first IF amplifier has no input signal. When troubleshooting an oscillator, all the DC voltages and resistances of the oscillator section are checked. Usually AC checks are not made. The incorrect values usually pinpoint the defective part. Then the defective part can be replaced. A general way to tell whether an oscillator is not operating is by substitution. One must first know the approximate frequency of the oscillator. Then a signal generator is adjusted for that frequency. The signal generator is connected to the output point of the oscillator section. The output point is usually at the plate or collector circuit. If the receiver then operates properly, it is evident that the oscillator section is not operating. Then detailed DC voltage checks and resistance checks can be made. If a tube type of receiver is being serviced, the oscillator tube should be checked or substituted. A crystal oscillator usually will have less frequency drift than any other type of oscillator. This is because the equivalent inductance and capacity remain constant over long periods of time and is the main advantage of crystal oscillators.

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TEST

Lesson Number 32

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 52-032-1.

1. An oscillator circuit is
   - A. a demodulator circuit.
   - B. an AC generator.
   - C. a rectifier circuit.
   - D. a power supply.

2. An oscillator requires a feedback circuit to
   - A. generate a difference frequency.
   - B. generate a sum frequency.
   - C. have continuous oscillations.
   - D. minimize ripple output.

3. An RF oscillator
   - A. usually uses an LC tank circuit.
   - B. always uses quartz crystals.
   - C. is used only in receivers.
   - D. is used only in signal generators.

4. The "heart" of an RF oscillator is the
   - A. supply voltage.
   - B. base or grid biasing circuit.
   - C. resonant circuit.
   - D. ripple filter.

5. The tank circuit of a Colpitts oscillator has
   - A. one coil and one capacitor.
   - B. two coils and one capacitor.
   - C. three capacitors and three resistors.
   - D. one coil and two capacitors.

6. A tuned-input tuned-output oscillator uses
   - A. three resistors and three capacitors.
   - B. one coil and one capacitor.
   - C. two coils and one capacitor.
   - D. two coils and two capacitors.

7. An Armstrong oscillator uses
   - A. transformer feedback.
   - B. RC feedback.
   - C. a quartz crystal.
   - D. two tuned circuits.

8. An electron coupled oscillator
   - A. always uses a crystal.
   - B. can use a pentode.
   - C. can use a triode.
   - D. can use a transistor.

9. An FET (field effect transistor) is similar to a
   - A. quartz crystal.
   - B. power supply.
   - C. pentode.
   - D. diode.

10. An AC signal of 600 kHz is heterodyned with an oscillator frequency of 1055 kHz. What is the difference frequency?
    - A. 455 kHz.
    - B. 555 kHz.
    - C. 2,095 kHz.
    - D. 2,195 kHz.

Notes

Notes

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HOW & WHY

Before you learn how to run, you learn how to walk and before that. . .how to crawl. Sometimes you may grow impatient and want to skip a step, only to find out later that it was a mistake.

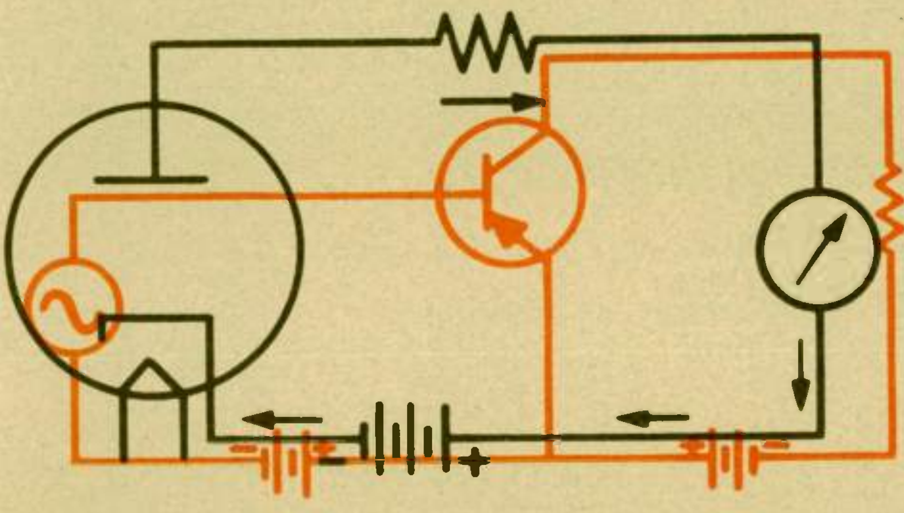
Most of us are like this and sometimes it takes self-discipline to follow the guidelines given to us. Especially in home study.

Discipline yourself to follow the guidelines set forth in your ASI Training. You must learn the "how" and "why" as well as "what to do" in order to be a successful electronic technician. Do not pass over any of your lessons, without first thoroughly understanding what is covered. Learn the "how" and "why" first and the actual servicing will be much easier!

S. T. Christensen

LESSON NO. 33

ANTENNAS & RADIO WAVES



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CONTENTS

ANTENNAS AND RADIO WAVES

INTRODUCTION

A person talking can be heard by many people at the same time. Everyone listening to him would receive his sound waves. Similarly, a radio station can affect many radio receivers at the same time.

Radio waves are sent out (radiated) by the station's antenna. The antenna is essentially a wire that has AC current applied to it. Electrostatic and magnetic lines of force surround the wire, and most of these lines of force travel out into space. Roughly, a transmitting antenna is similar to the primary of a transformer. The receiving antenna is similar to the secondary winding of a transformer. The electromagnetic lines pass through and induce a voltage in the antenna. This induced voltage is usually less than 1 volt since only a small amount of the station's output is intercepted; it may be several millivolts or only several microvolts.

A receiving antenna (Fig. 1) is like the secondary winding of a transformer that reacts to a station's signal but is *not* constructed as a winding since it must intercept an appreciable amount of the station's signal. This lesson covers transmission lines, antenna dimensions, and radio waves.

Transmission lines are wire-type devices that carry RF *to* transmitting antennas or *from* receiving antennas. They serve as a connecting link between an antenna and an electronic circuit. The basic radio receiver (Fig. 1) does not have a transmission line since the antenna wire is connected directly to the primary of the RF transformer. However, all FM and TV receivers use a short length of transmission line.

The tuned circuit (Fig. 1) has the largest current at the resonant frequency. In this way, the other radio stations are rejected and only the tuned-in station is heard. The amplitude of the RF is varying at an audio rate. The detector output is AF; the headphones respond to the audio electric current and produce sound waves.

DIPOLE ANTENNA

When RF current flows through a transmitting antenna, radio waves are radiated from the antenna in all directions in the same way that waves travel on the surface of a pond into which a rock has been thrown. Radio waves travel at a speed of 186,000 miles per second (300 million meters per sec-

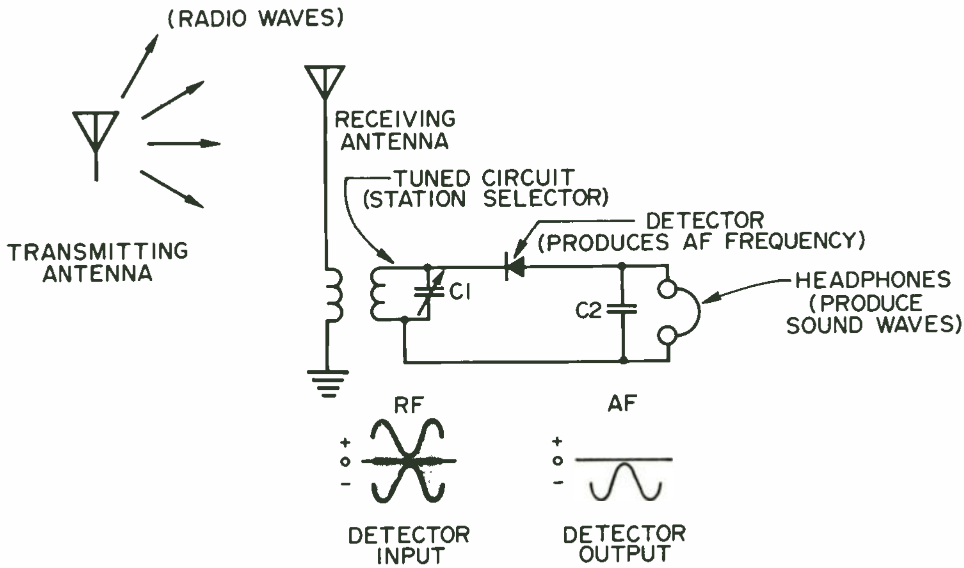


Figure 1 - Basic radio receiver.

ond). The frequency of the radio wave radiated by the antenna is equal to the frequency of the RF current.

Because the velocity of the radio wave is constant regardless of its frequency, to find the *wavelength* (which is the distance traveled by the radio wave in the time required for one cycle) divide the velocity of the wave by the frequency of the wave (Fig. 2).

For a frequency of 300,000 Hz or 300 kHz, the wavelength is 1,000 meters. For a frequency of 60,000,000 Hz or 60 MHz, the wavelength is 5 meters. FM frequencies are from 88 MHz to 108 MHz; taking 100 MHz as a typical value, the wavelength is 3 meters. A meter is 39.4 inches.

The basic antenna is a conductor one-half wavelength long. This antenna is called a dipole, doublet, or Hertz antenna. The formula in Figure 2 may be used to calculate the length of a half-wave antenna by dividing the answer by two. The formula in Figure 3 may be used also, since the answer is in feet. For 10 MHz, a dipole would have a length of 49.2 feet. For 60 MHz (TV channel 2), a half-wave antenna has a length of 8.2 feet. In actual practice, the dipoles are manufactured to a length approximately 5 per cent less than that calculated in Figure 3. The formula is:

$$\text{length of dipole in feet} = \frac{468}{\text{Freq. (in MHz)}}$$

However, it is unlikely that it will ever become necessary to use either of the formulas in practice because antennas are available completely manufactured.

The basic antenna, the dipole, is connected to the transmission line at the center, so the dipole actually consists of two quarter-wave segments.

In Figure 4, two wires are attached to the terminals of a high-frequency

$$\lambda \text{ wavelength} = \frac{\text{velocity}}{\text{frequency}} = \frac{300{,}000{,}000}{f}$$

f (frequency)	λ(wavelength)
300,000 hertz	1000 METERS
300 KHz	1000 METERS
15,000 KHz	20 METERS
60 MHz (60,000,000 hertz) (TV CHANNEL 2)	5 METERS 5 METERS
200 MHz (TV CHANNEL 11)	1.5 METERS
100 MHz (FM)	3 METERS
500 MHz (UHF TV CHANNEL 18)	0.6 METER
800 MHz (UHF TV CHANNEL 68)	0.375 METER

Figure 2 - Wavelength of radio waves.

$$\text{Length of dipole (in feet)} = \frac{492}{\text{Freq. (in MHz)}}$$

f	$\lambda/2$
10 MHz	49.2 FEET
60 MHz	8.2 FEET
100 MHz	4.92 FEET (4 FEET 11 INCH)
200 MHz	2.46 FEET (2 FEET 5½ INCH)
800 MHz	0.615 FEET (7⅜ INCH)

Figure 3 - Length of dipole in feet.

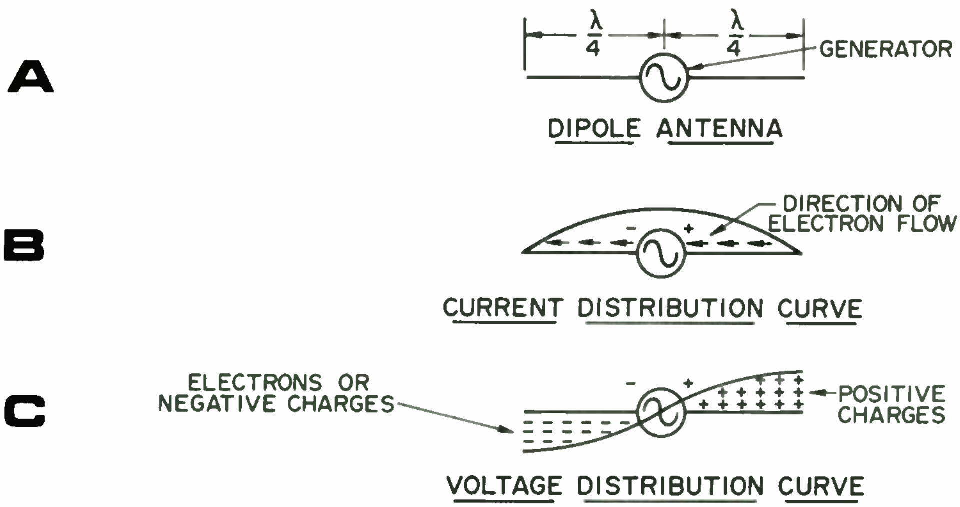


Figure 4 - Dipole antenna showing current and voltage distribution.

AC generator. The frequency of the generator output is chosen so that each wire is one-quarter of the wavelength corresponding to the generator frequency. The result is a common type of antenna known as a DIPOLE and is shown in Figure 4A. At a given instant, the right-hand terminal of the generator is positive and the left-hand terminal is negative. As like charges repel, electrons will flow away from the negative terminal as far as possible, while the positive terminal will attract electrons to it. Figure 4B shows the direction and distribution of electron flow at this instant. The current distribution curve indicates that the current flow is greatest at the center of the dipole and zero at the ends. At any given point along the antenna, except at the ends, the current variation is sinusoidal with respect to time (the generator voltage has a sine waveform). The relative current distribution is also sinusoidal with respect to the antenna length. Thus, an RF ammeter inserted near the center of the antenna will indicate a relatively large current, and an ammeter inserted near the end will indicate a small current. The relative current distribution over the antenna will always be the same no matter how much or how little current is flowing, but the current amplitude at any given point on the antenna will vary directly with the amount of voltage at the generator terminals.

The generator voltage initiates the flow of antenna current. The action of the antenna is like that of a capacitor. When a capacitor becomes fully charged, its voltage is maximum and the charging current ceases. In Figure 4C, the antenna voltage near the ends is maximum at the instant that the charging current is zero. Although no current flows at this instant, there is a maximum accumulation of electrons at the left end of the antenna and a deficit at the right end. Most of the charges are at the ends trying to get as far from the generator terminals as possible (like charges repel). The antenna voltage, like the antenna current, varies sinusoidally with respect to time. Also, the antenna voltage varies sinusoidally with respect to the antenna length. Thus, an RF voltmeter connected between ground and one end of the antenna indicates a relatively large voltage. As the voltmeter probe is moved toward the antenna center, the voltage decreases to a low value. The antenna has distributed inductance and capacitance and, therefore, acts like a resonant circuit.

ELECTROMAGNETIC FIELD

An alternating current flows in the antenna; therefore, an alternating magnetic field H is set up around the antenna as shown, at one instant (Fig. 5A). Alternate positive and negative charges also appear on the antenna, causing an electric field E to be set up (Fig. 5B). This field is represented by lines of force drawn between the positive and negative charges. The arrows indicate the direction a positive charge would move at those points.

The magnetic and electric components of the radiated field are in phase with each other. A moving electric field generates a perpendicular magnetic field in phase with it. Because the radiated electric field is moving, it generates a magnetic field in accordance with this principle. The result is a radiated electromagnetic field that can travel great distances and deliver a

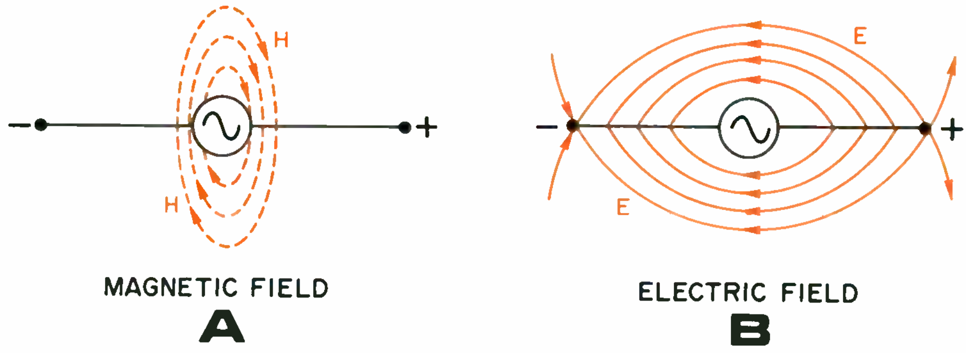


Figure 5 - Instantaneous field around an antenna.

usable part of its energy to a receiving antenna. The strength of the radiated field varies inversely with the distance.

RECEPTION

If a radiated electromagnetic field passes through a conductor, some of the energy in the field will set electrons in motion in the conductor. This electron flow constitutes a current that varies in accordance with the variations of the field. Thus, a variation of the current in a radiating antenna causes a similar varying current (of much smaller amplitude) in a conductor at a distant location. Any intelligence being produced as current in a transmitting antenna will be reproduced as current in a receiving antenna. The characteristics of receiving and transmitting antennas are similar, so that a good transmitting antenna is also a good receiving antenna.

ANTENNA INPUT IMPEDANCE

The antenna input impedance determines the antenna current at the feed point for a given value of RF voltage at that point. The input impedance may be expressed mathematically by Ohm's law for alternating current:

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

where Z is the antenna impedance and E and I are the RF voltage and current respectively.

In a half-wave antenna, the current is maximum at the center and zero at the ends, whereas the voltage is maximum at the ends and minimum at the center. The impedance, therefore, varies along the antenna and is minimum at the center and maximum at the ends. Thus, if energy is fed to a half-wave antenna at its center, it is said to be CENTER FED (current fed); if energy is fed at the ends it is said to be END FED (voltage fed). In the case of a half-wave antenna, isolated in free space, the impedance is approximately 73 ohms at the center and 2,500 ohms at the ends. The intermediate points have intermediate values of impedance.

An antenna at the end of a transmission line is equivalent to a resistance that absorbs a certain amount of energy from the generator. Neglecting the losses that occur in the anten-

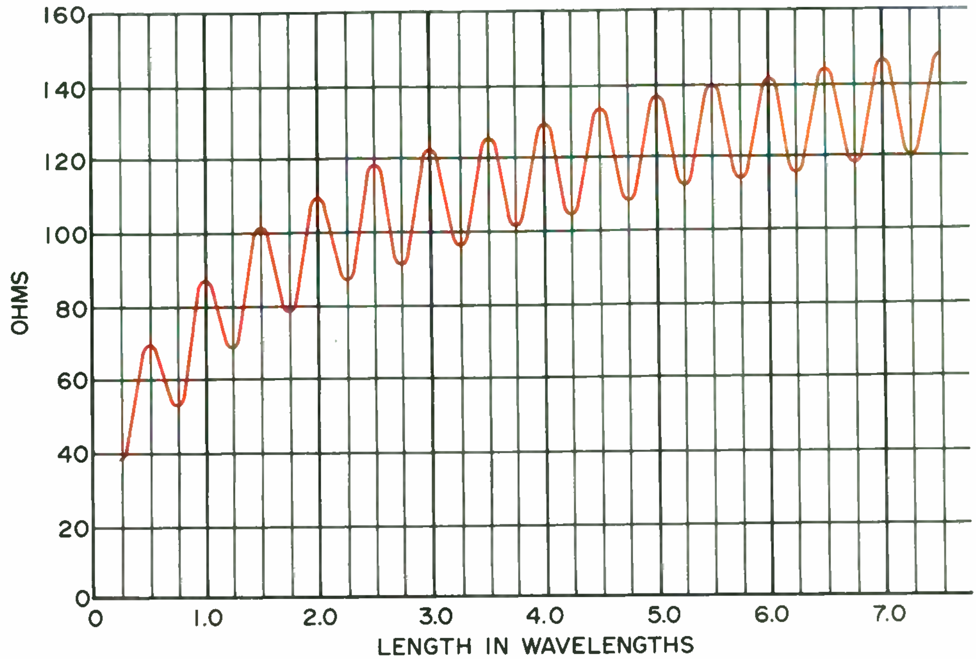


Figure 6 - Radiation resistance of antennas in free space plotted against length.

na, this is the energy that is radiated into space. The value of resistance that would dissipate the same power that the antenna radiates is called the RADIATION RESISTANCE of the antenna. The power dissipated in a resistor is equal to I^2R. Likewise, the power dissipated (radiated from) in an antenna is equal to the current squared, times the radiation resistance of the antenna. Figure 6 shows how the radiation resistance varies with antenna length for an antenna in free space. For a half-wave antenna, the radiation resistance is approximately 73.2 ohms measured at the current maximum which is at the center of the antenna. For a quarter-wave antenna, the radiation resistance measured at the current maximum is approximately 36.6 ohms. The radiation resistance is also affected somewhat by the height of the antenna above the ground and by its proximity to nearby objects. Antenna losses are caused by the ohmic resistance of the conductor and insulator resistance.

ANTENNA POLARIZATION

The direction of the electric lines of force determine the polarization of a wave. An antenna that is vertical with respect to the earth radiates a vertically polarized wave, while a horizontal antenna radiates a horizontally polarized wave. Figure 7A shows the vertical electric field of a vertical antenna as a sine wave in the plane of the paper. Figure 7B shows the horizontal electric field of a horizontal antenna as a sine wave lying in a horizontal plane. The first wave is vertically polarized; the second, horizontally polarized. For low frequencies, the polarization is not disturbed, and the radiation field has the same polarization at the distant re-

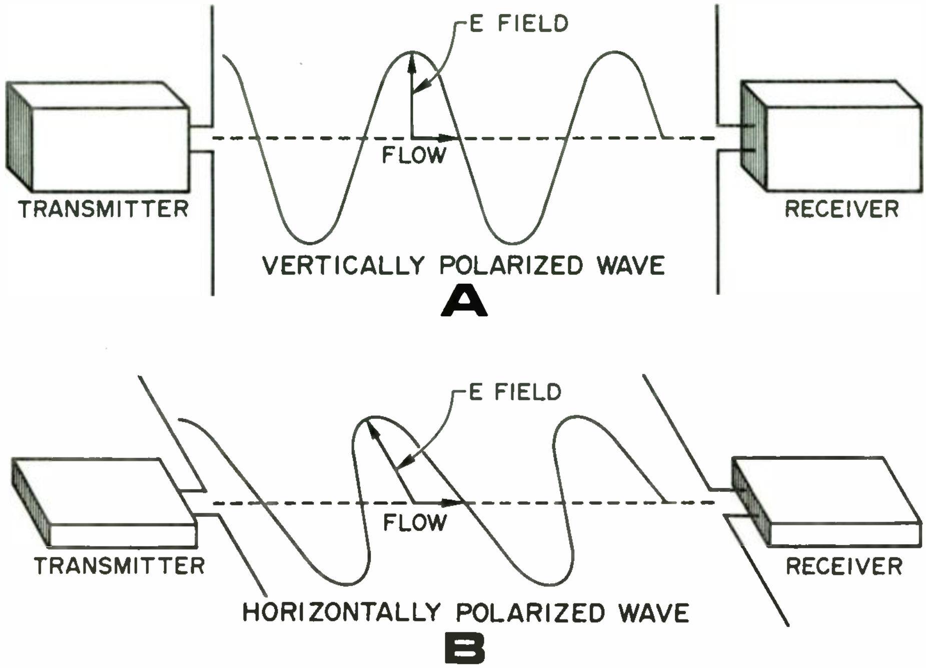


Figure 7 - Vertical and horizontal antenna polarization.

ceiving station that it had at the transmitting antenna. At high frequencies, however, the polarization usually varies, sometimes quite rapidly, because the wave splits into several components which follow different paths. These paths will not be the same length; therefore, the recombined electric vectors representing the several components generally will not be parallel. If this is the case, the path traced by the resultant vector may be circular or elliptical, and such a radiated field is known as either a circularly or an elliptically polarized field.

When antennas are close to the ground, vertically polarized waves yield a stronger signal close to the earth than do horizontally polarized waves. However, when the transmitting and receiving antennas are about one wavelength above ground, the two types of polarization give approximately the same field intensities near the surface of the earth. When the transmitting antenna is several wavelengths above ground, horizontally polarized waves result in a stronger signal close to the earth than is possible with vertical polarization.

RADIATION PATTERN FOR HALF-WAVE ANTENNAS

Because the current is greatest at the center of a dipole, maximum radiation takes place at this point, and practically no radiation takes place from the ends. If this antenna could be isolated completely in free space, the points of maximum radiation would be in a plane perpendicular to the plane of the antenna at its center. The doughnut-shaped pattern is shown

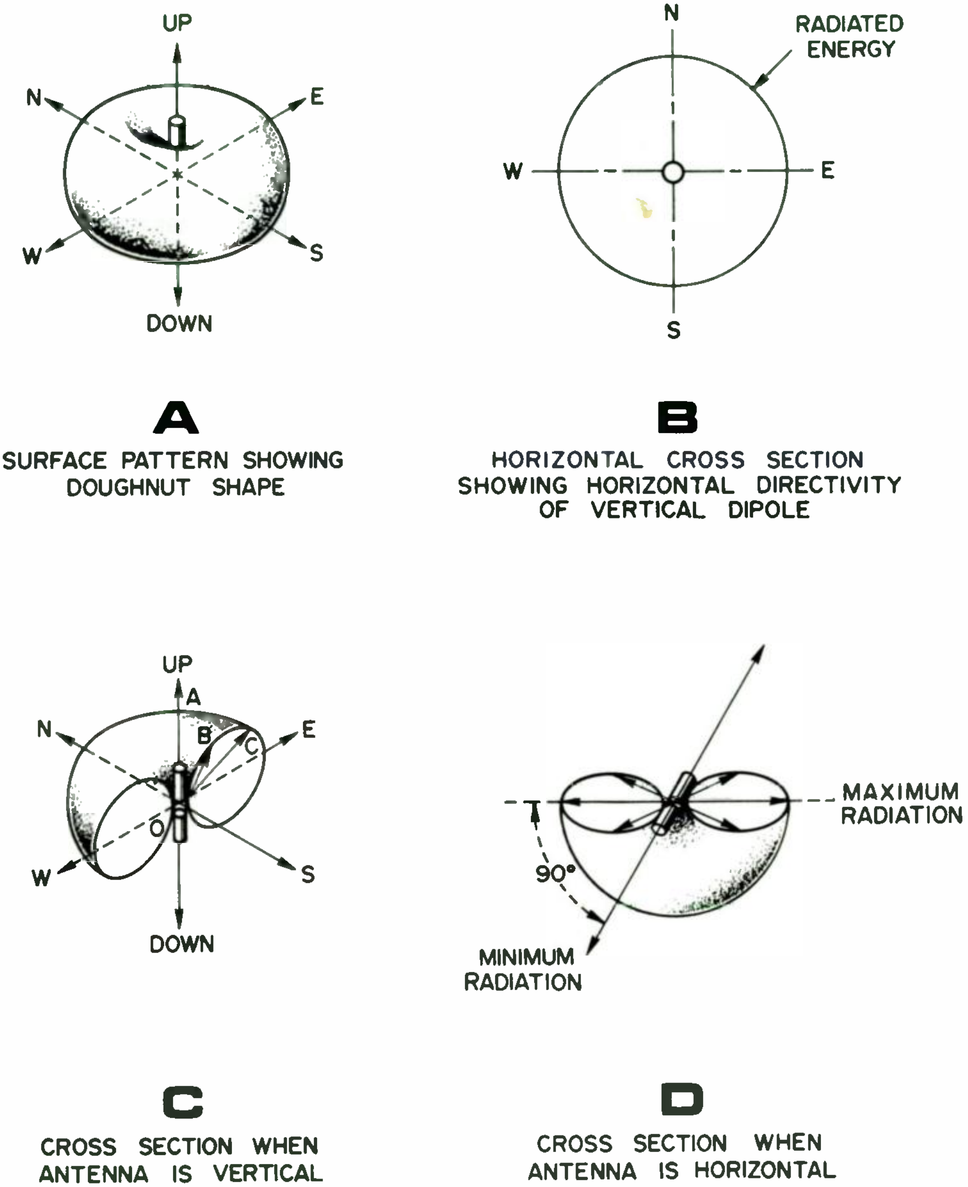


Figure 8 - Radiation pattern of a dipole antenna.

in Figure 8A and the horizontal cross-section pattern is shown in Figure 8B. Because a circular field pattern is created, the field strength is the same in any compass direction.

Theoretically, a vertical dipole has no radiation along the direct line of its axis. However, it produces a considerable amount of radiation at other angles measured to the line of the antenna axis. Figure 8C shows a vertical cross section of the radiation pattern of Figure 8A. The radiation along OA is zero; but at another angle, represented by angle AOB, there is appreciable radiation. At a greater angle AOC, the radiation is still greater.

Figure 8D shows half of the dough-nut pattern for a horizontal dipole. The maximum radiation takes place in the plane that is perpendicular to the axis of the antenna and that crosses through its center.

A polar diagram representing the radiation pattern of a horizontal dipole

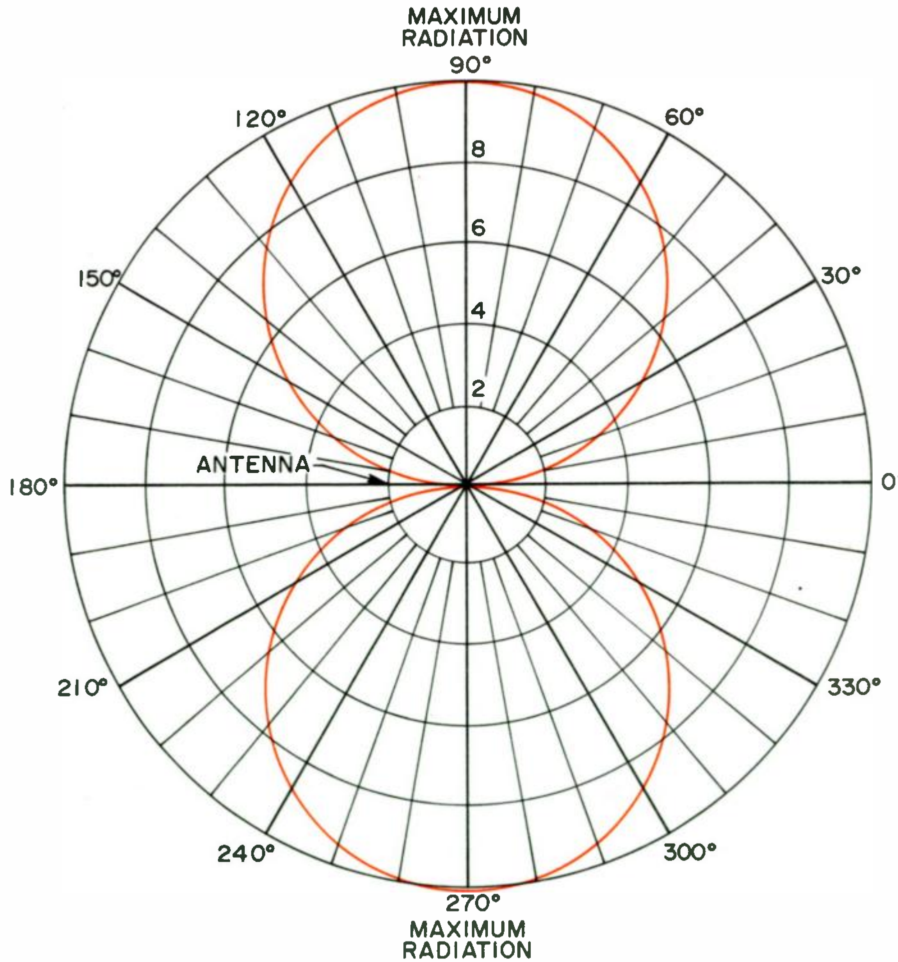


Figure 9 - Polar diagram of a dipole showing relative field strength.

is shown in Figure 9. This is a top view. The variation of signal strength around the antenna is shown. Zero distance is assumed to be at the center of the chart (indicating the center of the antenna) and the circumference of the circles is laid off in angular degrees. Computed or measured values of field strength then may be plotted radially in a manner that shows both magnitude and direction for a given distance from the antenna.

FM and TV transmitting antennas are horizontal, so the receiving antennas are horizontal also. Broadcast antennas are vertical; due to the longer wavelength at these low frequencies, the station antennas are less than a half-wave in length.

REFLECTORS

It has been found that a length of wire, rod or tubing, a little longer than a half-wave and placed near a dipole, acts as a reflector of radio waves (Fig. 10A). The reflector is not electrically connected to the dipole or to the transmission line. Two or more reflectors can be used to further increase the reflection effect. The radiation pattern is no longer that of a doughnut but of a fan shape (primarily in one direction). Assuming that the

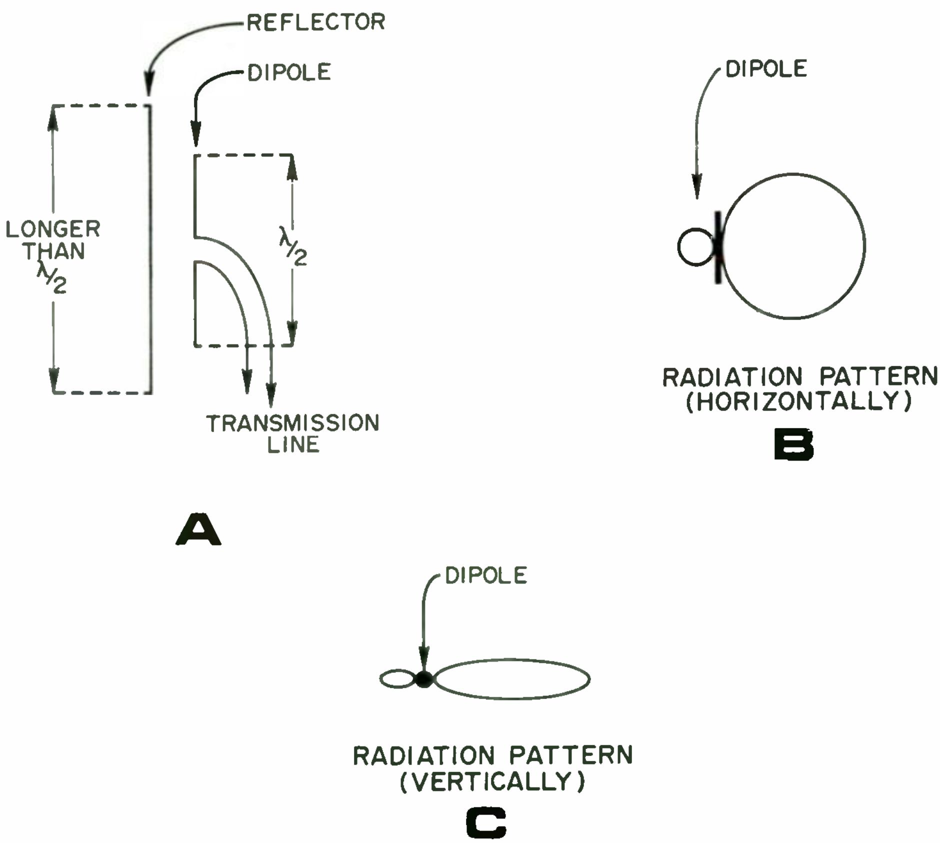


Figure 10 - Dipole and reflector.

antenna of Figure 10A is placed horizontally, Figure 10B shows the antenna pattern in a horizontal plane (top view) and Figure 10C shows the pattern in a vertical plane (side view). When many reflectors are used, the vertical pattern (Fig. 10C) narrows even more.

When a part of an antenna is not electrically connected to the transmission line, it is referred to as a "parasitic" element. Currents induced in the parasitic elements cause radio waves to be radiated. Because of this re-radiation, the antenna radiation pattern is no longer doughnut-shaped.

DIRECTORS

Parasitic elements shorter than a half-wave also have an influence on the radiation pattern of a dipole. These are called directors. The pattern is strengthened on the side of the antenna where the director is placed.

Both directors and reflectors can be used to make up an elaborate antenna system. The entire arrangement is referred to as an antenna "array." An antenna array might have only directors or only reflectors.

AM ANTENNAS

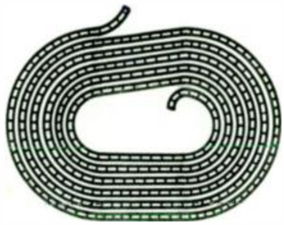
To a radio and TV serviceman, AM (amplitude modulation) receivers are simply the common radio. AM radios tune in stations from 550 to 1,600 kilohertz. Each station requires a channel of 10 kilohertz and the AF frequencies transmitted extend from 20 hertz to 5 kilohertz.

At 1,000 kilohertz, the length of a dipole (half-wave antenna) is 492 feet. This great length makes it impractical for the stations to use elevated dipoles, so shorter and grounded antennas are used, even as low as one-eighth of a wavelength. AM stations antennas are always vertical, so for best results, the receiver antenna *should* also be vertical; this is not practical due to the great length required. However, this presents no problem because the radio receiver is usually close to the station. So even a horizontal wire only 20 to 50 ft. long can serve as a very effective broadcast antenna.

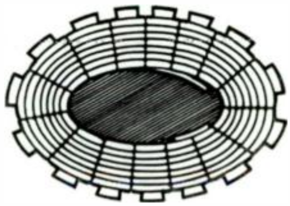
Most AM radios are now constructed with loop antennas (Fig. 11). These loop antennas are mounted at the back of the cabinet and are essentially inductors. They are usually as large as the radio cabinet size permits and so intercept more of the station RF than a small coil. Figure 11A shows a single winding used in parallel with a tuning condenser for station selection. Figure 11B consists of two windings: these two windings make the assembly an RF transformer. The primary consists of several turns wound at the outside position. An external antenna is connected to the primary, otherwise the primary would serve no purpose. The secondary is in parallel with a tuning condenser as that of Figure 11A.

Sometimes a coil about 6 inches long and about one-half inch in diameter with a ferrite core is the antenna. This inductance is variable for station selection. A fixed capacitor is in parallel with the coil to form a tuned circuit.

Both types of antennas (loop and ferrite) are directional. This is impor-



A



B

Figure 11 - Radio loop antennas.

tant to know when a weak station is to be tuned in. The radio's position is changed by rotating the entire radio until the sound is loudest. Otherwise a weak or distant station could not be brought in.

A loop antenna is safe in regard to the potential danger of being struck by lightning. Outdoor antennas, on the other hand, are very susceptible to being struck by lightning. A lightning arrestor should be used at the point where a wire or wires enter the building.

Unless a distant station is to be frequently tuned in, outdoor antennas are rarely used for AM radios. One reason is that radio stations are more powerful than they were many years ago.

FM ANTENNAS

FM (frequency modulation) receivers tune in stations from 88 to 108 megahertz. Each station requires a channel of 200 kilohertz and the AF frequencies transmitted extend from 20 hertz to 15 kilohertz.

All FM broadcast transmitting antennas are horizontally polarized; that is, the antenna dipoles are mounted horizontally. Thus, FM receiving antennas must be mounted horizontally. However, in technology, performance is always the final rule. If tilting the antenna improves performance, then by all means, the antenna should be tilted. However, in 99% of the FM antenna installations, horizontal antenna placement will prove to be satisfactory.

A dipole can be used to receive stations from two opposite directions (Fig. 12A). A horizontal dipole is bidirectional due to the doughnut radiation pattern at right angles to the dipole. If all the desired FM stations are in the same general direction (Fig. 12B), then a unidirectional antenna could be used, especially if one or more of the stations were at a greater distance. A dipole with a reflector and/or a director has an unidirectional radiation pattern. If many reflectors or directors were used, the radiation pattern would remain unidirectional; however, the vertical directivity would be increased.

If there were two FM stations about 90 degrees apart, (Fig. 12C) two antennas would be required. Or a rotatable antenna could be used. However, if both stations had strong signals, a single fixed antenna might

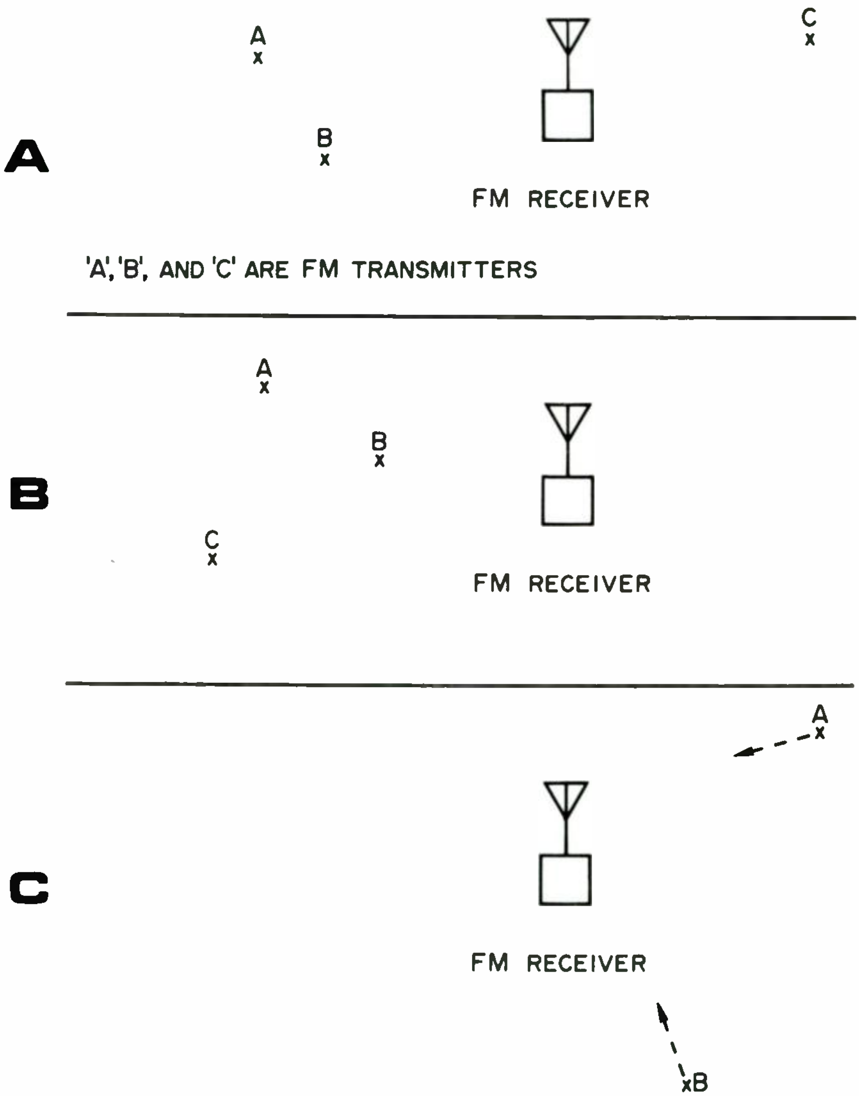


Figure 12 - FM transmitter location.

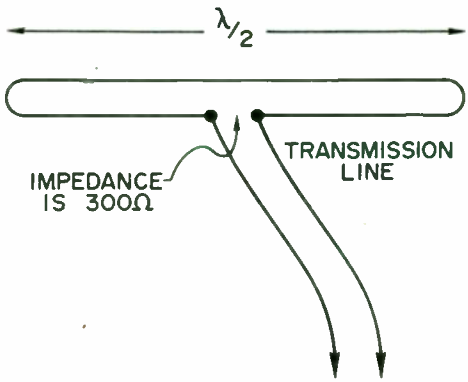


Figure 13 - Folded dipole antenna.

be adequate; in this case it would be aimed at a point midway between two stations.

For FM stations more than 5 or 10 miles away, increased antenna height will serve to give the FM receiver a stronger RF signal. Curvature of the earth tends to place the receiving antenna in a "shadow" at greater distances. The RF frequencies used by FM and TV travel along line-of-sight paths, so the antenna, for best results, should be higher when the FM station is further away.

A folded dipole is half-wave in length. Its construction (Fig. 13) essentially increases the width dimension without greatly increasing the wind resistance. This makes it less of a single-frequency antenna. It becomes a "broad-band" antenna; that is, it can respond to a wider band of frequencies. Its impedance at the center is 300 ohms as compared with the 72 ohms of a simple dipole. The significance of this will be discussed later in this lesson. A folded dipole with a reflector is shown in Figure 14A. A folded dipole with one reflector and three directors is shown in Figure 14B.

A conical antenna (Fig. 14C) is similar to the folded dipole since it increases the width dimension of the antenna without increasing the wind resistance. This permits it to respond to a wider band of frequencies. The reflector could be conical also.

When the antennas are placed one above the other, they are said to be "stacked." This method of construction increases the vertical directivity. If two dipoles were stacked, the radiation pattern would no longer be a doughnut but would consist of two beams in opposite directions. Nothing is lost since no station exists above or below the antenna. Using reflectors with the stack (Fig. 14D) produces a one-beam radiation pattern.

TV ANTENNAS

TV receivers tune in stations from 54 megahertz to 890 megahertz. This is done in three bands:

Low VHF	(channels 2 - 6), 54 to 88 MHz
High VHF	(channels 7 - 13), 174 to 216 MHz
UHF	(channels 14 - 83), 470 to 890 MHz.

Each station requires a channel of 6 MHz and includes two signals:

Video (picture)
Audio (sound)

The picture RF signal is AM, and the audio RF signal is FM. The audio signal utilizes 50 kHz of the 6 MHz channel, whereas the video signal takes about 5.25 MHz of the channel. About 250 kHz of the channel is not utilized; this serves as a guard band (prevents interference between close signals). The above is unchanged for color telecasts; the color information

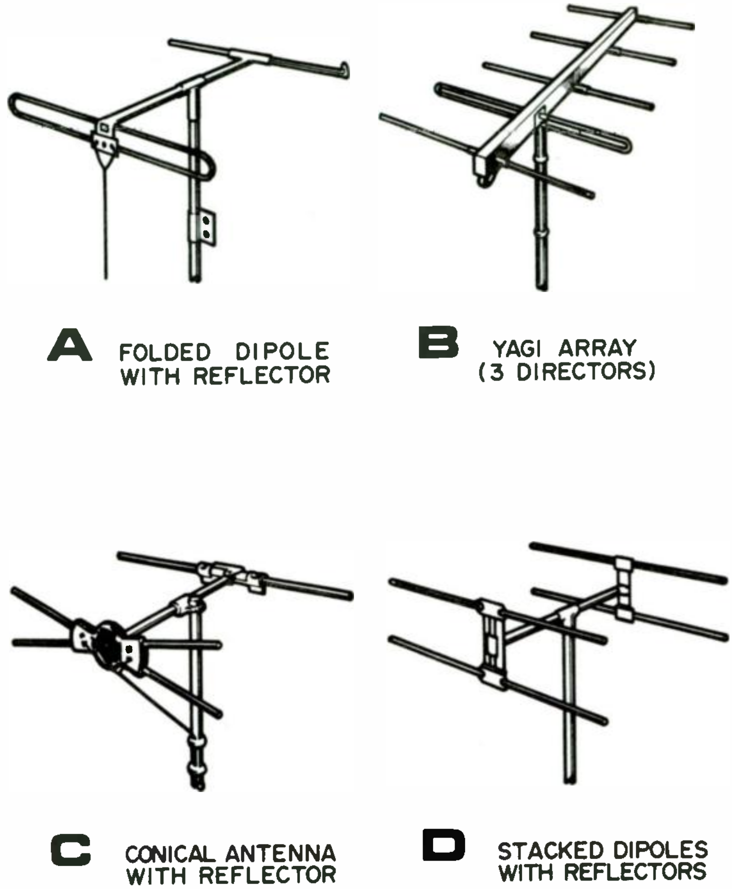


Figure 14 - Popular receiving antennas (VHF).

is sent within the video portion of the channel.

A single folded dipole is adequate for channels 7 through 13. This would be the short folded dipole of Figure 15A. The long folded dipole covers channels 2 through 6; there is a reflector for this band. The folded dipoles are said to be "in-line."

A "piggy-back" arrangement is another way of mounting dipoles for both VHF bands. A high-band folded dipole and reflector are mounted above the low-band antenna (Fig. 15B). The transmission line would be connected to both folded dipoles. With the reflectors, reception is possible from only one direction; from the side of the folded dipoles and perpendicular to them.

A stacked low-band antenna with reflectors (Fig. 15C) and a piggy-back high-band antenna is a popular TV antenna for the VHF channels. Since the high-band elements are smaller, both a director and reflector can be used without greatly increasing the overall dimensions. The transmission line is connected only to the folded dipoles.

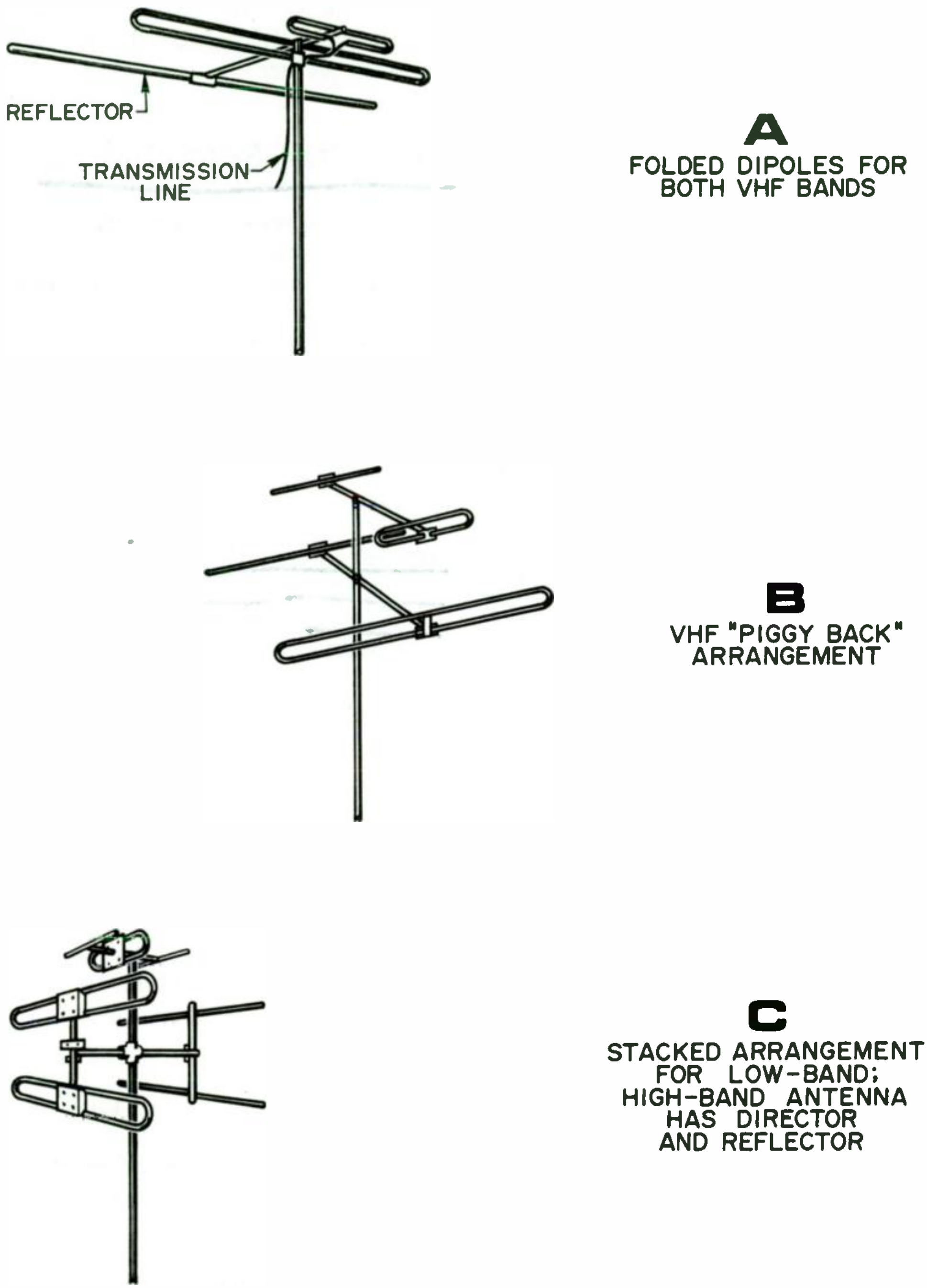


Figure 15 - Typical VHF TV antennas.

The dipole elements for UHF antennas are quite small, so more elaborate arrays can be used without having overly large dimensions. Consequently, stacked arrangements and/or a larger number of directors and reflectors are used. Occasionally, parabolic reflectors are used for UHF; the action of these is comparable to the reflector of an auto headlamp or a flashlight. They are built from tubing or rigid wire in order to minimize the wind resistance.

A well-designed monochrome (black and white) TV antenna will perform well as a color TV antenna. The only special requirement of an antenna for use in color television reception is for high gain and a full 6-MHz bandwidth. Some poorly designed antennas used for monochrome television reception do not pass the full 6-MHz bandwidth of the received signal. This does not affect the black-and-white picture reproduction. A reduced bandwidth will severely attenuate the color signals contained in a color television broadcast and can result in a complete loss of color in the color television picture.

If the TV stations are relatively distant, an indoor TV antenna will not be adequate and an antenna similar to those just discussed would be used. A disadvantage of an outdoor antenna is that it is subject to deterioration because of weathering. Also, it is not a simple task to inspect the antenna or the connections to it. This disadvantage can sometimes be overcome by installing the antenna in an attic or on the ceiling of a porch. In this way, weathering of the antenna is eliminated. Also, for isolated and exposed homes or homes on hills, the possibility of lightning striking the antenna is eliminated. However, if the signal received is weak, then a high outdoor antenna must be used. A weak signal is indicated by "snow" on the face of the picture tube. Also, there will be a poor grade of contrast (difference between the blacks and whites) in the received picture.

ANTENNA SENSITIVITY

A dipole will receive equally well from the front and the back. When a reflector is used, the ability to receive from the back is reduced, while the signal from the front has increased. We say that we have increased the "sensitivity" of the antenna. Using both a director and a reflector increases the sensitivity from the front direction even more (at the expense of sensitivity from the back). When several directors and reflectors make up the antenna array, the sensitivity is further increased. Whenever the directivity of an antenna increases, so does its sensitivity. A directional antenna will be very sensitive. When an antenna is highly directional, the exact orientation of the antenna and the tilt of the antenna mast can be critical. During installation, the receiver performance can be observed while the antenna is rotated and tilted in order to find the best position. Two people are required to perform this. One observes the receiver performance while the other adjusts the antenna.

MOBILE-TYPE ANTENNAS

Mobile antennas are antennas for car radios. Portable antennas are also included in this category.

A car radio must have some type of antenna because the metallic auto body acts as a shield and does not permit a loop antenna to function

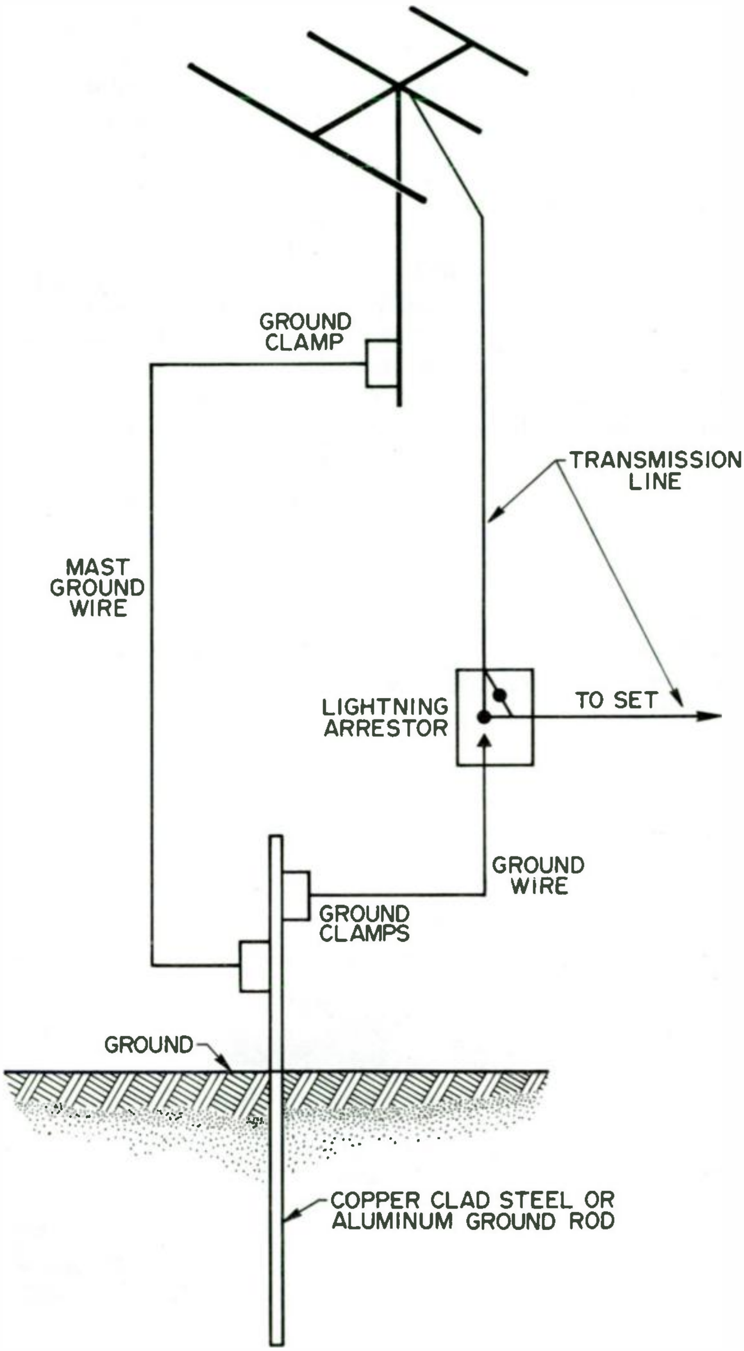


Figure 16 - Installation of lightning arrestor.

effectively. Since the wavelength is large for radio frequencies, an inductance is usually connected in series to increase the electrical length of the antenna. These coils are referred to as loading coils.

Portable antennas can be used for FM and TV when built-in antennas are not used or are inadequate. TV receivers, especially for channels 2 through 6 (VHF low-band), usually require portable or outdoor antennas. Some cabinets are large enough to house built-in antennas for VHF. These antennas are usually adequate for strong and nearby stations.

LIGHTNING ARRESTOR

When high outdoor antennas are installed on homes that are isolated or on hills, there is a possibility that the antenna or antenna mast can be struck by lightning. A lightning arrestor is used to prevent the lightning from entering the home. The arrestor (Fig. 16) is placed where the transmission line enters the home. This often is at a window sill. If lightning struck the antenna and passed along the transmission line, the lightning arrestor provides a path for the lightning to ground. If the antenna mast is metallic, a wire is attached to the mast and also to a metal rod driven into the earth. This ground rod is driven into the earth to a depth of four to six feet. The ground wires should be of copper or aluminum number 8 or larger (number 7 or number 6). The transmission line and mast ground wire should be secured to the home with standoff insulators.

TRANSMISSION LINES

A transmission line (or antenna

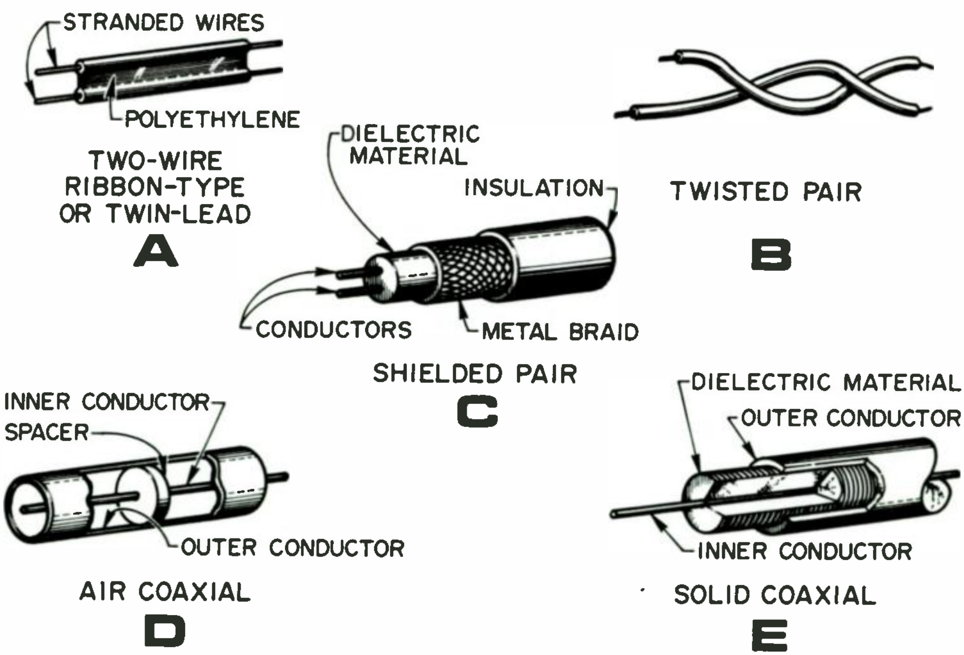


Figure 17 - Transmission lines for FM and TV.

feedline) conducts or guides electrical energy from the receiving antenna to the receiver. Of primary importance in the study and application of transmission lines is the characteristic impedance of the line.

A transmission line has inductance and capacity even though no inductors or capacitors have been wired into the line. This distributed inductance (of the wire) and capacity (between the wires) cannot be separated from one another. All transmission lines do not have the same inductance or capacity per foot of line because of the different ways of constructing transmission lines (Fig. 17).

It has been found that AC voltages and currents take time to travel along a line. If the electrical energy is not absorbed at the same rate that it is sent along the line, *reflections* will occur. Reflections on a transmission line will result in distortion of the received signal because the same signal can enter the receiver several times, but at delayed intervals.

To eliminate reflections, the transmission line must be connected to the proper value of impedance. The proper value of impedance varies with each type of line and is known as the *charracteristic impedance* or *surge impedance*. When the line is connected to its characteristic impedance, it behaves as though it were of infinite length. No reflections can occur on a line of infinite length since it would take an infinite time for the voltage and current to get to the end of the line. Strictly speaking, a transmission line guides electromagnetic waves, and if the end of the line is connected to its characteristic impedance, then all of the electrical energy is absorbed and none reflected. The surge impedance of a line is determined by the inductance and capacity per foot of line. The ribbon type line (Fig. 17A) is commonly made with two characteristic impedance values, 300 ohms and 75 ohms. The 300 ohm line is about one-half inch wide and is made of stranded wire. Because the wires are imbedded in only a thin ribbon of polyethylene, the dielectric is partly air and partly polyethylene. Moisture or dirt will change the characteristic impedance of the line. This effect becomes more serious if the line is not terminated in its characteristic impedance. The wires of the 75 ohm line are closer, and the field between the wires is confined largely to the dielectric. Weather and dirt will affect this line less than they affect the 300 ohm line.

A "twisted pair" is shown in Figure 17B. As the name implies, a twisted pair consists of two insulated wires twisted to form a flexible line. The twisted pair is not used for the higher frequencies because of the high losses occuring in the rubber insulation. When the line is wet, the losses increase greatly. The characteristic impedance of such lines is about 100 ohms, depending on the type of cord used.

The *shielded pair* (Fig. 17C) consists of two parallel conductors separated from each other and surrounded by a solid dielectric. The conductors are contained within a copper braid tubing that acts as a shield. This assembly is covered with a rubber or flexible composition coating to protect the line against moisture and friction. Outwardly, it looks much like an ordinary power cord for an electric motor. The principal advantage of the shielded pair is that the two conductors are balanced to ground; that is, the capacitance between each conductor and ground is uniform along the entire length of the line and the wires are shielded against pickup of stray fields. This balance is affected by the grounded shield that surrounds the conductors at a uniform spacing throughout their length. This type of line is built with a variety of impedances. The electrical losses are higher than for the other types so that its use is restricted to locations bothered by electrical noise.

The chief advantage of the coaxial line (Figs. 17D and 17E) is its ability to keep down radiation losses and noise pickup. In a coaxial line, no electric or magnetic fields extend outside the outer conductor. They are confined to the space between the two conductors. Thus, the coaxial line is a perfectly shielded line. Impedances vary from 50 to 150 ohms, with 72 ohms being most common. The type shown in Figure 17E is very flexible and is commonly used for FM and TV. However, the twin-lead line (Fig. 17A) is most common due to its lower cost. Most TV and FM antennas and receivers are equipped for twin-lead connections of 300 ohms. Some receivers have alternate 72 ohm terminals for coaxial line.

MATCHING DEVICES

In an ideal installation, three impedances are identical:

Antenna impedance.
Transmission line impedance.
Receiver impedance.

For example, they all might be 300 ohms. If the impedances are not the same, two things occur:

There is a loss of signal strength.
Reflections appear.

When the impedances are not the same, we say that there is a "mismatch." Thus, two mismatches are possible:

At the antenna (between line and antenna).
At the receiver (between line and receiver).

If there is a mismatch only at the receiver, no distortion can occur since the reflected signal from the receiver will be radiated into space by the antenna. However, there is loss of signal strength. If there is a mismatch only at the antenna, no distortion can occur since there will be no reflections at the receiver; the entire signal is being received from the line when the line is matched to the receiver. Again, there is some loss of signal strength due to the mismatch at the antenna. However, when there is a mismatch at the antenna and at the receiver, then distortion will occur.

The reflections at the receiver are again reflected at the mismatch at the antenna; thereby signals return to the receiver as a repeated, but delayed input. A longer line will delay the signal more than a short line. The distortion might not be noticeable when there is a long transmission line because the losses are greater in a long line and can completely dissipate the reflected energy.

Matching devices are available to eliminate mismatches between the line and antenna or the line and the receiver. These are called matching transformers and are made up of coils and capacitors. Receiver performance is the final test. When there is adequate signal strength, a single mismatch may not affect performance enough to warrant installing a matching transformer. For example, a 300 ohm antenna might be connected to a 75 ohm line. If the receiver has 72 ohm terminals, there is only one mismatch, and the installation may give satisfactory receiver performance. A matching device for this example would have two pairs of terminals; one would be marked 75 (or 72) ohms and the other, 300 ohms. The 300 ohm antenna would be connected to the 300 ohm terminals so that maximum signal power would be fed into the line. The 75 ohm line would be connected to the 75 (or 72) ohm terminals. Now, there would no longer be a mismatch at this end of the line.

When a receiver is located in the fringe area of TV or FM reception, a mismatch could prevent reception. Then, not only should mismatches be avoided, but also the antenna orientation should be carefully set. In this way it is possible to receive a signal that otherwise would have been impossible to receive. Mismatches produce a signal loss because maximum energy is not being transferred.

RADIO WAVES

A radio-frequency current flowing in a wire (antenna) of a finite length can produce electromagnetic fields that may be disengaged from the wire and set free in space. The principles of the radiation of electromagnetic energy are based on the laws that a moving electric field creates a *magnetic field*, and conversely, a moving magnetic field creates an *electric field*. The created field (either electric or magnetic) at any instant is in phase in time with its parent field, but is perpendicular to it in space. These laws hold true whether or not a conductor is present. The electric (E) and magnetic (H) fields are perpendicular to the direction of motion through space.

When a radio wave leaves a vertical antenna, the field pattern of the wave resembles a huge doughnut lying on the

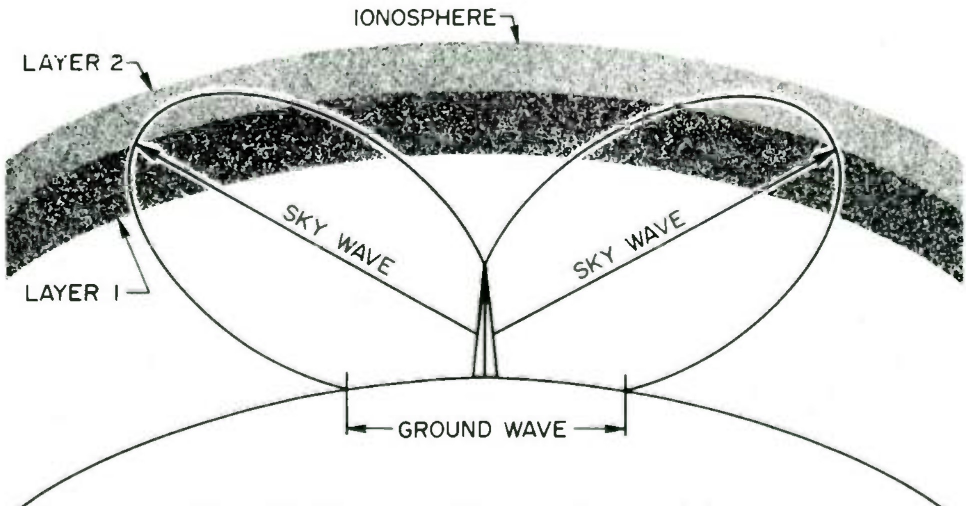


Figure 18 - Formation of the ground wave and sky wave.

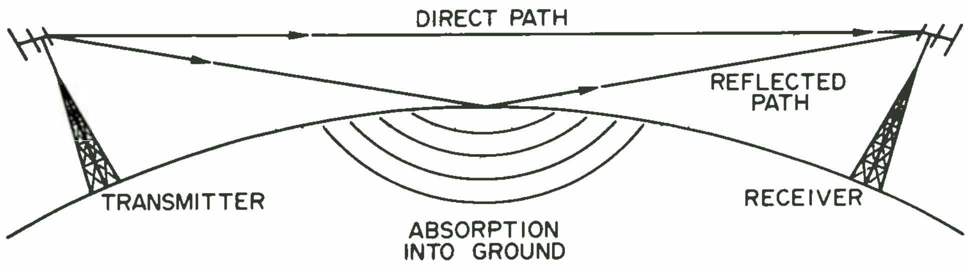


Figure 19 - Possible routes of ground and space waves.

ground with the antenna in the hole at the center. Part of the wave moves forward in contact with the ground to form the *GROUND WAVE*, and the rest of the wave moves upward and outward to form the *SKY WAVE*, as shown in Figure 18. Both waves are used by radio receivers. FM and TV receivers use only the sky wave, because the transmitter antennas are elevated and the frequencies are so high that there are no practical ground waves.

The ground wave is commonly considered to be made up of two parts, a surface wave and a space wave. The surface wave travels along the surface of the earth. The space wave travels in the space immediately above the surface of the earth in two paths: one directly from transmitter to receiver, and the other on a path in which the space wave is reflected from the ground before it reaches the receiver (Fig. 19). The space wave follows two paths of different lengths, therefore the two components may arrive in or out of phase with each other. As the distance from the transmitter is changed, these two components may add or they may cancel. Neither of these component waves is affected by the reflecting layer of atmosphere high above the surface of the earth, called the IONOSPHERE. The space wave part of the ground wave becomes more important as the frequency is increased or as the transmitter and receiver antenna height is increased.

The surface wave part of the ground wave is responsible for most of the daytime broadcast reception. As it passes over the ground, the surface wave induces a voltage in the earth, setting up eddy currents. The energy to establish these currents is absorbed from the surface wave, thereby weakening it as it moves away from the transmitting antenna. Increasing the frequency rapidly increases the attenuation so that surface wave communication is limited to relatively low frequencies. Since the electrical properties of the earth, along which the surface wave travels, are relatively constant, the signal strength from a given station at a given point is nearly constant. This holds true in nearly all localities except those that have distinct rainy and dry seasons. In those locations, the difference in the amount of moisture causes the conductivity of the soil to change. The conductivity of salt water is 5,000 times as great as that of dry soil. High-power low-frequency transmitters are placed as close to the edge of the ocean as practical because of the superiority of surface wave conduction by salt water.

That part of the radio wave that moves upward and outward and that is not in contact with the ground is called the SKY WAVE. It behaves differently from the ground wave. Some of the energy of the sky wave is refracted (bent) by the ionosphere so that it comes back toward the earth. A receiver located in the vicinity of the returning sky wave will receive strong signals even though it is several hundred miles beyond the range of the ground wave. FM and TV signals are not appreciably refracted by the ionsphere because at VHF frequencies, and higher, there is practically only line-of-sight transmission and reception.

The ionosphere is found in the thin atmosphere approximately 40 to 350 miles above the earth. It differs from the other atmosphere in that it contains a much higher number of positive and negative ions. The negative ions are believed to be free electrons. The ions are produced by the ultraviolet and particle radiations from the sun. The rotation of the earth on its axis, the annual course of the earth around the sun, and the development of sun spots all affect the number of ions present in the ionosphere, and these in turn affect the quality and distance of radio transmission.

The ionosphere is constantly changing. Some of the ions are recombining to form neutral atoms, while other atoms are being ionized by the removal of electrons from their outer orbits. The rate of formation and recombination of ions depends upon the amount of air present and the strength of radiation from the sun.

At altitudes above 350 miles, the particles of air are too sparse to permit large scale ion formation. Below about 40 miles altitude, only a few ions are present because the rate of recombination is so high. Ultraviolet radiations from the sun are absorbed in passage through the upper layers of the ionosphere, so that below an elevation of 40 miles, too few ions exist to affect skywave communication.

Densities of ionization at different heights make the ionosphere appear to

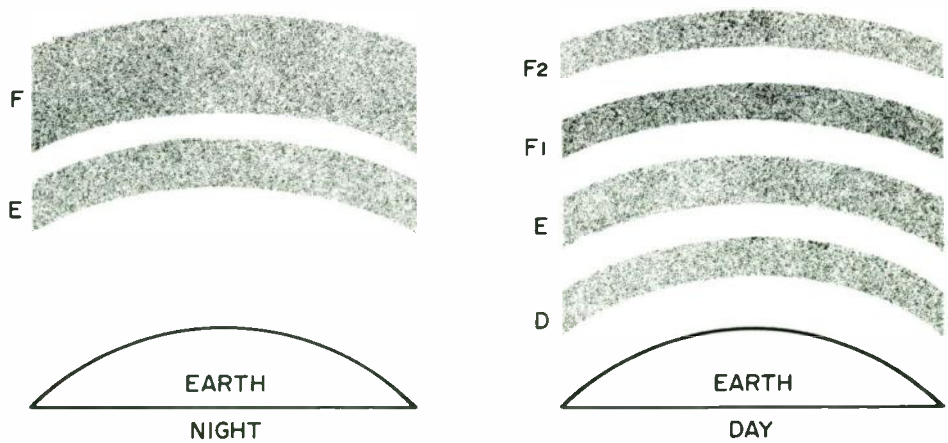


Figure 20 - D, E, and F layers of the ionosphere.

have layers. Actually there is thought to be no sharp dividing line between layers but, for the purpose of discussion, a sharp separation is shown (Fig. 20).

The ionized atmosphere at an altitude of between 40 and 50 miles is called the D layer. Its ionization is low and it has little effect on the propagation of radio waves except for the absorption of energy from the radio waves as they pass through it. The D layer is present only during the day.

The band of atmosphere at altitudes between 50 and 90 miles contains the E layer. It is a well defined band with greatest density at an altitude of about 70 miles. This layer is strongest during the daylight hours and is also present but much weaker at night. The maximum density of the E layer appears at about noon local time.

The ionization of the E layer at the middle of the day is sometimes sufficiently intense to refract frequencies up to 20 MHz back to the earth. This action is of great importance to daylight transmissions for distances up to 1,500 miles.

The F layer extends approximately from the 90 mile level to the upper limits of the ionosphere. At night, only one F layer is present; but during the day, especially when the sun is high, this layer often separates into two parts, F_1 and F_2, as shown in Figure 20. As a rule, the F_2 layer is at its greatest density during early afternoon hours, but there are many notable exceptions of maximum F_2 density existing several hours later. Shortly after sunset, the F_1 and F_2 layers recombine into a single F layer.

The ionosphere has many characteristics. Some waves penetrate and pass entirely through it into space, never to return. Other waves penetrate but bend. Generally, the ionosphere acts as a conductor and absorbs energy in varying amounts from the radio wave. The ionosphere also acts as a radio mirror and refracts (bends)

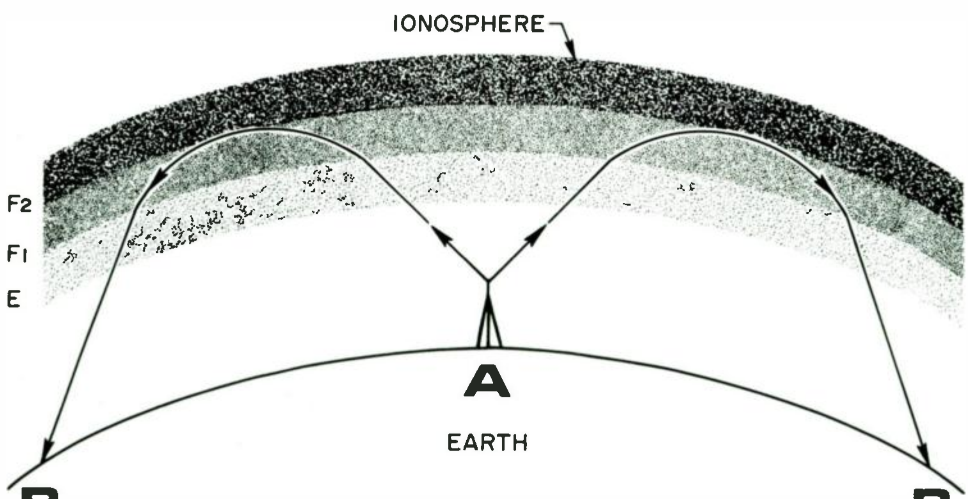


Figure 21 - Refraction of sky waves by the ionosphere.

the sky wave back to the earth, as illustrated in Figure 21. Here, the ionosphere does by refraction what water does to a beam of light.

The ability of the ionosphere to return a radio wave to the earth depends upon the angle at which the sky wave strikes the ionosphere, the frequency of the transmission, and ion density.

When the wave from an antenna strikes the ionosphere at an angle, the wave begins to bend. If the frequency is correct (and the ionosphere is sufficiently dense and the angle is proper), the wave will eventually emerge from the ionosphere and return to the earth. If a receiver is located at either of the points B (Fig. 21), the transmission from point A will be received. The antenna height in the figure is not drawn to scale. The tallest antennas are not over 1,000 feet in height.

The increased ionization during the day is responsible for several important changes in sky wave transmission. It causes the sky wave to be returned to the earth nearer to the point of transmission. The extra ionization increases the absorption of energy from the sky wave; if the wave travels a sufficient distance into the ionosphere, it will lose all of its energy.

A radio wave may be refracted many times between the transmitter and receiver locations, as shown in Figure 22. In this example, the radio wave strikes the earth at location A with sufficient intensity to be reflected back to the ionosphere and there to be refracted and returned to the earth a second time. Frequently, a sky wave has sufficient energy to be refracted and reflected several times, greatly increasing the range of transmission. Because of this multiple-hop transmission, transoceanic and around-the-world transmission is possible with moderate power.

Fading is a term used to describe the variations in signal strength that occur at the receiver during the time a signal is being received. Variations in absorption and in the length of the

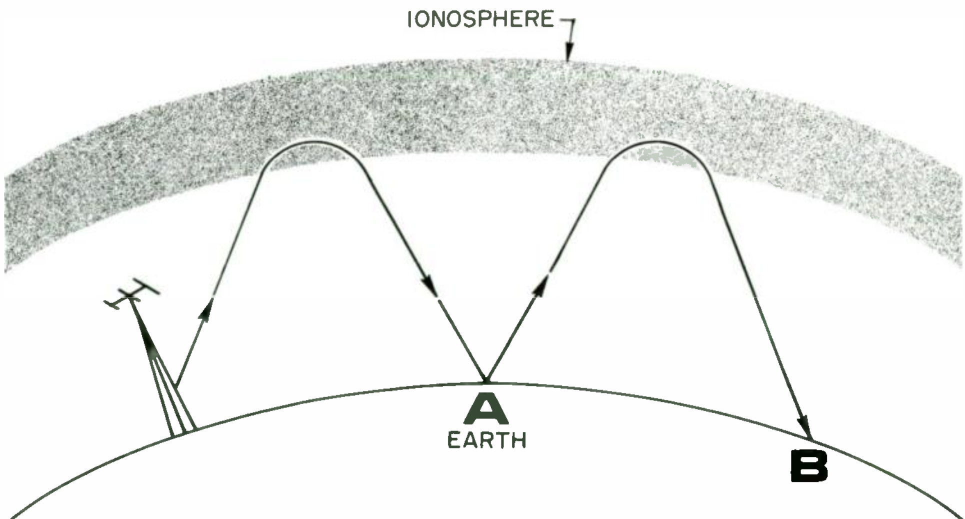


Figure 22 - Multiple refraction and reflection of a sky wave.

path in the ionosphere are responsible for fading. Occasionally, sudden disturbances in the ionosphere cause complete absorption of all sky wave radiation providing that it was not line-of-sight reception, because there can be very little interference with line-of-sight operation.

SUMMARY

A transmitting antenna has inductance and capacity that is distributed in space. This makes it possible for an electromagnetic field to leave the antenna. In turn, the electromagnetic field causes voltage and current to appear in a receiving antenna.

VHF frequencies range from 30 MHz to 300 MHz while UHF frequencies range from 300 MHz to 3,000 MHz. Early concepts suggested that VHF and UHF transmissions traveled in straight lines. This leads to the assumption that the UHF or VHF transmitter and receiver must be within sight of each other in order to make contact. Extensive use and additional research show the early line-of-sight theory to be frequently in error because radio waves at these frequencies may be refracted. The receiver does not always have to be in sight of the transmitter. Although this type of transmission still is called line-of-sight transmission, it is better to call it VHF and UHF transmission. In general, the VHF and UHF waves follow approximately straight lines, and large hills or mountains cast a radio shadow over these areas in the same way that they cast a shadow in the presence of light rays. A receiver located in a radio shadow will receive a weakened signal and, in some cases, no signal at all. Theoretically, the range of contact is the distance to the horizon, and this distance is determined by the heights of the two antennas. However, communication is sometimes possible for hundreds of miles beyond the assumed horizon range.

Wave propagation through the atmosphere provides the link between transmitter and receiver. Roughly, this can be compared with transformer action; the transmitter antenna is the primary, and the receiving antenna is the secondary.

A dipole or any other antenna has the same antenna pattern and directivity for transmission as for reception. This fact simplifies the study of antennas.

Modern radios for broadcast reception do not require elaborate antennas because most stations transmit a very powerful signal. If it were not for this fact, broadcast radios would contain many more circuit parts and long outdoor antennas would be necessary. Similarly, present day FM and TV stations also transmit powerful signals, thus making built-in and portable antennas adequate for many locations. However, when outdoor antennas are called for, they can be technical works of art, because dipole dimensions are realizable (they are not realizable for broadcast).

The purchasing and installation of an appropriate external antenna, when required, actually presents little difficulty. Manufacturers now supply an antenna system for almost any situation you may encounter. They come with easily understood instructions for installation in every conceivable location. Good reception is a matter of choice and your local supplier is always there to help you choose correctly.

TEST

Lesson Number 33

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 52-033-1.

1. Another name for a dipole antenna is
   - A. Hertz antenna.
   - B. long-wire antenna.
   - C. eighth-wave antenna.
   - D. quarter-wave antenna.

2. The impedance at the center of a dipole is
   - A. 10 ohms.
   - B. 72 ohms.
   - C. 156 ohms.
   - D. 200 ohms.

3. Which of these TV channels would have the longest wavelength?
   - A. Channel 2.
   - B. Channel 11.
   - C. Channel 18.
   - D. Channel 68.

4. Which of the following antennas would be the most sensitive?
   - A. The simple dipole.
   - B. A dipole used with a reflector.
   - C. A dipole used with a director.
   - D. A dipole used with several reflectors and directors.

5. What is the velocity of a radio wave?
   A. 60 miles per hour.
   B. 186,000 miles per hour.
   C. 300,000,000 meters per second.
   D. 300,000,000 centimeters per second.

6. Which is the lowest layer of the ionosphere?
   A. D
   B. E
   C. F1
   D. F2

7. Refraction is the same as
   A. bending.
   B. amplification.
   C. rectification.
   D. straightening.

8. A mismatch at a transmission line can cause
   A. signal detection.
   B. signal modulation.
   C. losses and distortion.
   D. a new antenna pattern.

9. A loop antenna is satisfactory for many radio receivers because
   A. it is a dipole.
   B. it uses a reflector.
   C. it is a half-wave antenna.
   D. many station signals are powerful.

10. To receive a radio frequency of 100 MHz, the length required of a dipole antenna is
   A. 8.2 ft.
   B. 4.92 ft.
   C. 2.46 ft.
   D. 49.2 ft.

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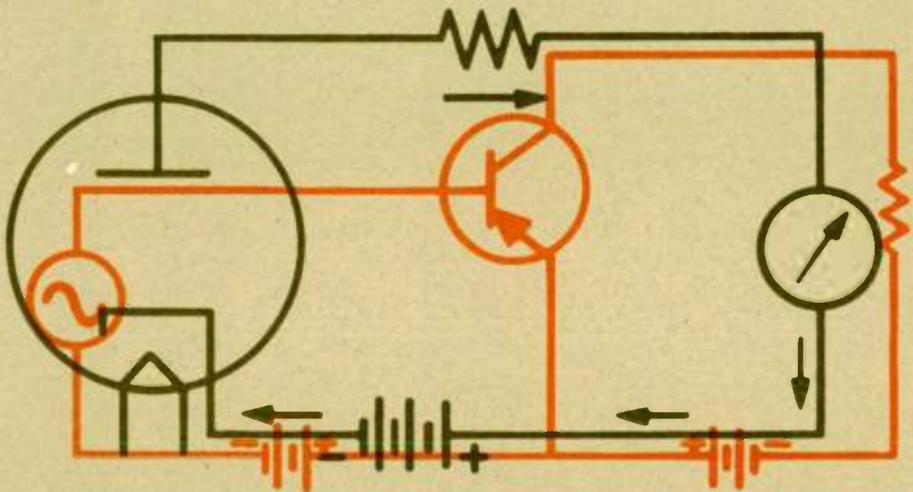
LESSON NO. 34

REVIEW FILM LESSONS 30-33 BOOKLET



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-034
412

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

Revised September 1973
Reprinted December 1974

REVIEW FILM TEST

Lesson Number 34

The ten questions enclosed are review questions of lessons **30, 31, 32, & 33** 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 34

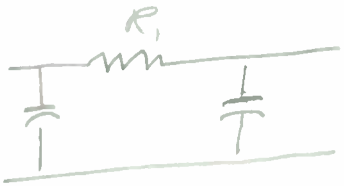
IMPORTANT

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 52-034-1.

1. In a resonant tank circuit with the magnetic field about the inductance collapsing, the capacitance is
   A. neutral.
   B. steady.
   C. charging.
   D. dis-charging.

2. The Q of a resonant circuit is expressed as
   A. $Q = X_L \cdot R$
   B. $Q = X_L/R$
   C. $Q = R/X_L$
   D. $Q = X_L/X_C$

3. The purpose of a filter network connected to the output of a rectifier circuit is to
   A. produce a pure AC sine wave.
   B. provide a high impedance load for the rectifier.
   C. produce a square wave output.
   D. remove the AC ripple.



4. A multivibrator always
   A. has a sine wave output.
   B. has unity gain.
   C. has two tubes or transistors.
   D. has high voltage output.

5. The output of the schmitt trigger is
   A. a square wave.
   B. a sawtooth wave.
   C. a sine wave.
   D. none of the above.

6. The output of a differential amplifier is
   A. the sum of the two input signals.
   B. the difference between two input signals.
   C. two signals 180° out of phase with each other.
   D. a signal 180° out of phase with the input signals.

7. The Colpitts oscillator can be identified by
   A. two capacitors having a 10 to 1 ratio across a coil.
   B. the type of tube or transistor used.
   C. the output waveform.
   D. all of the above.

8. The electron-coupled oscillator
   A. uses PNP transistors only.
   B. uses NPN transistors only.
   C. utilizes the interelectrode capacitance of the transistors.
   D. cannot be transistorized.

9. Most TV and FM antennas are the
   A. Macaroni type.
   B. Hertz type.
   C. folded dipole type.
   D. fringe type.

10. Electrically grounding a mobile antenna is accomplished by using
    A. a counterpoise.
    B. a capacitor network.
    C. an inductive network.
    D. a ground strap.

Notes

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EDUCATION

Daniel Webster once said . . .

"The human intellect can only grow by its own action. Every man must, therefore, educate himself. His books and teachers are but helps; the work is his. A man is not educated until he has the ability to summon, in an emergency, his mental powers in vigorous exercise to effect its proposed object."

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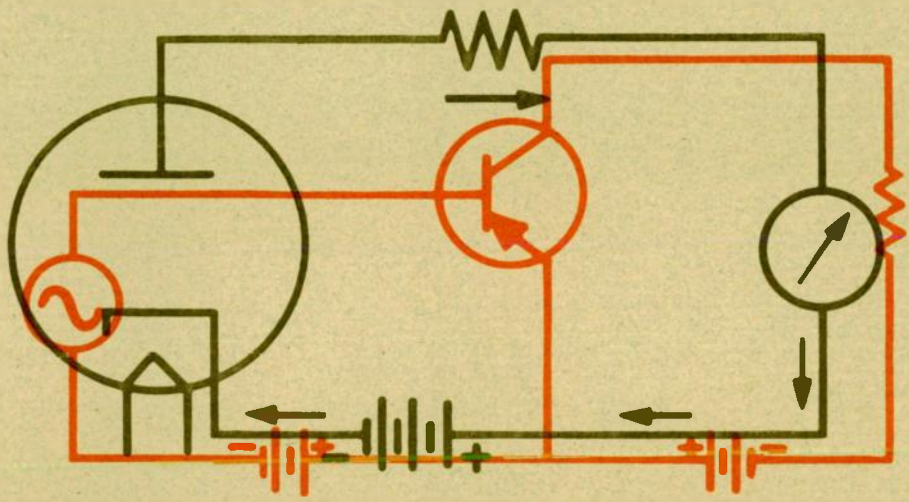
The success you have is up to you. We hope that what you learn from your ASI training "sticks by" to help you achieve the success you want in life.

S. T. Christensen

LESSON NO. 35

AMPLITUDE MODULATION



RADIO and TELEVISION SERVICE and REPAIR

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CONTENTS

AMPLITUDE MODULATION

INTRODUCTION

Amplitude modulation is the transmitting system that varies the amplitude of the RF carrier of a transmitter at an audio rate. It is the RF energy that increases and decreases in accordance with the energy delivered by the audio modulator. When the audio frequency is high, the radio frequency varies in amplitude more rapidly than when the audio frequency is low. Also, when the audio signal is loud in volume, the RF energy is increased and decreased by a larger percentage than if the audio signal is soft.

RF CARRIER

When the RF carrier is not being modulated by an audio signal, the radio station is transmitting this RF energy at the frequency assigned to it by the FCC. This unmodulated carrier is a continuous wave (CW) signal that occupies essentially no bandwidth in the radio frequency spectrum. This carrier frequency is always represented as a thin, vertical line on a graph that plots amplitude versus frequency (Fig. 1A). When this carrier is modulated by audio frequencies, they produce what is known as upper and lower sideband frequencies (Fig. 1B). Although it might appear that the direct transmission of electromagnetic waves at audio frequencies would be a simple method, a review of such a simple system will show why it is not feasible.

AUDIO FREQUENCIES

Audio frequencies extend from 20 hertz to 20,000 hertz as shown by the audio frequency spectrum in Figure 2. The human voice extends from about 87 hertz to 1175 hertz. The violin has a range of approximately 200 hertz to 3000 hertz and the bass viol extends from approximately 40 hertz to 250 hertz. The pure tones of the piccolo extend to about 5000 hertz. However, combinations of sound frequencies produce harmonics that extend up to 20,000 hertz. These combinations of frequencies give to speech or music the identifying characteristics that distinguish one person from another and one type of musical instrument from another.

It is not practical to transmit an electromagnetic wave in this low frequency range. Electromagnetic waves at these audio frequencies have

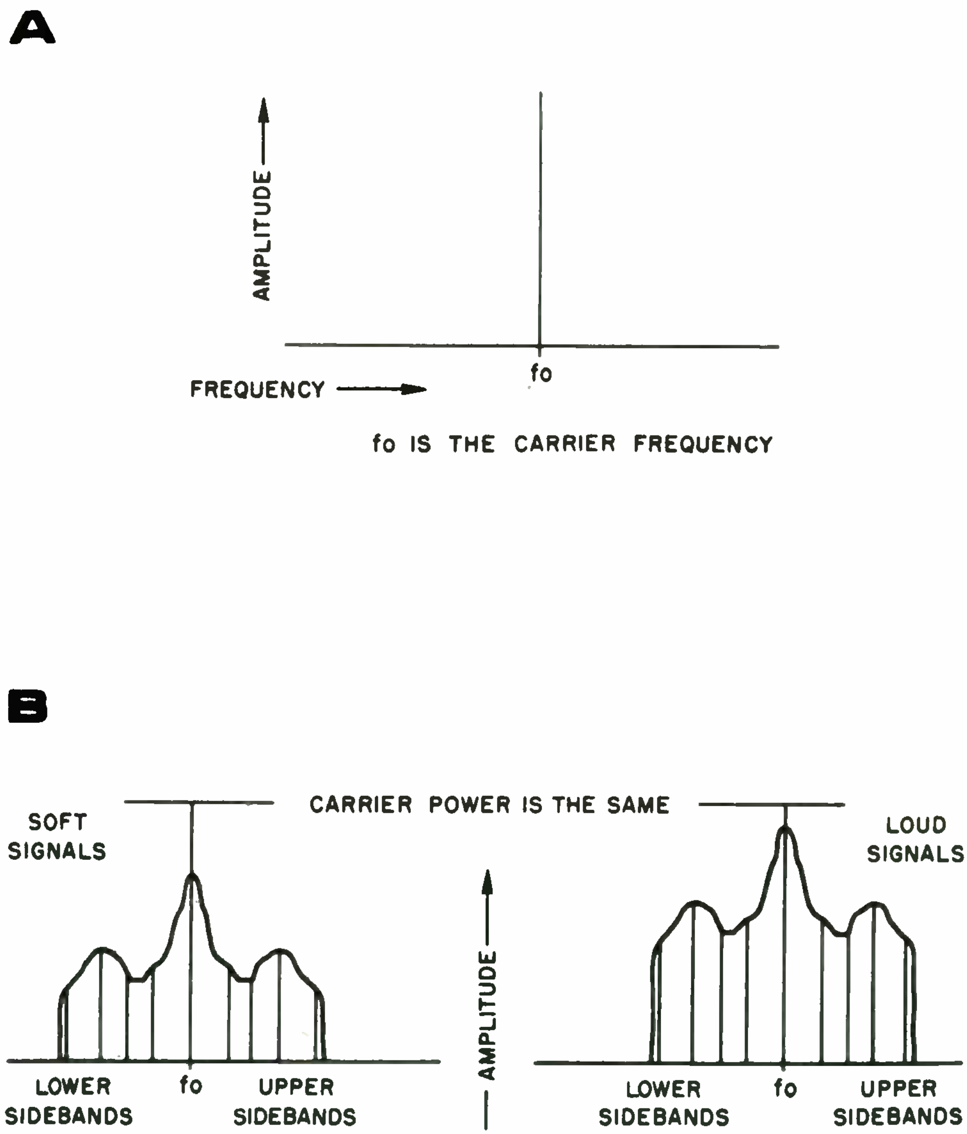


Figure 1 - Sidebands extend equally either side of the carrier frequency. Louder signals have a greater amplitude than softer signals.

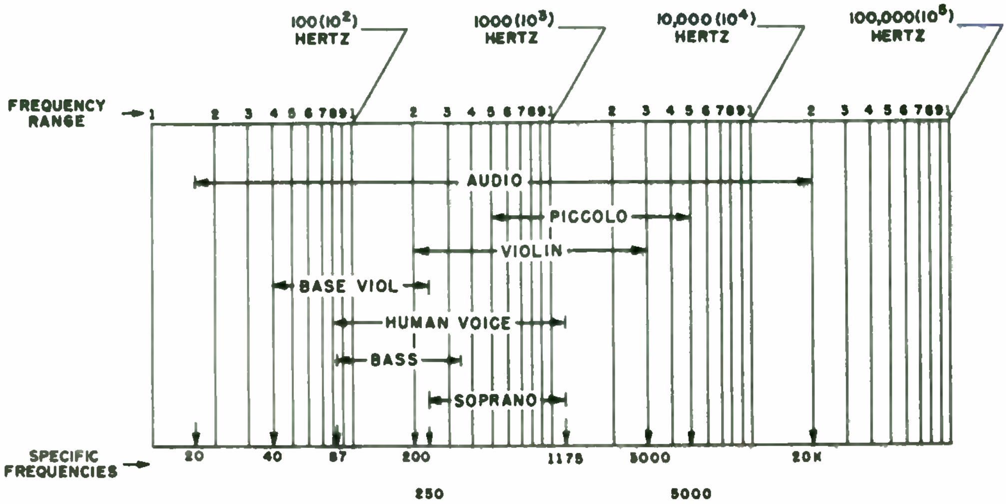


Figure 2 - The audio frequency spectrum, and an illustration of the specific frequency ranges of human voices and musical instruments.

poor transmission characteristics because:

1. the range of such transmission would be very limited because of the poor radiation efficiency of antennas at these low audio frequencies;
2. all transmitters would operate in the same frequency range, and therefore the signals could not be separated in the receivers;
3. the antennas would have to be excessively long to be in resonance at the middle frequency in the audio range (it follows that the antenna would be considerably out of tune at the end frequencies); and
4. the inductors and capacitors would have to be very large in order to produce resonance at these low frequencies.

The problems of poor transmission at audio frequencies may be overcome by the use of a modulated RF carrier at the transmitter. Such a system, however, requires a method of removing the modulation at the receiver. The efficiency of radiation is improved by this system, as each carrier with its associated modulation component is confined to a relatively narrow band in the RF spectrum. The interference that does exist between stations is tolerable even though it might still be a problem in certain instances.

SIDEBANDS

An analysis of the generation of sidebands by using an audio tone of a single frequency will show that three separate radio waves are produced (Fig. 3).

The lower sideband has a frequency equal to the difference between the modulating and carrier frequency and is shown directly above the carrier.

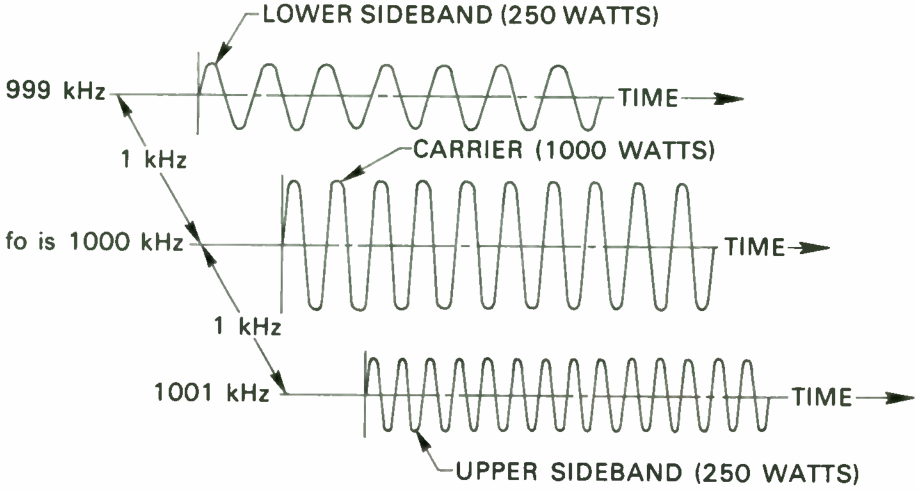


Figure 3 - When the audio modulating frequency is 1 KHz, two sidebands are generated that are located 1 KHz above and below the carrier frequency of 1000 KHz.

The upper sideband has a frequency equal to the sum of the carrier and modulation frequency and is shown below the carrier. The carrier and the sidebands are not merely mathematical abstractions, as they may be separated from one another by filters and used individually.

In an AM wave, only the sidebands contain the intelligence to be transmitted; the audio frequency as such is not transmitted. Because the audio frequencies (that modulate the carrier) contain the information to be transmitted, as much power as possible should be put into the sidebands. In other words, the amplitude of the carrier wave during modulation should be varied as much as possible (up to 100 percent). Lesson 16 on Modulation and Demodulation explained that 100 percent modulation is the maximum amount allowable. Any amount of modulation less than 100 percent produces weak sidebands, while any amount of modulation greater than 100 percent will produce a distorted audio signal.

BANDWIDTH

Because an AM wave has sidebands on each side of the carrier, the transmission of information by amplitude modulation requires the use of a band of frequencies rather than a single frequency. Music may contain frequency components as high as 15,000 hertz, so that music modulated upon a carrier would produce sideband components extending to

15,000 hertz on each side of the carrier frequency.

Local AM broadcast stations are allocated a total bandwidth of only 10 kHz (5 kHz on each side of the carrier frequency) because of the large number of stations on the air. Since the total bandwidth is only 10 kHz, audio frequencies above 5 kHz cannot be transmitted without causing interference between stations.

MODULATION METHODS

A block diagram of an AM transmitter contains an RF section, an AF section, and the DC supply that powers the entire system (Fig. 4). The RF section generates the high-frequency carrier radiated by the antenna. The carrier frequency is generated at a low level in the oscillator, and amplified in the buffer amplifier. The AF section includes a speech amplifier that receives a few millivolts of audio signal from the microphone and amplifies it to several volts for input to the driver stage. The driver stage is made up of power amplifiers that convert the signal into a relatively large voltage with appreciable current at the input to the modulator. The modulation transformer is capable of handling considerable audio power. Its output is fed to the final RF power amplifier in a way that alternately adds to and subtracts from the plate voltage of the RF amplifier.

The result is that the amplitude of the RF field at the antenna is gradually increased in strength during the time the audio output is increasing the RF carrier power and gradually decreased in strength during the time the audio output is decreasing the RF carrier power.

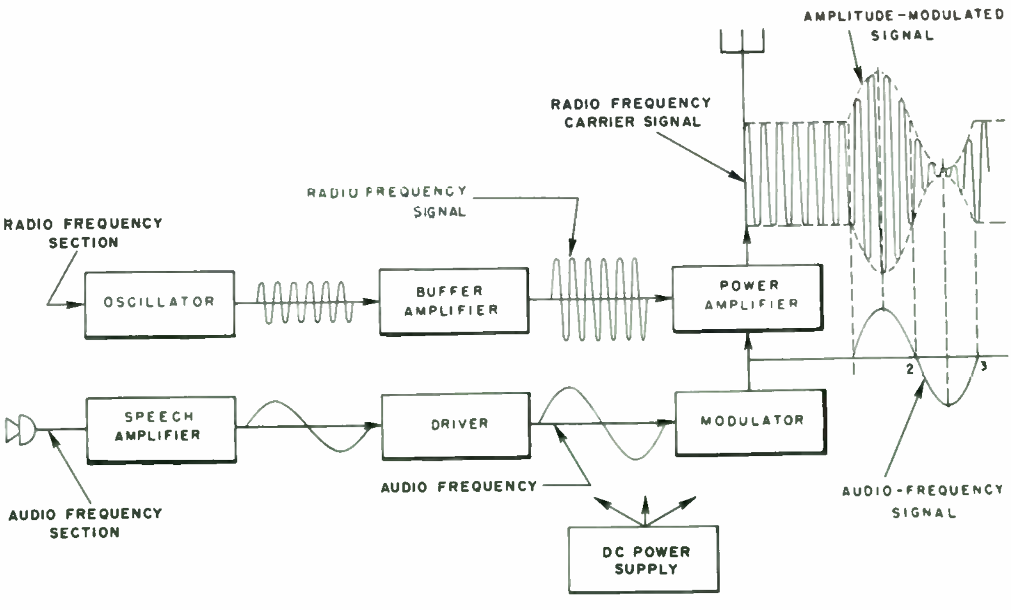


Figure 4 - Block diagram of an amplitude modulated (AM) transmitter.

In other words, during the positive alternation of the audio signal (between point 1 and point 2 in Figure 4, the amplitude of the RF output wave is increased, and during the negative alternation (between point 2 and point 3) it is decreased. Amplitude modulation consists of varying the amplitude of the RF antenna current (and consequently the RF output wave) gradually over the relatively long cycle. Thus, the RF field strength is alternately increased and decreased in accordance with the strength of the AF signal and at the AF rate.

There are a number of methods of producing amplitude modulation, such as plate modulation, grid modulation, screen-grid modulation, etc., but the two most important are plate modulation and grid modulation.

Plate Modulation

Plate modulation is more properly termed High Level Plate Modulation (Fig. 5). It is called high level modulation because the audio signal is injected into the plate circuit of the final RF power amplifier. The schematic diagram illustrates the use of a class C RF power amplifier using a triode (V1) in the final amplifier circuit. The audio amplifier section must have a final tube (V2) that is large enough to handle an audio signal equal to one-half of the power output of the RF tube V1. In other words, if the RF transmitter is rated at 1000 watts, the audio section must supply 500 watts for 100 percent modulation.

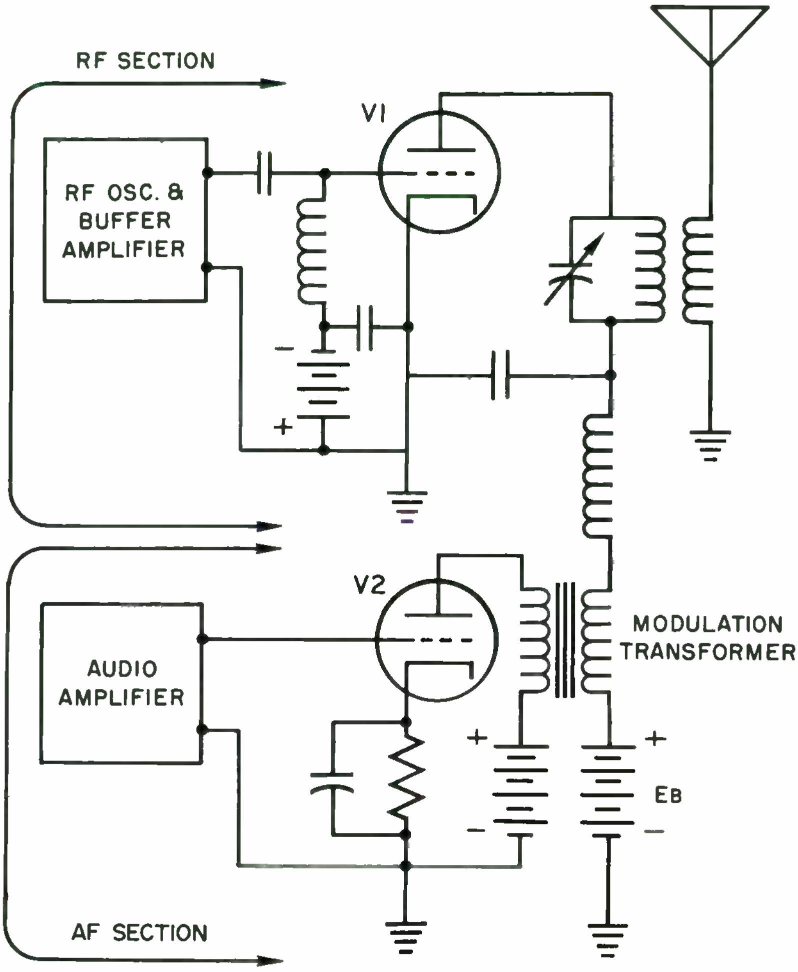
As each sideband carries the same intelligence, it is only necessary for the receiver to detect one sideband. Thus, half of the 500 watts, or 250 watts, is the actual strength of the audio signal sent out on one sideband. Thus, 250 watts carries the intelligence of an AM radio transmitter that is rated at 1000 watts.

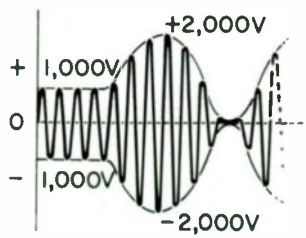
Grid Modulation

Low-level grid modulation requires less bulky equipment than high-level plate modulation, with consequent savings in space, weight, and input power. The audio signal is applied in series with the grid circuit of the RF power amplifier tube. The audio signal varies the grid bias, which in turn varies the power output of the RF amplifier. This variation in power output causes a modulated wave to be radiated. This method is known as *grid bias modulation.*

A circuit using grid-bias modulation is shown in Figure 6. A modulation transformer is placed in series with the grid return lead of the RF power amplifier. The audio voltage from a modulating amplifier adds to or subtracts from the fixed grid-bias voltage and thus controls the output power from the RF amplifier. The audio modulator tube supplying the modulation transformer must be operated as a class-A amplifier.

A large amount of power is not required to vary the grid bias of the final RF output tube. However, it is





The RF carrier voltage swings a total of 2000 volts, when no audio signal is applied.

When an audio signal of 1000 volts is applied through the modulation transformer, the RF is modulated to produce a total swing of 4000 volts, producing 100 percent modulation.

Figure 5 - Basic circuit of a plate modulated transmitter.

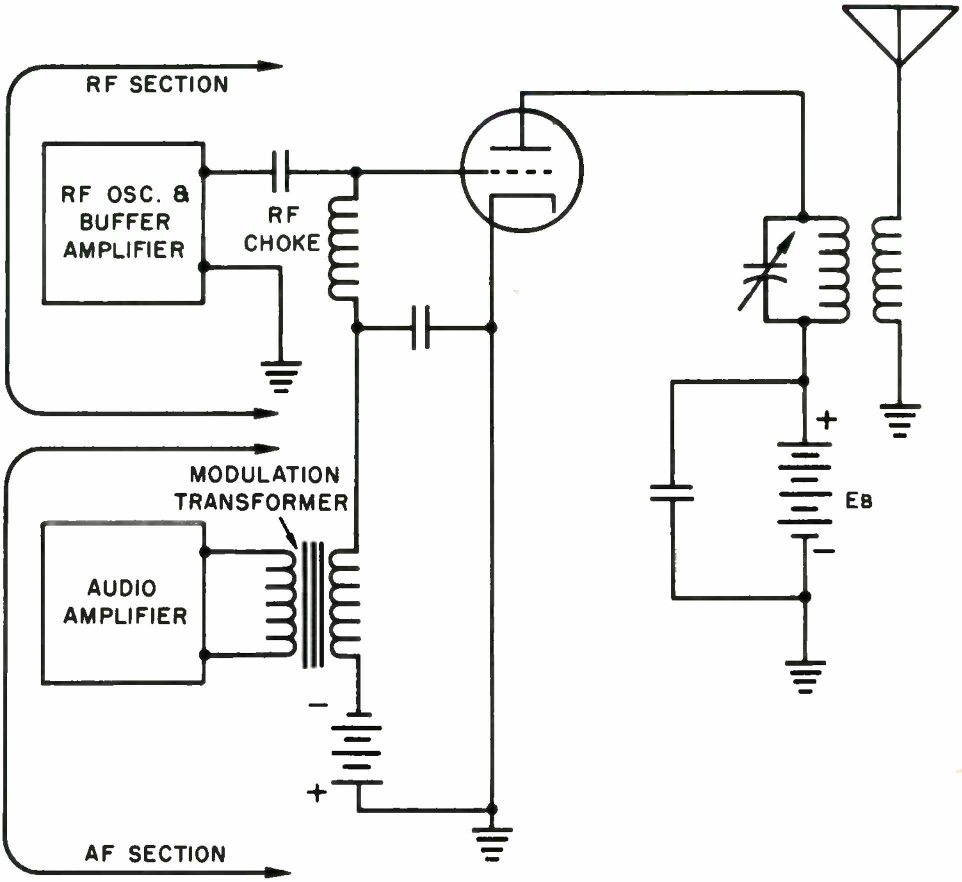


Figure 6 - Basic circuit of a grid bias modulated transmitter.

difficult to achieve any large degree of modulation by this method, and the RF carrier output power is about one-quarter of the plate-modulated transmitter; consequently the intelligibility of the signal is decreased.

AUDIO AMPLIFIERS

The preferred system of modulation for a commercial AM broadcast transmitter is plate modulation. This system assures the potential of both 100 percent modulation of the carrier, and excellent signal quality. However, a much larger amount of audio signal power is required with plate modulation than with other systems.

Modulators

The audio power amplifier (more commonly called modulator) used to modulate the carrier is a sophisticated system incorporating components and circuits especially designed to handle large audio signals. Only the best quality components are used and these have ratings far in excess of their requirements.

Probably the most critical components in modulators are the vacuum tubes themselves. Considerable heat is generated and it must be dissipated with some kind of forced cooling.

Generally, the modulator is housed in a temperature and humidity controlled room with the transmitter. Although the central room conditioning is more than adequate for the protection of most components, the tubes need additional cooling.

Additional cooling of the modulator (and final RF tubes) is provided by forcing air or a liquid coolant through some form of heat exchanger attached to them.

Medium power transmitter tubes are usually cooled with forced air. They are provided with radiating fins similar to those on the cylinder of an air cooled gas engine. A motor driven blower directs a steady stream of air past these fins to remove the heat.

In high power applications, special liquid cooled vacuum tubes are required. Water or some other liquid is constantly forced through a heat exchanger attached to each tube. Heat from the tube is absorbed by the stream of liquid and removed to a radiating unit where it is dissipated.

Most high power broadcast stations are required by the FCC to operate at reduced power during the night time hours when signal ranges are greatest. This prevents the occurance of interference between stations operating on the same assigned frequencies.

Power reduction at the transmitter can be effected by one of two methods. One method is to switch to a lower powered transmitter. Another is to reduce the supply voltage to the final RF amplifier.

When the transmitted RF power is reduced it must be accompanied by a similar reduction of the modulating power. This must be done to prevent over modulation of the reduced power RF carrier. Overmodulation, if allowed to occur, would cause distortion of the modulated signal and generation of spurious RF frequencies.

A modulation power reduction can be accomplished by applying the same methods as those used to reduce RF power. Either a lower powered modulator can be used or the supply voltage to the modulator tubes can be lowered. Either method is acceptable and the choice is strictly one of economics.

Many broadcast stations have their studios located some distance away from the transmitter and antenna. In this way the studios and offices can be located in a town or city convenient for their personnel. The transmitter and antenna, on the other hand, can be located where the terrain is more favorable for the construction of an efficient antenna system. By locating the transmitter near the antenna, the high power RF signals can be fed to the antenna through short transmission lines having small losses.

The program material from the studio is conveyed to the transmitter by one of several methods. If the distance is short it can be connected through shielded underground cables. Longer distances require the use of open lines, such as phone lines, to reduce losses.

Even longer distances can be covered using line-of-sight transmission by microwave. When microwave transmission is used, the low level audio signals from the studio modulate a low power ultra-high frequency carrier that is then connected to the microwave link between the studio and transmitter. The microwave signal is detected at the transmitter site. The audio portion is then recovered from the microwave carrier and applied to the input of the broadcast transmitter for broadcasting.

STUDIO SOUND EQUIPMENT

Programs are generated at the studio using high quality audio processing equipment. Programs may originate in either the studio doing the broadcasting or at some remote studio. Coast-to-coast network programs are broadcast live, originating at a convenient studio. The programs are than transmitted to each station in the network over phone lines or by microwave links. Other program material that originates elsewhere is recorded on tape or disc for later transmission. This system of prerecording is particularly adaptable when programs are broadcast in different time zones.

Programs are prepared in the orginating studios and either broadcast at the time of production or recorded for later broadcasting. In either case the first link between sound and audio is a microphone.

Microphones convert sounds into audio impulses in the form of voltages or currents. Actually both voltage and current exist; however, the signal is called a voltage signal or current signal according to which form is predominant. High impedance "mikes" work into high impedance loads requiring very little current and are, therefore, considered to be voltage producing devices. On the other hand, low impedance mikes produce a considerable amount of signal current at low voltages and are termed current producing devices.

In large studios, several different types of microphones may be used during a single production. The correct one will be assigned or selected by an audio engineer to satisfy certain conditions or produce specific effects.

Generally, more than one mike is used simultaneously during a production. This is done in order to reproduce all the sounds produced regardless of sound level or where a sound may originate in the studio.

When more than one microphone is used, the microphones are all connected to a mixer prior to being applied to the main amplifier. The mixer assures that desired audio signal levels are applied to the amplifier for broadcasting. The mixer also provides electrical isolation between "mikes."

Studio engineers (located in a control room) monitor the signals and switch microphones or adjust audio levels by remote control. Studio engineers can also quickly switch to backup equipment should any of the regular equipment fail.

Signals from the mixer are amplified in a microphone pre-amplifier before being applied to the line amplifier or microwave modulator. This amplification process assures that adequate signal levels will be available at the transmitter. The line amplifier is included to provide an impedance match between the signal source and the audio signal line to the transmitter.

Studio tape and record players are high quality units designed to authentically reproduce program material. They contain their own preamps which can be connected into the station's master audio system by remote control from the control room. The capability of studio recording equipment is always superior to that which is required. In fact, all commercial broadcast equipment is rated conservatively.

RECEIVING EQUIPMENT

In previous lessons, we discussed the different types of radio receivers. In these lessons, we stated that the superheterodyne receiver is, for all practical purposes, the only type in widespread use. Other kinds of receivers are produced in limited quantities for special communication purposes only.

All radio receivers, regardless of type, must perform the following three functions:

1. amplify the received signal;
2. detect the modulated signal and make the audio available to the audio amplifier;
3. reproduce sound.

Detection

Detection of an amplitude modulated signal is done with rectification and filtering. Any attempt to recover audio from an amplitude modulated signal without rectifying it first results in the destruction of the RF carrier with its audio counterpart or serious distortion of the resultant audio.

Once the signal is rectified, the gaps between RF peaks can be filled with a simple RC filter. This filter has a very short time constant and responds only to the high frequency RF fluctuations. The capacitor in the filter charges during the rise and discharges during the fall of the RF pulse. Figure 7 (A through D) illustrates how rectification of the carrier and filtering of the RF peaks causes recovery

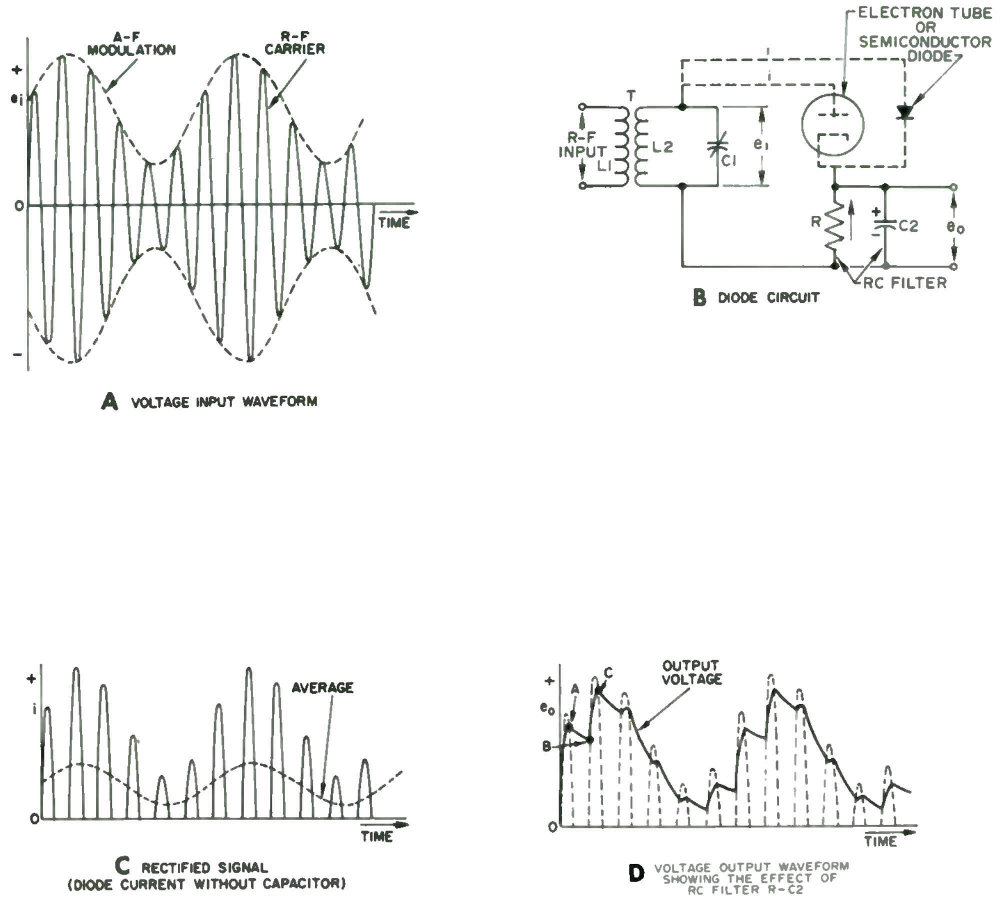


Figure 7 - Rectification and filtering applied to the demodulation of an amplitude modulated wave.

of the audio portion of an amplitude modulated wave.

In Figure 7A, we show the modulated RF waveform. It is applied to L1 of transformer T (Fig. 7B) which induces a similar voltage into L2. Current flows in the forward direction through L2, the diode, and R, developing a voltage drop across R, from where the output is taken.

Refer momentarily to Figure 7C; this particular illustration ignores the presence of the effects of C2. The illustration in C shows the presence of only positive RF pulses. Notice how they follow the amplitude variations of the modulation.

In Figure 7D, the effect of the filtering action of C2 is shown. Capacitor C2 functions as a smoothing device similar to a filter in a power supply. Its constants are chosen, however, to remove only the RF variations, not the audio. Although the recovered audio waveform at D looks somewhat ragged, it does approximate the original audio closely enough to produce good quality sound.

SUMMARY

Amplitude modulation is the system that varies the magnitude of the RF carrier. The RF carrier is always present even if an audio signal is not modulating it. The audio frequencies cannot exceed 5000 hertz, as the width of the upper and the lower sidebands will total 10 kHz. This is the maximum amplitude modulation allowed by the FCC in the standard broadcast band.

The audio frequencies create both an upper sideband (which is the *sum* of the carrier frequency and the audio,) and a lower sideband (which is the *difference* between the carrier frequency and the audio). Even though audio frequencies extend upwards of 15,000 hertz, the total allowable bandwidth is only 10,000 hertz (10 kHz) or 5000 hertz (5 kHz), each side of the center frequency.

Plate modulation can give 100 percent modulation of the carrier, but the audio system must be one-half as large as the RF system. The power supply to the plate of the final RF amplifier tube is varied at the frequency of the audio. To vary this high power, the final audio output tube must have the capability of handling at least one-half of the RF voltage.

Grid modulation does not require as large components in the audio amplifier as those in the plate modulation system. The audio modulating voltage is in series with the grid bias voltage of the final RF output tube, and produces modulation by varying the grid bias. This system has the advantages of less cost and less voltage required, but cannot produce as much modulation of the RF carrier.

Audio and studio sound equipment is very complex and its operation requires a knowledge of many special techniques. In most large broadcast studios, a staff of technicians, under the direction of an engineer, are required to operate and maintain this equipment. Several years of experience is necessary before the technician can become an accomplished sound studio engineer.

Although broadcasting is an ever-expanding field with many new jobs being made available, there is considerable competition for these positions. However, once a technician is thoroughly versed in the basics of electronic components, circuits, and systems, he can easily acquire the additional training and skills necessary for one of these jobs.

TEST

Lesson Number 35

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 52-035-1.

1. Amplitude modulation causes the ________ of the RF carrier to vary at the audio rate.
   A. phase
   B. frequency
   C. amplitude
   D. none of the above

2. The audio frequency range is considered to be
   A. 20 Hz to 20 kHz.
   B. 0 Hz to 50 kHz.
   C. 500 Hz to 5.5 kHz.
   D. 540 Hz to 1600 kHz.

3. In AM broadcasting the audio information
   A. modulates an RF carrier.
   B. is broadcast separately along with an RF carrier.
   C. has no effect on the RF carrier.
   D. is not used.

4. The audio information in standard AM broadcasting appears
   A. only in the upper sideband.
   B. only in the lower sideband.
   C. on both sidebands.
   D. only on the center frequency.

5. The maximum allowable percentage of modulation in commercial AM broadcasting is
   - A. 100%.
   - B. 75%.
   - C. 50%.
   - D. 25%.

6. In an AM broadcast receiver, the received signal is
   - A. fed directly to the speaker.
   - B. rectified and filtered to recover the audio.
   - C. converted to FM.
   - D. never rectified.

7. Commercial AM broadcast equipment is
   - A. simple and of low cost.
   - B. complex but of low quality.
   - C. complex and of good quality.
   - D. simple but costly.

8. Program material for AM broadcasts originate from
   - A. tape recordings.
   - B. disc recordings.
   - C. microphones.
   - D. all of the above.

9. Audio information is routed to a station's remote transmitter by
   - A. shielded cables.
   - B. phone lines.
   - C. microwave transmission.
   - D. all of the above.

10. A station's audio and sound equipment is controlled
    - A. by musicians and actors.
    - B. by technicians and engineers.
    - C. by administrators and managers.
    - D. completely by automation.

Notes

Notes

Notes

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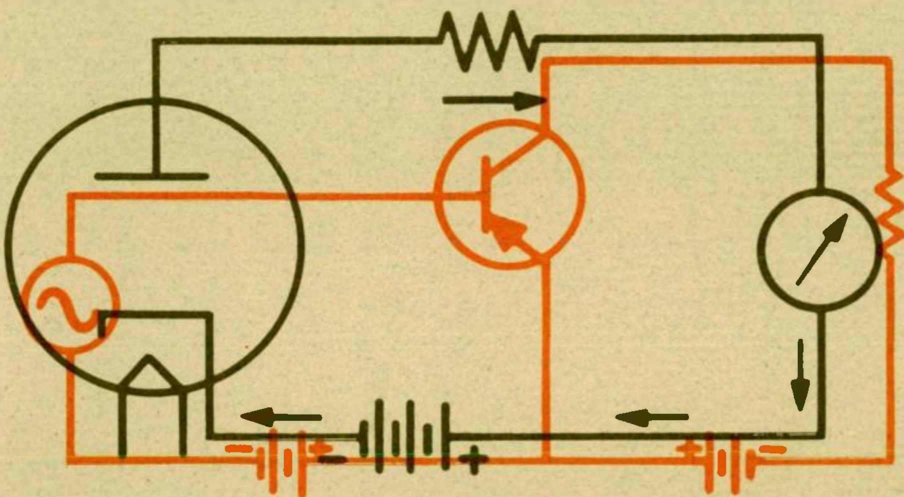
Good students are enthusiastic in their Electronic training because they are always striving to better themselves in the Electronic servicing field. Arouse the enthusiasm in an ambitious person and the results are startling.

Continue to develop your enthusiasm in radio and T.V. service and excellent results will astound you. Your life will be more profitable and happier!

S. T. Christensen

LESSON NO. 36

FREQUENCY MODULATION



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-036

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CONTENTS

FREQUENCY MODULATION

INTRODUCTION

As explained in lesson 35 on amplitude modulation (AM), the RF carrier wave is varied in amplitude by the audio frequency that modulates it. With frequency modulation, the frequency of the carrier wave itself is varied while the amplitude of the RF carrier is left unchanged. The methods used for both transmission and reception of an FM signal is somewhat more complex than methods used to produce and receive an AM signal. An important fact to remember about frequency modulation is that it is the *rate* of change of the carrier frequency that must be detected in the receiver and converted to an audio signal.

Modulation Graph

Sound has two characteristics that must be conveyed by the FM transmitter if sound is to be properly reproduced. These two characteristics are *frequency* and *loudness*. In FM broadcasting, frequency variation of sound affects the speed at which the center frequency increases or decreases; and the loudness of the sound affects the *swing* from center frequency, with a loud sound causing an increase, and a soft sound causing a decrease in frequency.

Figure 1 shows how one cycle of the audio signal affects the RF wave. At zero audio amplitude, the carrier frequency remains unchanged, but as the audio signal increases in amplitude, the carrier frequency changes and increases in frequency. When the audio signal starts to return to zero amplitude, the RF carrier decreases and returns to its original frequency. But as the audio signal goes through the negative portion of its cycle, the carrier frequency lowers. Again, as the audio signal approaches zero, the carrier returns to its original frequency. Throughout this frequency change, note that the amplitude of the RF carrier remains at a constant amplitude.

Bandwidth

Lesson 35 on amplitude modulation (AM) pointed out that FCC rules limit AM bandwidth to 5 kHz on either side of an RF carrier. As the AM broadcast band extends from 535 kHz to 1605 kHz, there are 107 channels in this frequency space, each channel having a width of 10 kHz. The intermediate frequency (IF) amplifying system used in an AM receiver is adjusted to deliver a "peak" output with broad frequency response. The AM/IF stage must have broad frequency response so that it will not lose any

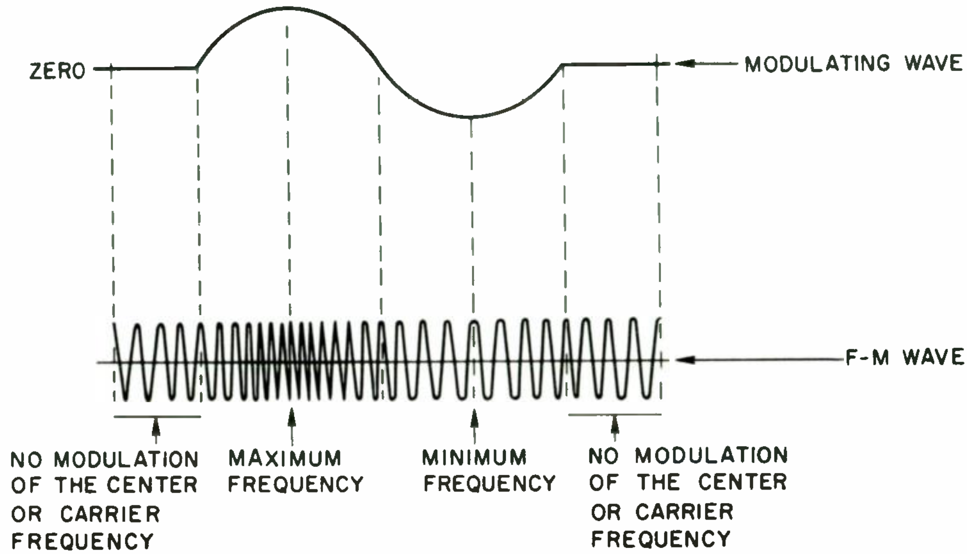


Figure 1 - The frequency of the audio signal modulates the FM carrier. The frequency of the carrier is changed above and below the center frequency at the audio rate.

of the RF signal that approaches 10 kHz in width. In FM, however, our deviation from the initial carrier is 100 kHz wide and the IF system must be broadband tuned to retain all the information contained in a bandwidth of 200 kHz. This width of 200 kHz is 20 times wider than the AM requirements of 10 kHz. If the standard AM broadcast band used FM principles, it could accommodate only 1/20th of the present number of AM stations. Consequently, the bandwidth allocated to FM broadcasting has to be much wider. The FCC has selected a frequency range that extends from 88 to 108 MHz for FM broadcasting.

TYPES OF FREQUENCY MODULATION

The basic principle of frequency modulation is the use of an audio frequency signal to vary the radio frequency carrier wave. This change in frequency may be produced either: (1) by varying the oscillator frequency, or (2) by shifting the phase angle. Whichever system is used, the end result is the same.

The change in frequency varies with the amplitude of the audio signal. The frequency of the audio signal determines the number of times this happens.

The distance the sidebands extend from the carrier or center frequency is called "deviation." This deviation in frequency is the number of Hertz above and below the carrier. As audio has both amplitude variation and frequency variation at any given instant of time, the FM signal is continually reacting or deviating from its center frequency. This deviation is not necessarily a permanent value of deviation, but rather a deviation for that fraction of time.

Stability

The RF carrier is known as the *center frequency*. It is both the point or position on the tuning dial and the carrier frequency of the broadcasting station. This frequency must remain absolutely stable, and the ability of the carrier to remain constant is called "frequency stability." The stability of the center or carrier frequency is of prime importance.

Direct Method

In the direct method of frequency modulation, stability becomes somewhat of a problem because the actual transmitter carrier is continually varying. The use of a device like a reactance tube is used to vary frequency, while an Automatic Frequency Control (AFC) maintains the carrier at its chosen frequency. The carrier is continually being varied by the reactance tube circuit. It is this change in reactance, caused by a changing (audio signal) that varies the carrier frequency. But as carrier frequency must always return to its original center, or carrier frequency, an AFC circuit is necessary (Fig. 2A).

Extremely careful design must be used in both the oscillator and the AFC circuit to maintain the stability of the center frequency, otherwise the signal becomes distorted. The reactance tube "reacts" to an audio signal, and the AFC continually compares it to a crystal oscillator.

Indirect Method

The indirect method of frequency modulation is called *phase modulation* (Fig. 2B). This method is easily understood when you remember the meaning of phase angle. Phase angle means the number of electrical degrees that separates one wave from another, such as the number of degrees that separates the crest of one wave to the crest of the second wave. In phase modulation, the carrier or center frequency is *delayed* a certain number of degrees which amounts to a shift from the *normal* position of the carrier. This shift from the normal position of the carrier is caused by the audio signal. Thus, the shift is the phase angle of the modulating frequency, and is called, simply, *phase modulation.*

This phase shift of the carrier can be produced by changing the reactance in a portion of the transmitter circuit. The change in reactance may be created by a change in the inductance value or the capacitance value in the circuit. The effect of altering an inductive or capacitive value in a resonant circuit will alter the frequency and at the same time shift the phase angle of the circuit. A crystal oscillator is used to insure that the carrier always remains at a fixed frequency.

DEMODULATION

The process of demodulation of an FM signal is different from the system used to demodulate an AM signal, even though the result is the same. The changes in frequency of the FM

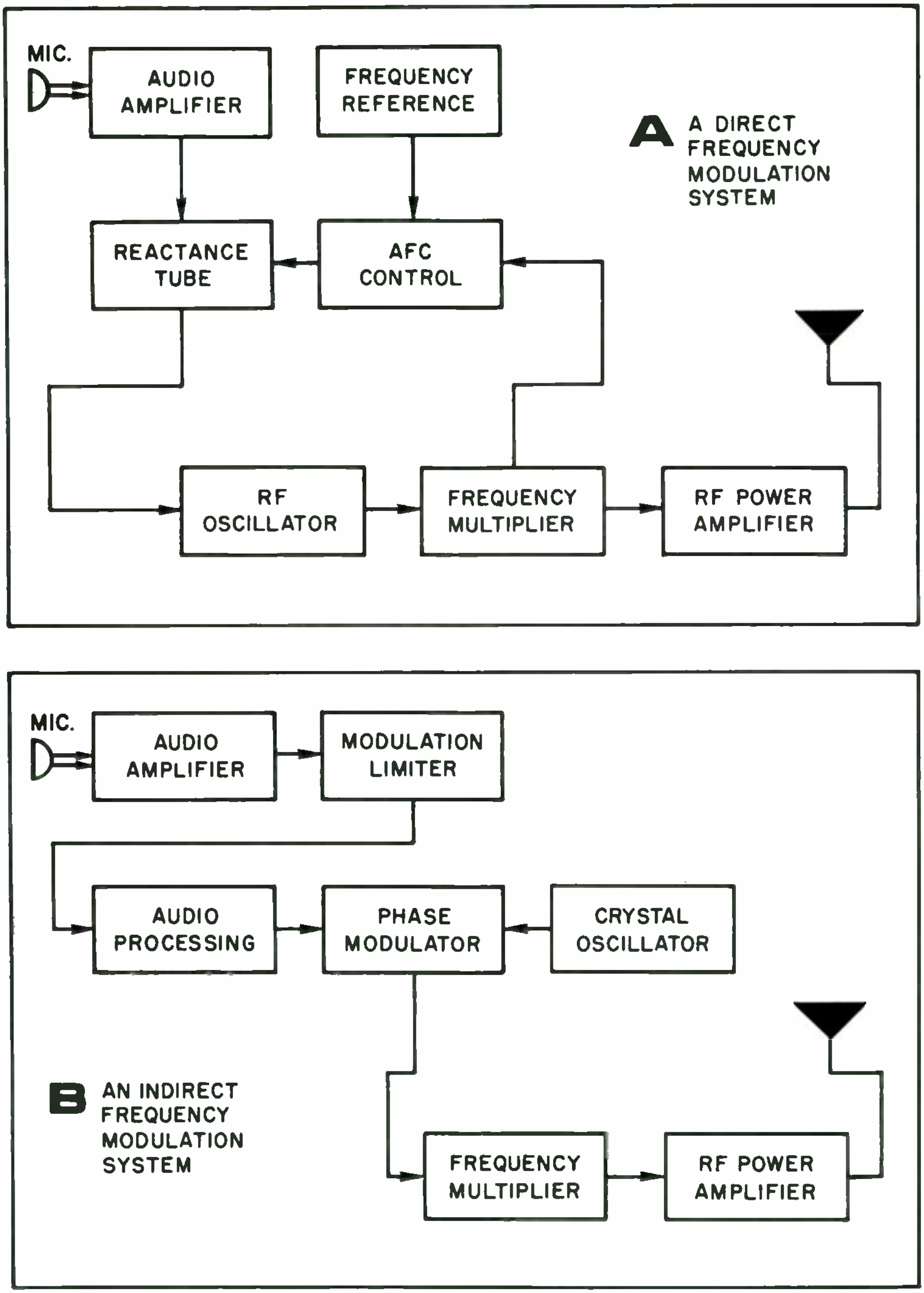


Figure 2 - Methods used to frequency modulate a carrier.

signal are converted to the original audio signal, as it is the audio signal that causes the frequency swings of the FM carrier at the transmitter. The demodulation consists of converting the *frequency changes* into *amplitude changes* which are in turn detected and filtered.

This conversion may be accomplished in two basic ways, just as modulation can be performed in two ways. We may: (1) take advantage of the change in impedance of a circuit due to the change in frequency of the FM signal or (2) make a comparison of the phase difference between the *FM center frequency* and the actual *FM modulated frequency.*

Triple Tuned Discriminator

Most FM receivers use 10.7 MHz as the center frequency of the intermediate frequency (IF) amplifier. As FM signals can swing widely both above and below this center frequency, provisions must be made to both accept this wide frequency range and *discriminate* the audio frequencies. The triple-tuned discriminator circuit is used to show a basic method of demodulating an FM signal (Fig. 3A). The name "triple-tuned" is an indication that the circuit must respond to three frequencies. The primary is tuned to 10.7 MHz, the center frequency, while the two secondaries are tuned to frequencies both above and below the center frequency. All of the components in Figure 3A make up the triple-tuned discriminator.

Capacitor C1 and inductor L1 form the input or primary circuit that is tuned to 10.7 MHz. The secondary coil, L2, and capacitor C2 are adjusted to resonate 100 kHz above the center frequency, and the other secondary coil, L3, and capacitor C3 resonate 100 kHz below the center frequency. We now have a transformer that is tuned at 10.7 MHz, 10.8 MHz and 10.6 MHz in its respective windings. Note that the total bandwidth of the transformer is 200 kHz wide, and their combined response is shown in Figure 3B.

The diode rectifiers, D1 and D2, are active on alternate half cycles, and when a signal of 10.6 MHz resonates in L3 and C3, the diode D2 will permit a maximum current to flow in R2, while R1 remains almost unaffected. Therefore, point A will become negative because of the direction and value of the IR drop.

At 10.8 MHz, the opposite action will occur because current will now flow through D1 and the IR drop will be in the opposite direction. At 10.7 MHz, both diodes conduct equally and there is no voltage drop from A to the ground because both IR drops are equal and opposite in polarity. Notice that the voltage drops are totally dependent upon the conduction of the diodes. The amount of current passed by the diodes depends upon the proximity or closeness to resonance of the two secondary circuits. When these changes occur at a particular audio frequency rate, it becomes the rate of the audio signal and the familiar audio wave with amplitude characteristics is generated in the output portion of the circuit.

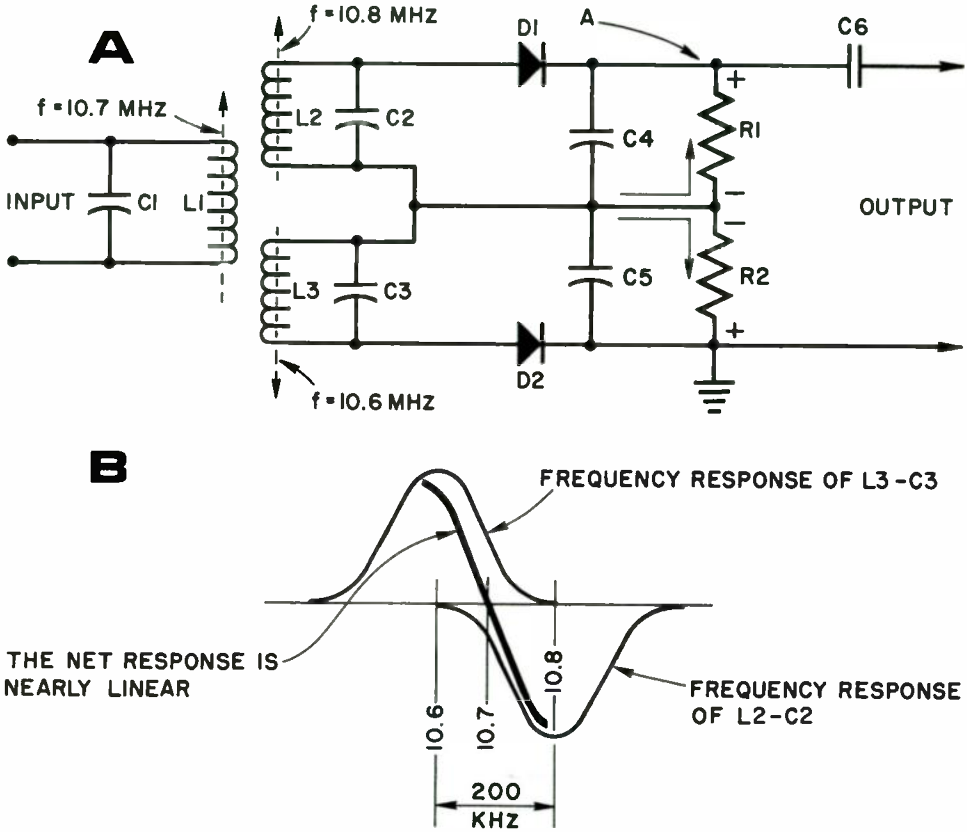


Figure 3 - A triple-tuned discriminator circuit used in demodulation.

Characteristic Curve

A characteristic curve as shown in Figure 3B is sometimes referred to as the *ideal* curve, but it is "ideal" in name only. It can be approached in practice but is seldom reached. Figure 3B is a more realistic illustration of an actual response curve of each of the two secondaries. These two values are then combined into the net response curve. This net response approaches the shape of what might be called a typical, ideal characteristic curve (Fig. 4). The curve in Figure 4 illustrates the desired response curve, and is sometimes referred to as an "S" curve. It is not a sine wave, as an inspection of it will show that there is a straight line, or linear portion that is the net result of the response curve from each secondary.

Note the frequency indications of 10.6 MHz, 10.7 MHz, and 10.8 MHz in Figure 4. These indications represent the peak response points of the primary and the two secondaries of the discriminator transformer. The "S" curve represents the net response of the entire circuit for all audio

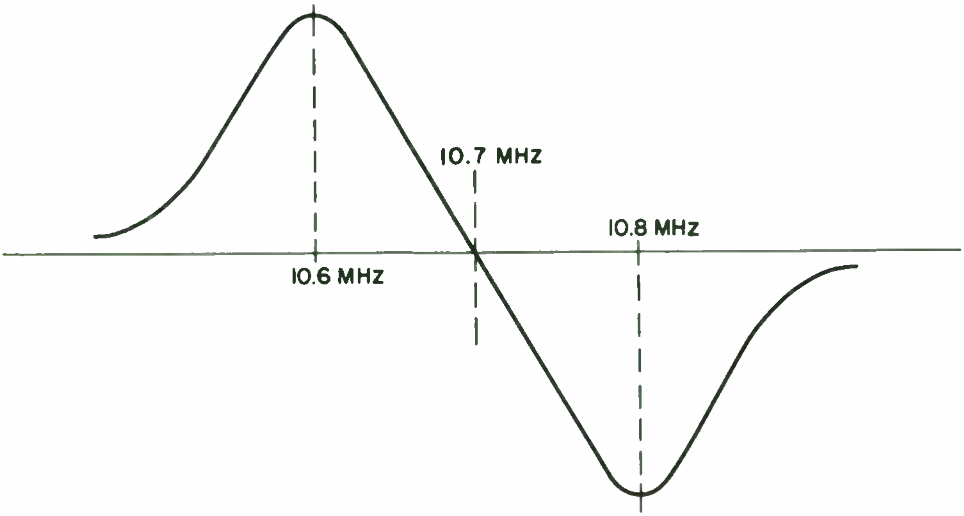


Figure 4 - This S curve illustrates the shape of a desired response curve.

frequencies. The audio that is present after total detection is really contained within a range of 75 kHz on each side of the carrier frequency. It is important to note that the curve shows linearity almost 100 kHz on either side of the carrier.

Double Tuned Transformer

The use of vectors to illustrate the phase relationships existing between two or more waves has been presented in previous lessons. The lessons on AC, Capacitance, Inductance, plus the lesson on Impedance and Reactance have used vectors to show how voltages or currents may be added vectorially, and to illustrate the phase relationship between waves. The four quadrants of a circle were used to illustrate how voltage leads current in a purely inductive circuit (remember ELI) by 90 degrees, and current leads the voltage by 90 degrees in a purely capacitive circuit (ICE).

When one vector leads another by exactly 90 degrees, they are said to be in *quadrature.* The word quadrature is used in other branches of science in the same sense in which it is used in electronics: it indicates that two objects, such as vectors, are 90 degrees apart.

One of the principles of detection in the FM receiver takes advantage of the quadrature, or the 90 degrees out of phase relationship that exists in a tuned transformer. Actually, the voltages of the secondary and primary are in quadrature, or 90 degrees out of phase.

This can be explained from the diagram in Figure 5, which is funda-

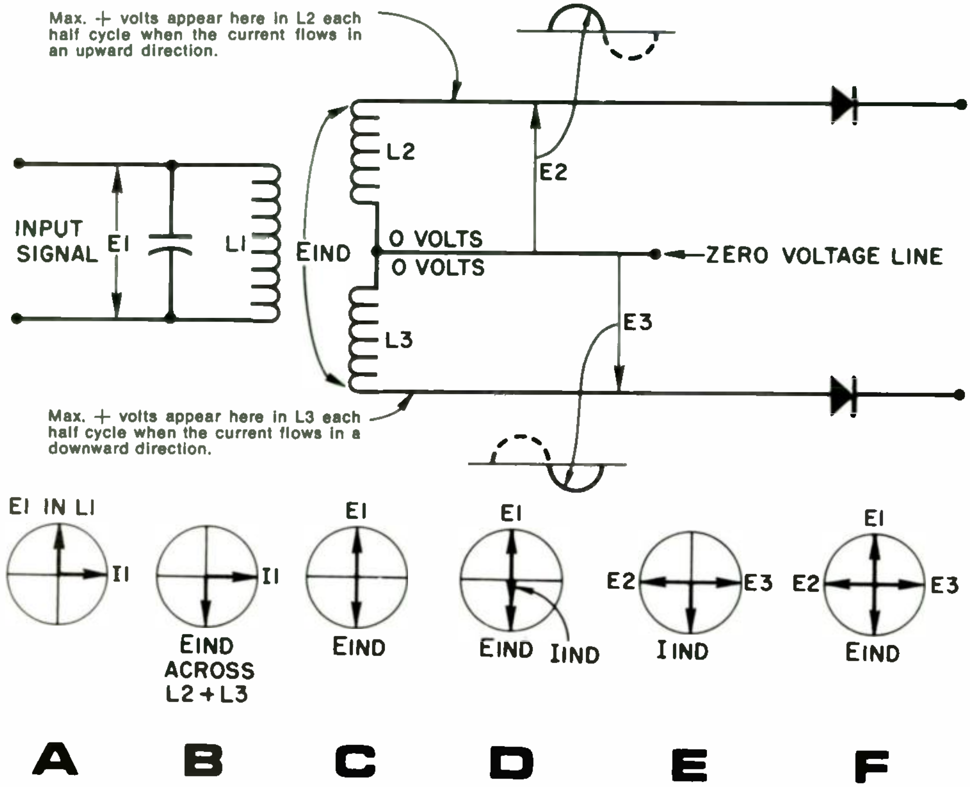


Figure 5 - Vectors show the phase relationship of the voltages in the discriminator circuit.

mentally the same circuit as in Figure 3, but simplified for this review using vectors. L1 is the primary input with the voltage E1 existing across it. The secondary is again divided, and the center tapped connection acts as the zero level of voltage. As in all inductive circuits the voltage E1 leads the current I1 as shown in Figure 5A. Figure 5B shows how the induced voltage EIND lags the primary current I1, and Figure 5C shows that the induced voltage EIND is 180 degrees out of phase and is opposite the primary voltage E1.

At resonance, the induced current IIND is in phase with the induced voltage EIND (Fig. 5D). When a current is *flowing* in a coil (Fig. 5E), the voltage E3 in that coil is approximately 90 degrees ahead of the current IIND. As E2 is opposite E3, it can be located as shown in Figure 5F. The phase relationship of E1 and EIND to these two secondary voltages is also shown in Figure 5F.

Phase Discriminator

When no signal is being transmitted on the FM carrier, the four voltages present in the circuit have the phase relationship shown in Figure 5F. To learn what effect an FM signal will have on the phase relationship of these voltages, and how the audio signal is reproduced, a practical discriminator circuit will be used (Fig. 6). This circuit is almost identical with the circuits shown in Figures 3 and 5, except for the addition of capacitor C5 and coil L4. At a quick glance it might not appear that the combination of C5 and L4 are in parallel with the primary circuit of C1 and L1, but an inspection of the two circuit paths will show that they are parallel. One circuit across terminals T1 and T2 is the parallel circuit formed by C1 and L1. The second circuit that is also across the terminals T1 and T2 can be followed by starting at T1. The circuit extends through C5, to the center tap connection of the secondary coil, through coil L4, through capacitor C4 to the ground connection. As T2 is also grounded, this effectively returns the lower connection of C4 to terminal T2, completing the return path of the circuit. This second path is a series circuit while the first one, the primary of the transformer, is a parallel circuit.

There is a purpose in connecting the primary to the secondary, through capacitor C5. It places the same voltage E1 and the same phase across the coil L4 that appears across the input circuit. Thus, we can replace the symbol E1 in Figure 5F by the voltage E4, and we did just that when we redrew the vector diagram in Figure 7A. It becomes apparent that the voltages that exist in the diode portion of the circuit must be combined vectorially before we can determine the value applied to the diodes. This vector addition is shown in Figure 7B where the two voltages E2 and E4 combine vectorially to produce the resultant voltage ED1 that is applied to diode D1. Similarly, the two voltages E3 and E4 combine vectorially to produce the resultant voltage ED2 that is applied to diode D2. As the two voltages ED1 and ED2 are of equal value, they will produce the same current flow through each diode. Equal voltages will then appear across resistors R1 and R2 of Figure 6, and as these two

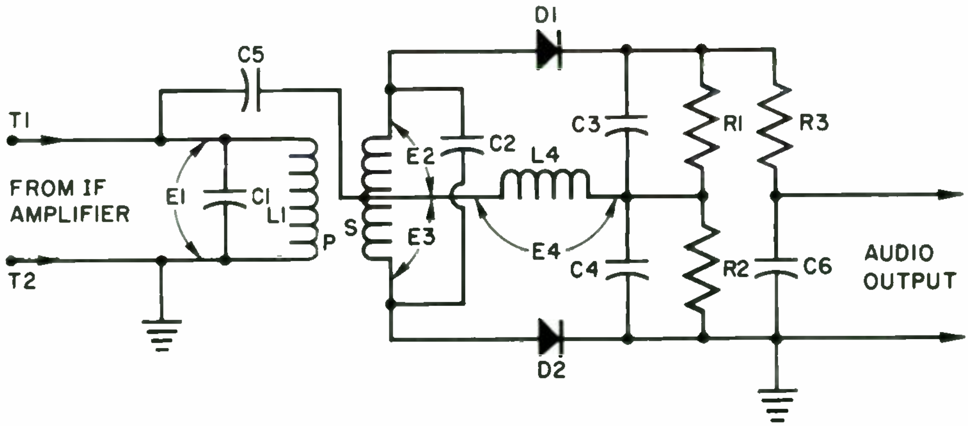
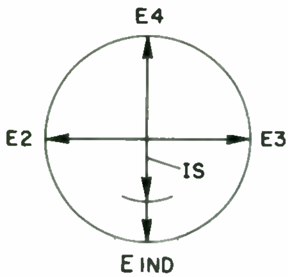
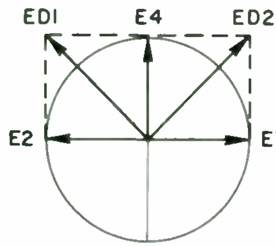


Figure 6 - A discriminator circuit that compares the phase relationship of the modulated signal with the RF carrier signal to demodulate the FM signal.



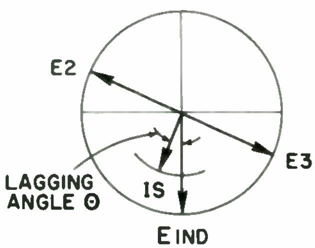
A

The relationship of voltages in the diode position of the circuit.



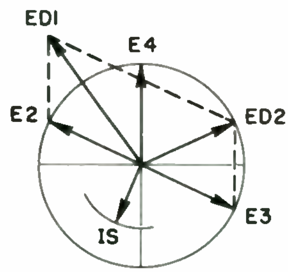
B

The "no-signal" condition produces two voltages, ED_1 and ED_2.



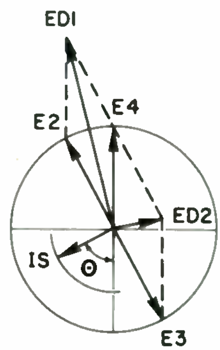
C

A higher FM frequency will cause the secondary current Is to lag behind the induced voltage in the coil.



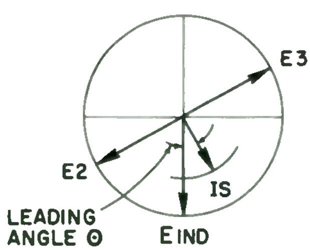
D

A higher frequency creates two unequal voltages ED_1 and ED_2.



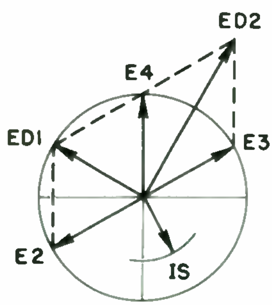
E

A much higher FM frequency creates more voltage unbalance from the two output signals.



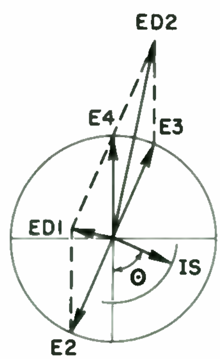
F

A lower FM frequency will cause the secondary circuit Is to lead the induced voltage in the coil.



G

A lower frequency creates two unequal voltages but with a greater negative output as ED_2 is larger.



H

A much lower FM frequency creates more negative voltage from the unbalance of voltages.

Figure 7 - Illustrating the phase shift of frequency modulated signals by their vector representation.

voltages are in opposition, no audio output will be produced. This is the condition in the discriminator circuit when no audio signal is modulating the FM carrier.

When an FM carrier is modulated, the carrier is increased or decreased in frequency. These two conditions of higher or lower frequency will be analyzed in the same manner that a "no-signal" carrier was analyzed. The higher input frequency causes the signal voltages E2 and E3 to take the vector positions shown in Figure 7C. A higher frequency signal acting on the series resonant circuit consisting of the secondary transformer coil in series with the capacitor C2, will meet more opposition from an inductance than from a capacitor. This means that the coil will cause the secondary current Is to lag behind the induced voltage EIND taking the position as shown in Figure 7C. As voltage leads current in an inductor (ELI), the voltages across the two halves of the secondary are always 90 degrees from the current vector Is. Remember that the current Is flows through the two secondary coils, and is responsible for creating the voltage vectors E2 and E3 that are 90 degrees from the current vector Is. E3 is in opposition to E2 as the coil is grounded at the center tap.

An inspection of Figure 7D shows that the resultant of E2 and E4 is the voltage vector ED1, that appears across the resistor R1. When E3 and E4 are combined, the vector voltage ED2 is the resultant voltage that appears across resistor R2. As ED1 is larger than ED2, there will be a greater voltage across R1, producing an output voltage that is positive with respect to the ground terminal.

When the audio frequency swings the FM signal at an extremely high frequency, the phase shift becomes larger as indicated by the large lagging angle Θ in Figure 7E. This produces a much larger voltage ED1, which appears as a much larger, positive voltage at the output.

A lower input frequency causes an opposite shift of the phase relationship between the induced voltage EIND and the secondary current Is (Fig. 7F). When the input frequency is below the resonant frequency of the tuned circuit, the capacitive reactance becomes greater than the reactance of the coil, and the current leads the voltage (ICE). This accounts for the angular location of the current vector Is leading the induced voltage vector EIND. The resultant voltages ED1 and ED2 take the positions as shown in Figure 7G. As ED2 is greater than ED1, the output voltage is *negative* with respect to ground. A much lower frequency than the FM carrier frequency will produce a still *greater negative* voltage as indicated in Figure 7H.

The unbalance of voltages caused by a shift in frequency produces a linear voltage change (Figs. 3B and 4). This linear portion of the voltage change on the S curve produces a change at an audio frequency rate, and thus the original signal is reproduced in the radio receiver.

Limiting

The FM signal from the transmitter conveys information solely by the frequency variation of the RF carrier. When this FM signal is received, the frequency variations must be converted into an audio signal by the FM detector. There may be some outside electrical influence upon the signal between the place it is transmitted and the place it is received, generally resulting in a variation in amplitude. As a variation in amplitude at a uniform rate is what we want at the *output* of an FM receiver, any spurious and unwanted variations of the incoming FM signal itself, will produce unwanted noise. If we can prevent the incoming FM signal from varying in amplitude, by making it pass through the equivalent of a narrow electrical passageway, we can cut off the peaks caused by the amplitude variations. Such a system is included in all FM receivers and is known as a limiter circuit.

An FM wave that is modulated by an audio sine wave is shown in Figure 8. If this wave is affected by electrical noise or static, the wave shape at the input to the detector circuit in the FM receiver will be as shown in Figure 9. Both the positive and negative peaks have been clipped at the right portion of the illustration to show the action of a limiter circuit. Only the peaks have been clipped, and the frequency variations have been left untouched, which is the prime concern.

A method of producing this clipping action is shown in Figure 10.

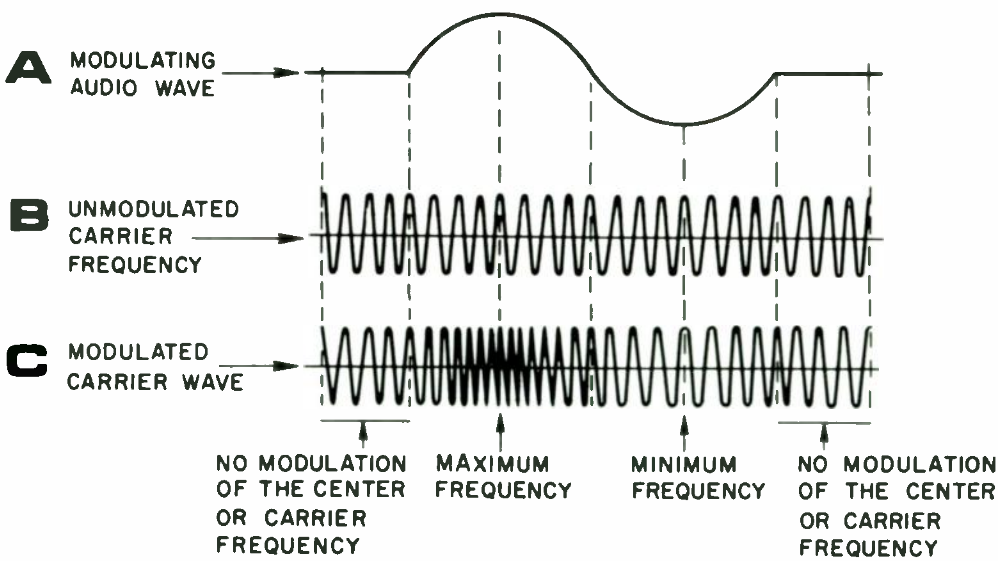


Figure 8 - When an FM carrier wave is audio modulated, the resultant wave varies as shown in C.

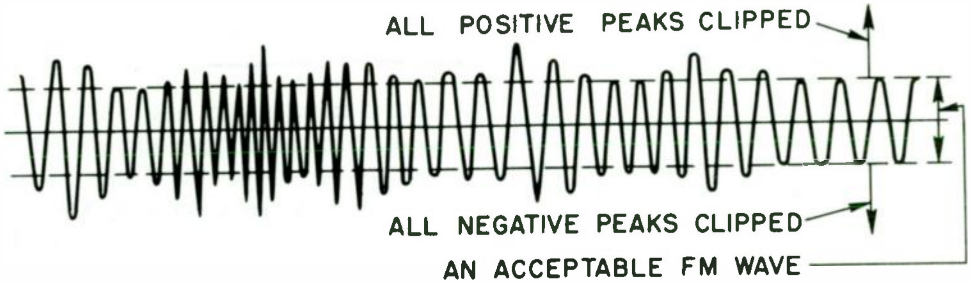


Figure 9 - Electrical noises will change the amplitude of an FM wave. These amplitude changes can be clipped or limited to restore the constant-amplitude FM wave.

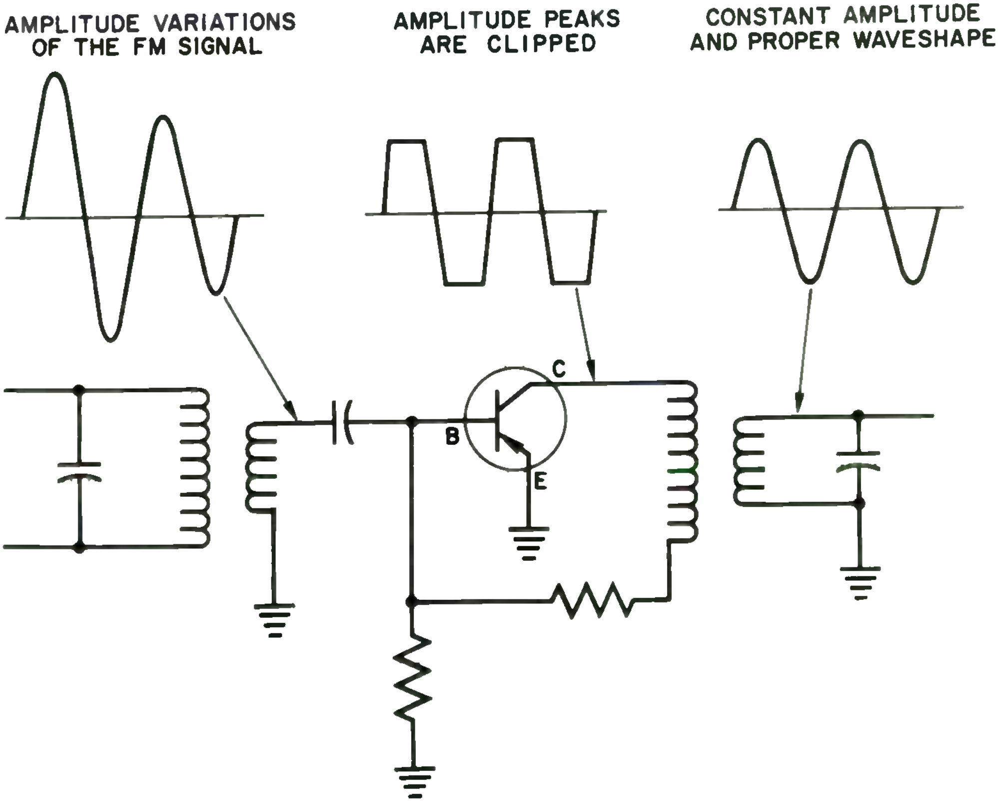


Figure 10 - A basic limiter.

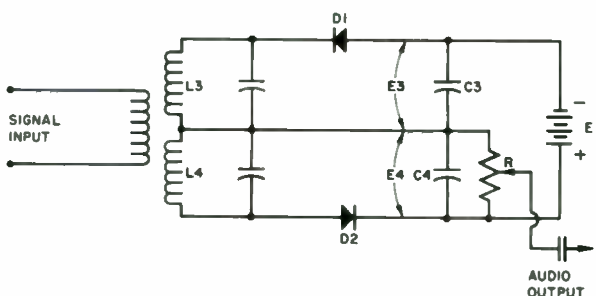
This circuit could be an IF stage that has the transistor biased to a condition close to saturation. When a strong signal is applied to the input, it drives the transistor past its cutoff point. Actually, the transistor is "overdriven" and only allows a limited output even though there is a wide range of strong signal inputs. This is the clipping action that limits the amplitude of the FM signal. No harm is done to the intelligence on the RF carrier since the desired frequency variations remain unchanged.

There are other discriminator circuits but all of them require a limiter circuit to remove any amplitude variations that are riding on the FM wave. One of the disadvantages of a limiter circuit is the excessive amplification required to bring a weak signal up to a strong signal level. It is necessary to do this to be certain that the limiter will be driven to the saturation point by any peaks present in the carrier.

Ratio Detector

New circuits and new methods are under continual development in the electronics industry. One of the significant developments is the *ratio detector circuit* which is an FM detector that eliminates the need for an amplitude limiter. This ratio detector is similar to a discriminator and the simplified version of the circuit is shown in Figure 11. As the battery maintains a voltage across two equal-valued capacitors C3 and C4, any voltage added by either one of the two diodes, D1 or D2, affects the final ratio of the voltages in the right-hand portion of the circuit.

A practical ratio detector circuit would not have the battery E to maintain a voltage across the two capacitors, C3 and C4 (Fig. 11). Any system that would eliminate the battery could be used, but the simplest one is to replace the battery



- The voltage E3 is equal to the voltage E4.
- The battery voltage E equals the sum of E3 and E4.
- With the polarity of the battery as connected, to D1 and D2, no current can flow.
- The resonant frequency of L3 is above the center frequency, and L4 resonates below the center frequency.
- With an incoming signal resonating in L3, the total voltage across C3 rises; the voltage from L4 at the same frequency is lower, and the resulting voltage E4 across C4 is lower.
- As E3 has a larger voltage and E4 has a lower voltage, under this condition, a ratio of voltages between the two has been created.
- The battery voltage E maintains a set voltage E equal to the sum of E3 and E4. Only the ratio of the voltages between E3 and E4 can vary, as a variation of amplitude has no effect on the ratio.
- The voltage that varies across C4 also appears across the resistor R, permitting the audio volume to be adjusted.

Figure 11 - Operation of an FM ratio detector.

with a capacitor (C) that will become charged to a selected maximum voltage. This maximum voltage is determined by the circuit designer (Fig. 12). He establishes the value of the voltage that he wants to maintain across the capacitor by placing a resistor in parallel with it. The resistor will establish a current flow through itself, thus extablishing the constant voltage available across the capacitor.

The capacitor is initially charged by the signal voltage, and is continually recharged during the time that a signal is received.

AM-FM RECEIVER

A typical AM-FM receiver circuit is shown in Figure 13. The ratio detector portion that is of interest here, is shaded in color. All of the solid-state units are identified around the border of the diagram, together with the function they perform. Diodes D6 and D7 are plainly marked as "FM/DET", which on inspection of the circuit shows them to be the *ratio detectors* of the FM portion of the circuit. A further inspection of this portion of the circuit (Fig. 14) will show that the IF transformers T7 and T8 have additional windings on them. It is not always apparent why the designer added them, without knowing whether they are added to neutralize unwanted electrical feedback, or to change the phase relationship in a certain part of the circuit, etc. Every circuit is bound to have slight variations in its design, but an understanding of the basic operation of receiving circuits is all that is required.

At the completion of this lesson, it would be wise to return to this circuit (Figs. 13 and 14) and attempt to follow both an AM signal and a FM signal from the antenna to the speaker. Some of the circuits will be

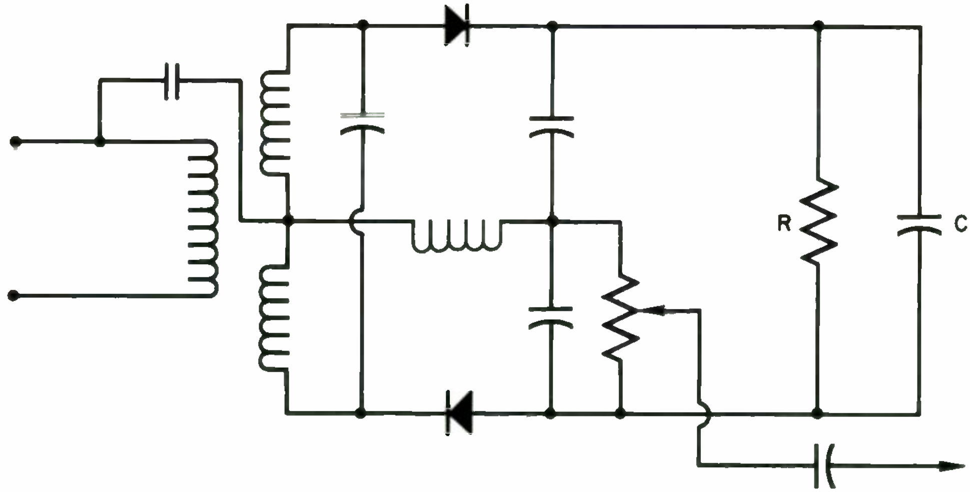


Figure 12 - One practical ratio detector circuit.

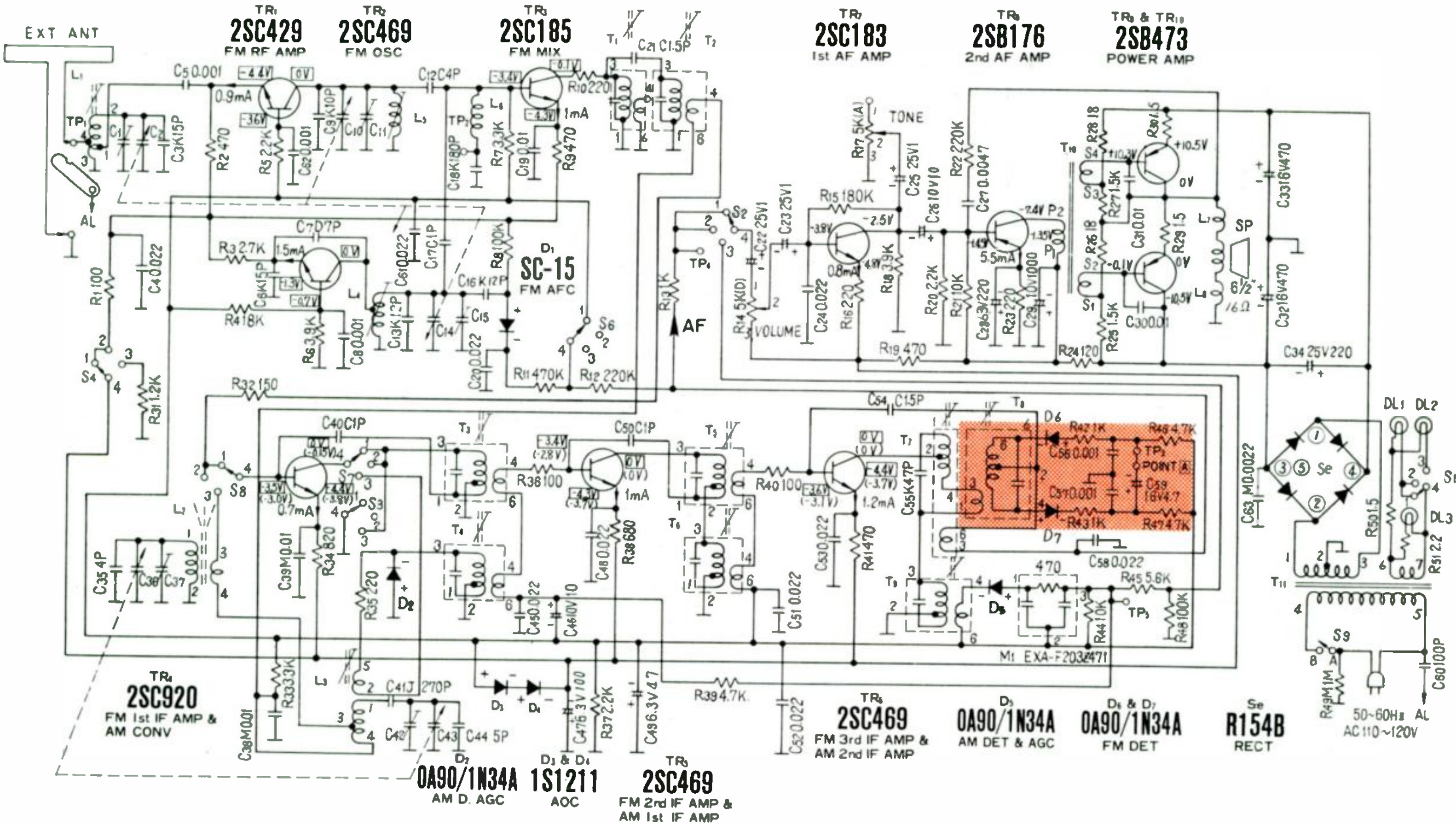
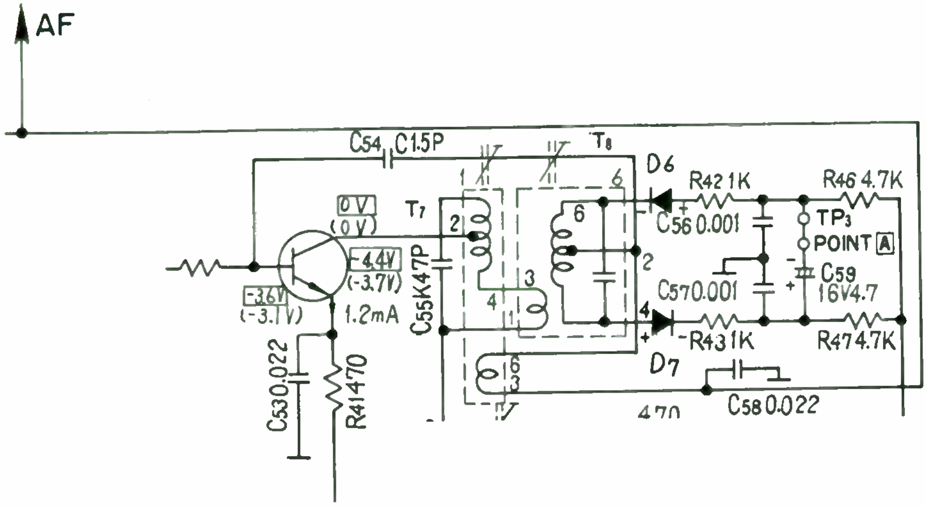


Figure 13 - A ratio detector circuit used in a modern commercial AM-FM radio. Courtesy of Panasonic.



Notes:

1. S1~S8: Band selector switch in "FM" position.
2. S9: Power source switch in "OFF" position.
3. DC voltages measurements are taken with circuit tester (10KΩ/V) from chassis.
   ☐......FM position ( )......AM position.
4. Capital letters (M, K, D, J, C) in the circuit diagram show allowable tolerance of resistors and capacitors as follows:

   C=±0.25PF D=±0.5PF J=±5% M=±20% K=±10%
   - Tolerance of resistor is ±10% (K) if not otherwise indicated.
   - Tolerance of capacitor is +100% − 0% (P) if not otherwise indicated.
5. PF=pico farad=mmf
   μF=micro farad=mfd
6. All resistor values in ohms (K=1000Ω).
7. All capacitor values in micro farads (P=mmf).

Figure 14 - The ratio detector portion of the AM-FM receiver of Figure 13. The notes refer to the entire circuit shown in Figure 13. Courtesy of Panasonic.

easy to follow and the understanding of them will be simple. Other circuit paths are bound to be confusing at first glance, but eventually they become clearer. Each receiver will have certain illustrations on the diagram that generally can only be understood after the actual receiver is inspected. An example of this is the narrow oval drawn in just under the abbreviation EXT/ANT in the upper left hand corner. It is obvious to a skilled serviceman that the abbreviations mean the connections for an external antenna (and designed for FM reception by the shape of the drawing). The narrow oval with a small circle at one end acts as a pivot. The letters "AL" that have an arrow underneath them, indicate that there is another connection somewhere marked AL. This other connection is in the lower right-hand corner of the drawing and has a capacitor in series with it, before it connects to one side of the power plug. An experienced serviceman will know that there is no need to clutter up the drawing with a long line just to indicate that this AM-FM receiver uses one side of the power line as an antenna. In a well-populated area having strong stations, an outside antenna is not needed.

With a better understanding of the methods used in receiving and detecting an FM signal, another inspection of the S curve is in order (Fig. 15). The S curve can illustrate the relationship of the input signal to

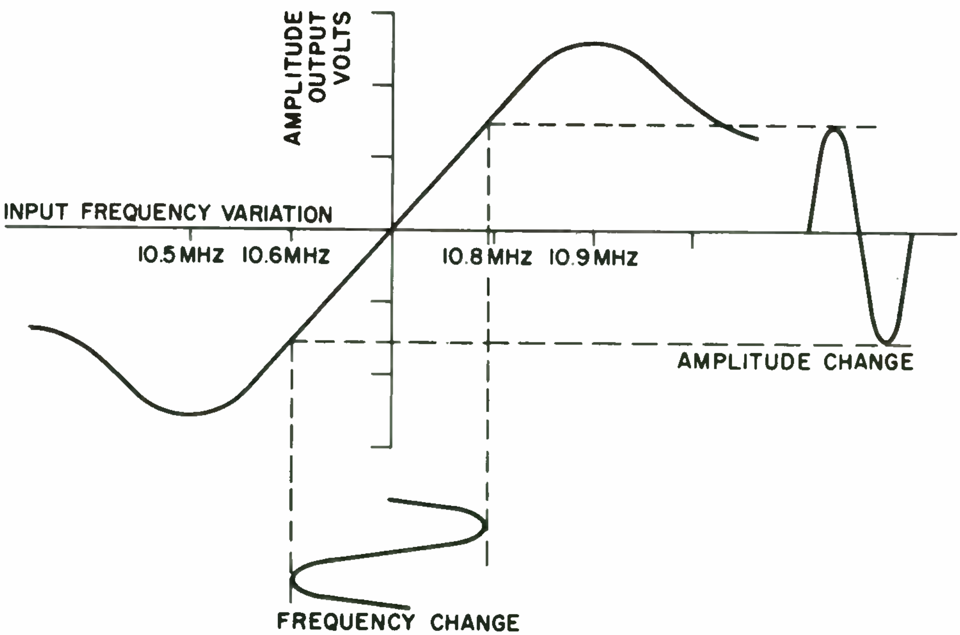


Figure 15 - An S curve illustrates the relationship between an FM frequency variation input signal and an audio amplitude output signal.

the output signal by showing in a general way that a *frequency change* is converted to an *amplitude change.*

GATED-BEAM TUBE

A unique approach to reducing the number of components in an FM receiver, and at the same time improve the performance, was the development of the Gated-Beam vacuum tube. The tube was so named, as it incorporates beam forming plates, and has three grids, two of which act as gates. This gated-beam tube is a pentode type, and is numbered 6BN6 (Fig. 16A). The circuit used with it is similar to many other circuits using pentode tubes, with one exception. A tuned circuit connected to grid No. 3 is the difference. Grid No. 3 is directly connected to the parallel combination of C and L which is tuned to resonate at the IF of 10.7 MHz.

The internal construction of the gated-beam tube is shown in Figure 16B. The electrons emitted by the cathode are restricted to a narrow beam in their path to the plate. This narrow beam of electrons can be controlled more accurately by the three grids. The first grid (G1), functions in a normal manner, allowing electrons to flow during the positive half of the input signal. Grid G2 acts to reinforce the variations of the electron beam on its way to the plate.

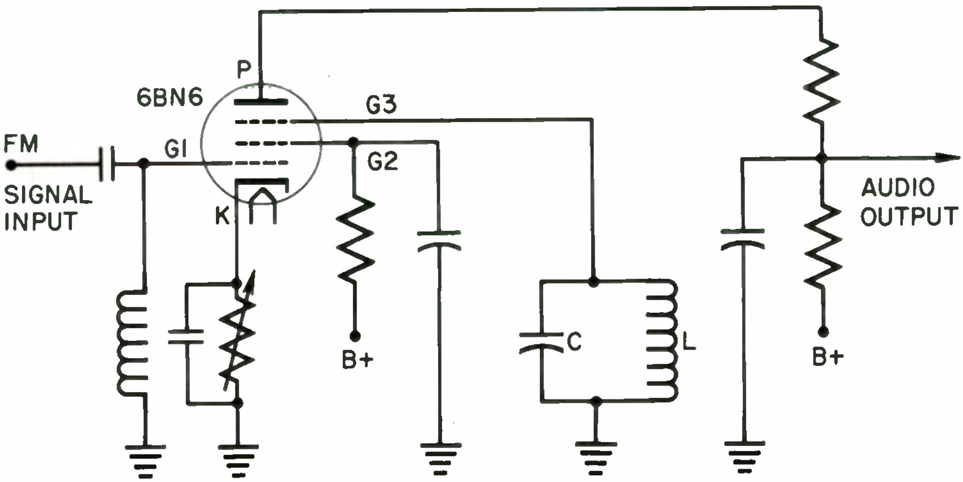
The electron beam increases in intensity during the positive half of the input signal but does not flow during the negative half of the input. This action is produced by the signal grid (G1). The electron stream now appears to be varying the third grid (G3). Also, the electrostatic charge produced by the electron stream on grid G3 has the effect of creating a current flow in the resonant circuit that is tuned to the IF signal frequency. It is the variation in the positive half of the input signal that appears to grid G3 as a varying electrostatic charge. This electrostatic charge on grid G3 produces a current in the resonant circuit connected to it. When a current flows in a circuit it produces a voltage that leads the current, and thus a voltage appears at grid G3.

This voltage at grid G3 is 90 degrees out-of-phase with the signal input voltage impressed on grid G1. But, this phase difference is exactly 90 degrees only when there is no signal on the carrier. When the incoming FM signal is varying in frequency, the phase difference between grids G1 and G3 varies. It is this difference in phase that affects the electron flow and produces a variation in the plate current flow at an audio rate. Because the voltage on grids 1 and 3 are 90 degrees out of phase, grid G3 is sometimes referred to as the quadrature grid.

The tube is so designed that the plate current will reach a maximum value no matter how high the positive value of the incoming signal voltage becomes. Thus, unwanted amplitude variations are eliminated.

Another tube that is used in FM receivers is the 6DT6. It functions in

A A CIRCUIT USING A GATED-BEAM TUBE.



B INTERNAL ARRANGEMENT OF THE ELEMENTS IN A GATED-BEAM TUBE.

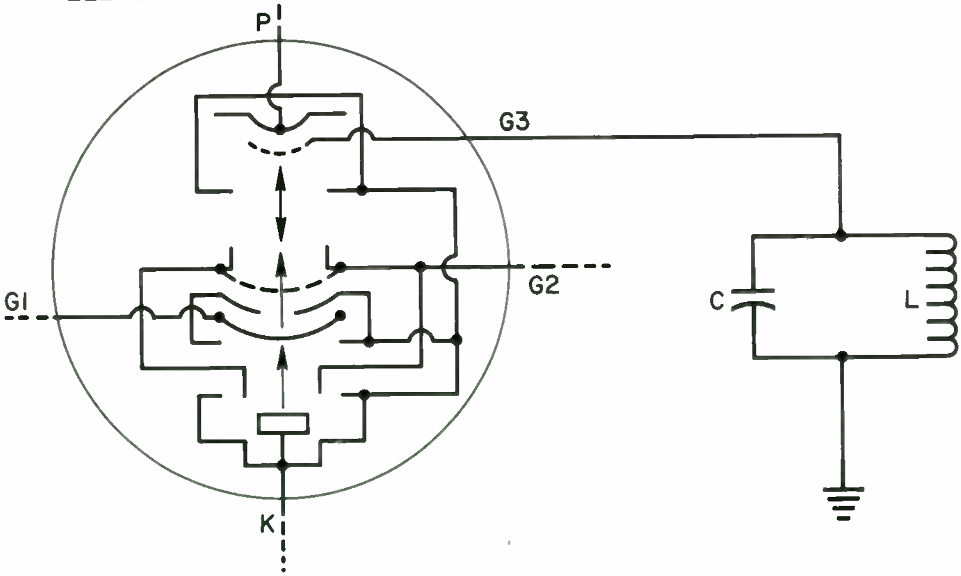


Figure 16 - The Gated-Beam vacuum tube.

somewhat the same manner as the 6BN6. It is a pentode type tube and its internal structure is not as complex as the 6BN6. It also has the characteristic of improving a weak FM signal.

The manufacturers of present day FM tuners and receivers are using solid state components, due to their low cost. Some older receivers might still need tubes replaced of the type described to return the equipment to its original operation condition.

TELEVISION SOUND

Television sound is transmitted by FM and consequently the TV receiver must have the equivalent of a complete FM receiver circuit. The TV picture information is an AM signal. Thus the TV channel contains both an AM picture signal and an FM sound signal.

A TV channel is simply a definite width of frequencies in the radio frequency spectrum that was chosen by the FCC for the transmission of a TV signal. The width of every TV channel is 6.0 MHz wide to allow the AM picture signal enough room for its wide frequency swings. This 6 MHz is only wide enough to accommodate the upper sideband of this video signal. The FM sound signal is located exactly 4.5 MHz above the position assigned to the carrier frequency of the AM signal.

The bandwidth of the TV tuner is wide enough to accept the two signals that are located in this 6.0 MHz frequency range. After amplification of this composite TV signal, the FM signal at 4.5 MHz is directed to the FM portion of the receiver. The separated FM signal appears to the receiver as an FM signal that has a center or carrier frequency of 4.5 MHz. Thus, the sound-IF frequency of most TV receivers is 4.5 MHz, and the signal from this point is handled like any other FM signal, reproducing voice and music without any extraneous noise or static in the speaker(s).

FIDELITY

A frequency modulated signal deviates from its center frequency at the rate of the audio signal that is modulating it. This FM signal is almost unlimited in its ability to transmit and reproduce the original audio. The increase in frequency of the audio signal causes an increase in deviation, with 75 kHz on either side of the carrier frequency set aside for this modulated signal. Even though an FM signal produces good fidelity, compensating systems and devices are employed at the FM transmitter, primarily for noise suppression or to compensate for the variations in the response of the human ear to audio frequencies. The human ear does not "hear" low frequencies as well as they do the higher frequencies, so transmitters and receivers are designed to give music hall quality to the audio.

Due to the wide range of the radio spectrum that is available for each FM signal, it is possible to transmit additional signals within this frequency spread. Placing one additional signal within this frequency spread has permitted the transmission of stereo signals. The transmission of stereo signals is accomplished without upsetting the transmission of the single or monaural signal. The grouping of two signals results in a composite FM stereo signal, and the method used to form this stereo signal is described in a later lesson.

Hi-Fi

Hi-Fi is an abbreviation for "High-Fidelity" and is many times applied to receivers that do a poor job of reproducing a signal with initially good fidelity. Hi-Fi is not confined solely to the reproduction of classical music, as it is just as important to reproduce fine jazz, rock, or country and western music. High-fidelity is the ability to reproduce an original signal as faithfully as possible, complete with all inherent harmonics, with a full dynamic range, undistorted, without an "electronic sound." To reproduce a signal as faithfully as possible is a costly thing to do. But most manufacturers reach a happy compromise in their designs and accurately call their products "high-fidelity receivers," because they are much better than those previously available. Audio amplifiers that are virtually distortion free, are extremely expensive and the expense of the receiver (tuner) or reproducers (speakers) must be added to this cost.

Stereophonic Sound

Stereophonic sound (stereo) is sound coming from two sources so that our ears will receive the sound from two directions just as we would hear it when listening to a live performance. Whether it is stereo tapes, records or FM radio, stereo sound requires two amplifiers, and two reproducers. However, the stereo FM signal requires only one tuner, since it carries two separate modulated signals on the same carrier separated by 38 kHz. But, if we wish to have Hi-Fi quality, we must use high quality components to obtain Hi-Fi reproduction in stereo.

A recent innovation is the quadrophonic sound which is, as its name implies, sound coming from four sources. This system requires twice the number of amplifiers and reproducers, as a stereo system requires.

Disadvantages of High Fidelity

The combination of record players, tapes, and FM radios into a single package comes naturally because of the use of high fidelity reproduction in all three units. The frequency response limitation of 5 kHz for each sideband in an AM signal requires the AM broadcast studio to use high quality amplifiers so that distortion will be minimized. What appears to be distortion in AM broadcasts is actually the loss of the higher frequencies in the audio range. The advantage of such an AM radio transmission system is that playing records that have not been recorded with the best fidelity will not sound much worse than those of high fidelity records, except for mechanical noise and wow (uneven rotation of a turntable causes wow in the signal). When this AM signal is heard on high-fidelity amplifiers, all transmitter errors and distortions become extremely noticeable.

Not all commercial FM stations take advantage of the high-fidelity available with the FM type of transmission. In fact, many receivers are not capable of handling the full audio frequency range required to produce high fidelity. For example, in a given area, there might only be a few FM stations really concerned enough about high fidelity to make a concerted effort to transmit the full range available with classical music, drama, lectures, etc. The processing of a high-fidelity signal can become quite expensive for both the station and the listener.

Problems of the Repair Shop

The problem of the service technician sometimes becomes one of public relations. Too often the customer complains that their transistorized portable radio doesn't sound as good as the "Hi-Fi" set in the house, and their Hi-Fi set doesn't sound as good as the neighbor's. The problems here are quite complex. Before the service technician can determine how good the quality of sound reproduction should be, he must acquaint himself with the reproducers, amplifiers, and in fact, even the RF and IF sections of the receiver to determine their capabilities. The service technician must also be familiar with the quality of transmission generated at the station. Since there is no necessity to monitor the FM broadcast for overmodulation as in an AM broadcast, the soft passages may be too weak for the listener and the strong passages too loud. If the home installation has a good quality 25 watt speaker, which far exceeds the possible listening amplitude of the human ear even in a large room, it will take a maximum signal without damage or distortion. However, a 0.5 watt speaker used in a transistor portable radio would literally blow apart. The voice coil could shake loose from the cone, or the overload would be so distorted that it would appear to be noise. But, transistors themselves do have the capability of absorbing an overload and small portables are designed to handle a minimum amount of power output. The service technician must realize that although high-fidelity is a specialized field in its own, he must be prepared to have some answers for the questions of the customer.

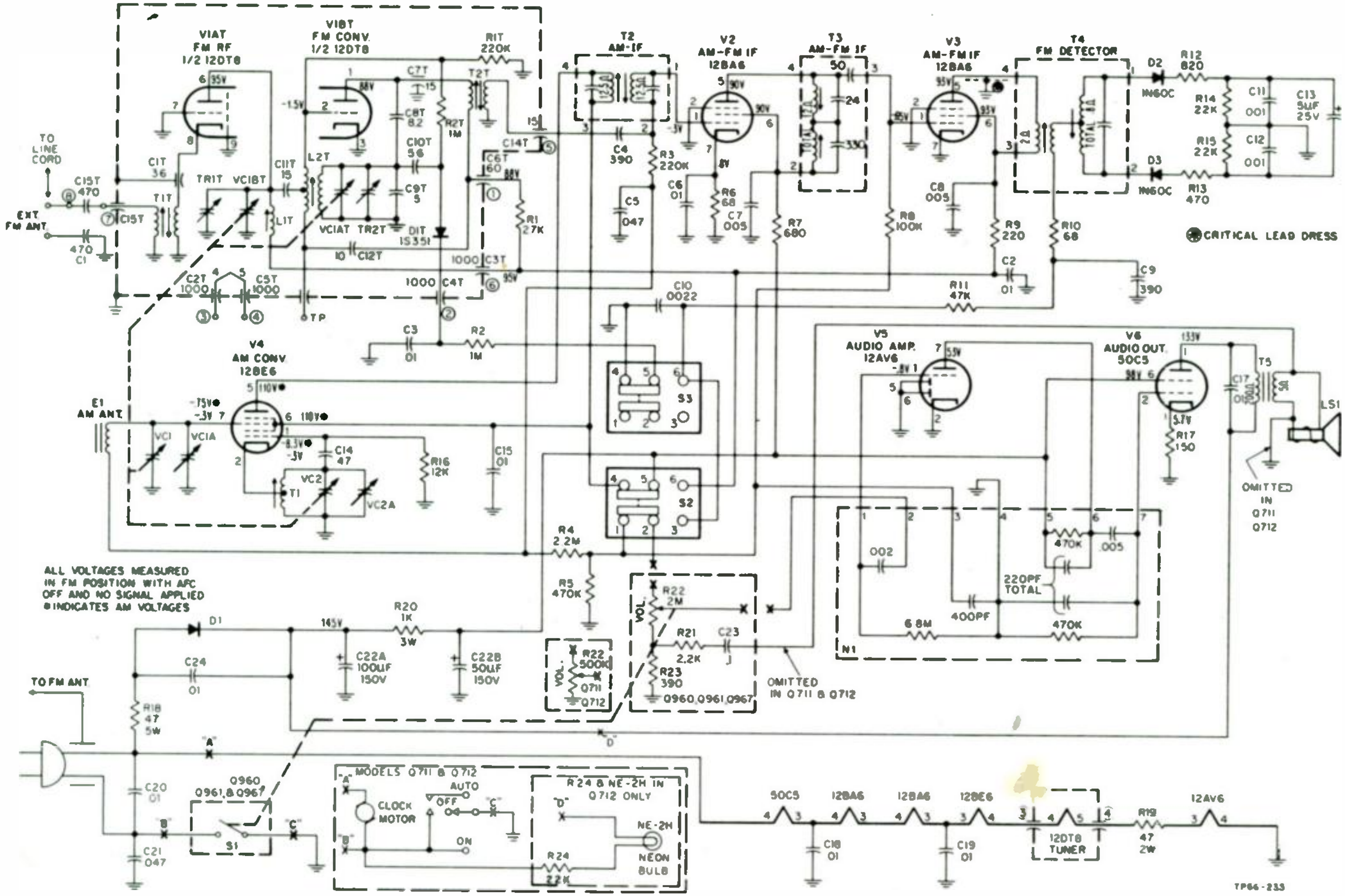
Stereo and Mono Reception

One of the requirements of the FCC is that certain systems be compatible with each other. One of these is that FM receivers must receive both stereo and mono signals. This means that even though a receiver is equipped with multiplex circuitry for stereo, it must also be capable of reproducing a monophonic broadcast with the same equipment. The reverse is not true, however, since not all receivers are equipped with the multiplex system used for stereo reception.

TYPICAL CIRCUITS

Clock/AM-FM Radio

The diagram in Figure 17 illustrates different versions of the same AM-FM



Schematic Diagram, Models Q711, Q712, Q960, Q961, & Q967.

Figure 17 - A composite circuit diagram used for five models of clock radios. Courtesy of Philco-Ford.

receiver circuits. This one circuit diagram is used to illustrate the schematic diagram(s) for five models of receivers made by this manufacturer. The components for all five models are shown on one diagram, together with notes to advise the serviceman which parts are used in which model. The student should spend some time tracing the circuit to obtain a further understanding of how table radios of this type operate.

Television Receiver

The circuit diagram of Figure 18 combines a digital clock with the TV receiver. This is a well laid out diagram, and it has an uncluttered appearance because most of the B+ connections are simply indicated, and not drawn in. An interesting review for the student is to trace the Bb voltage from the power supply point to all of the points on the diagram that show that they are connected to the supply. Note that the value of the Bb supply voltage is 350 volts, yet the actual voltages at the plates of the vacuum tubes are much less. This indicates that some portion of the supply voltage is dropped across the resistors in series with the plates.

An enlarged view of the FM amplifier circuit is shown in Figure 19. The FM signal is taken from the plate circuit of the last video amplifier tube V5. The tube is identified as a "VIDEO AMP, V5, ½ 10DX8/P," and it tells the serviceman that the filament voltage is 10 volts, and this half of the tube is the pentode section. This can be verified by counting the elements, and confirming that the "P" on the diagram stands for pentode.

The transformer T151 in the plate circuit is tuned to 4.5 MHz, and the secondary of this transformer directs the signal to the grid of the other half of the same tube, identified as "SIF AMP, ½ 10DX8/T." This is the triode section, identified by the letter "T." This is the first Sound Intermediate Frequency amplifier, indicated by the abbreviation SIF. The signal is fed to the SIF/DET which is a 4DT6A tube type. This tube is similar to the 6DT6, with the exception that the filament voltage is 4 volts instead of 6, and generally the A indicates a second generation tube of the same type but with improved characteristics.

The 4DT6A is a so-called quadrature tube, as it employs a tuned circuit connected to the third grid. The inductor in the parallel tuned circuit is identified as L201, with the capacitor C209 and the resistor R206 connected "across" the coil. The plate load consists of the components in the dotted area termed Z203, with the DC supply connected to Bb. The capacitor C211 in the Z203 area couples the audio signal to the volume control and then on to the audio output tube V7.

Adjustment instructions for the alignment of the different circuits of this TV receiver are included in the repair manual prepared by the manufacturer. Sometimes repair instructions of this type indicate the use of expensive test equipment, which many service people do not have. An example of this is the very complete

SCHEMATIC DIAGRAM OF MODEL AN-112T & AN-112TC

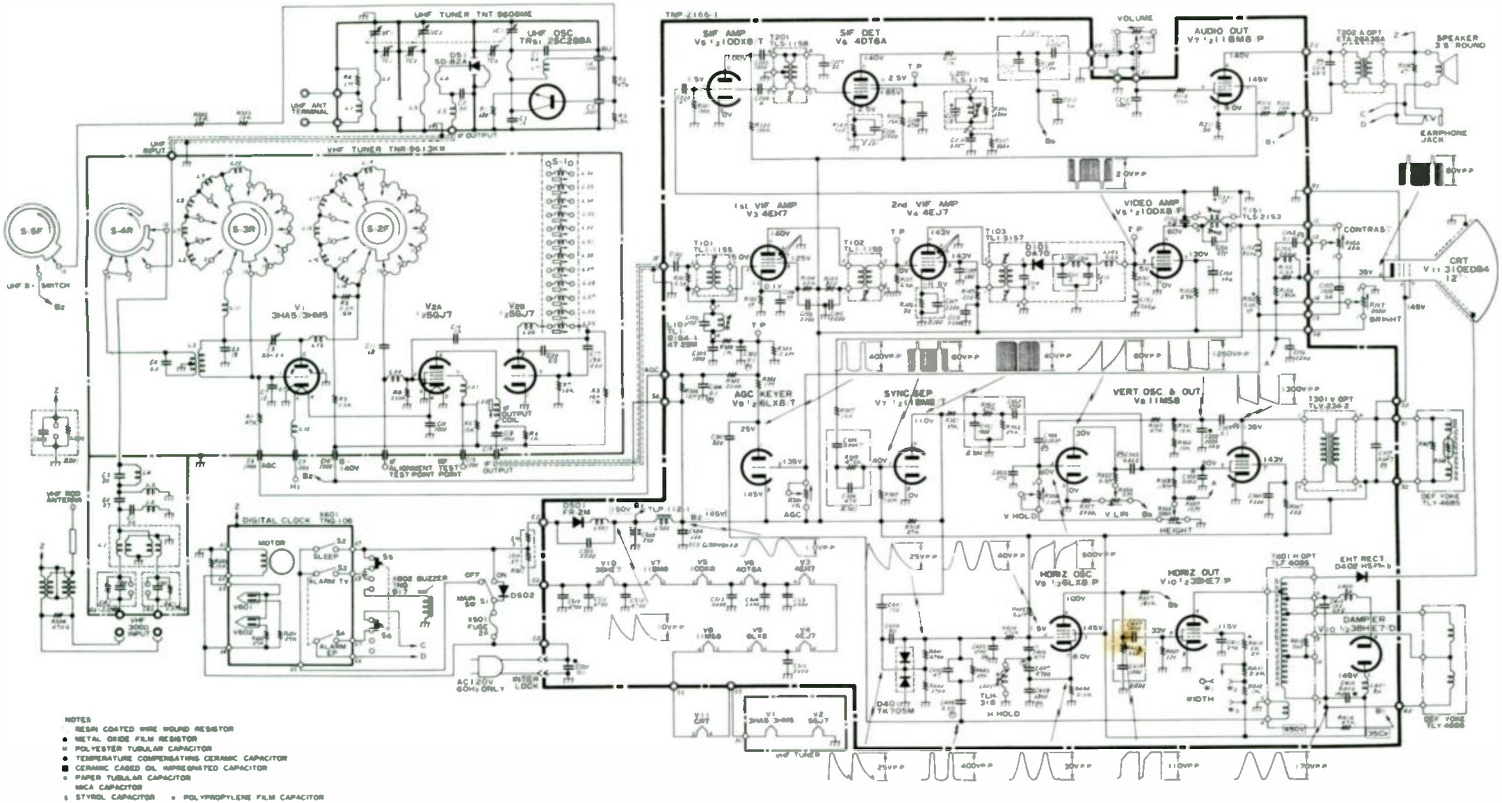


Figure 18 - This circuit diagram clearly shows how the FM sound signal is removed from the video signal and directed through the IF amplifier and detector. Courtesy of Panasonic.

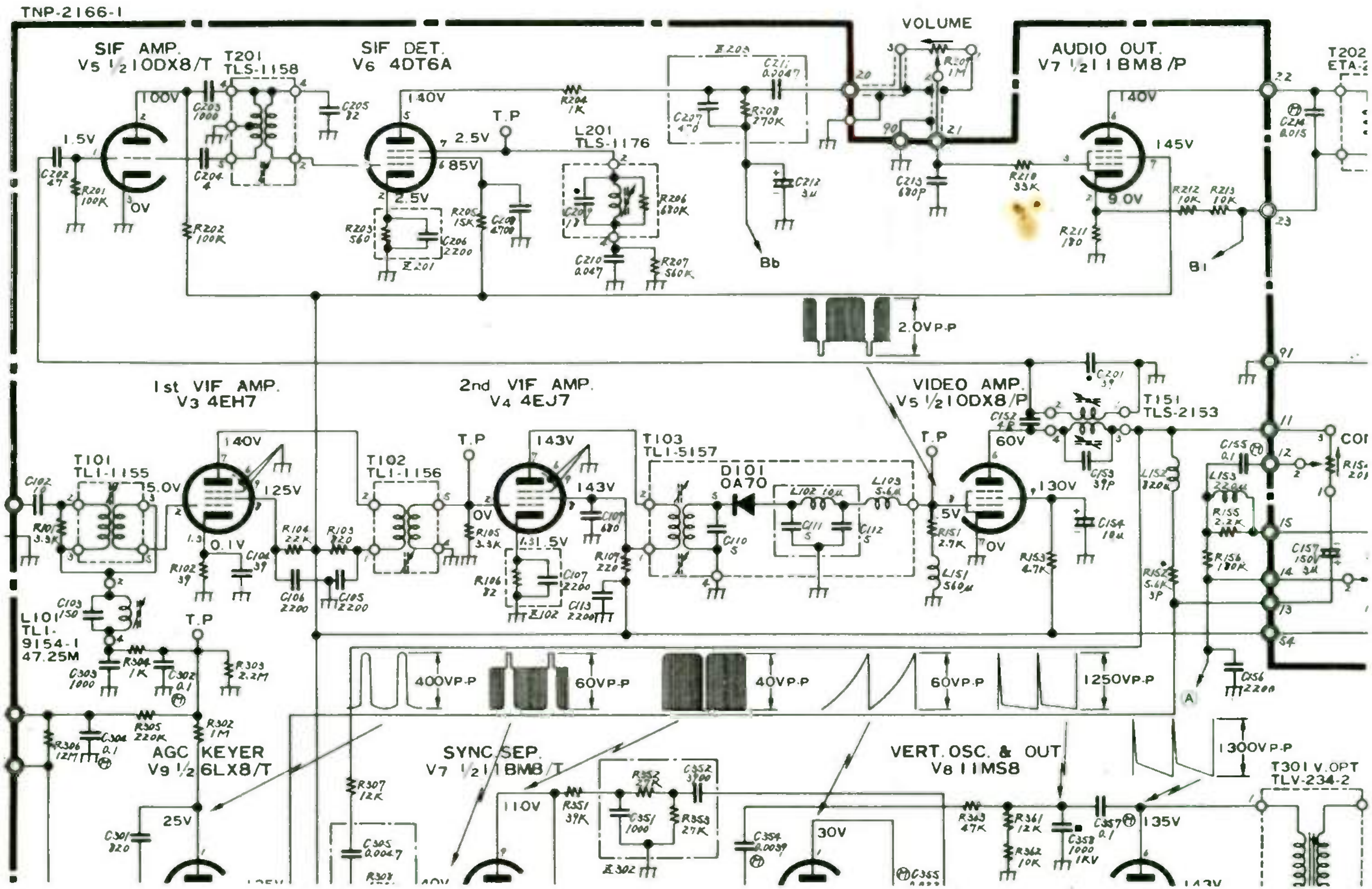


Figure 19 - An enlarged view of the sound IF and detector circuit of Figure 18. Courtesy of Panasonic.

"Sound IF Alignment" instructions that are followed by the manufacturer's service shop, or by a service shop that is equipped with this type of test equipment (Fig. 20).

It is a rare occurrence for the FM sound strip to need a complete realignment, but when it does, the manufacturer's instructions should be followed exactly, providing the proper test equipment is available. If, however, the equipment is not on hand, it is best to have this portion of a receiver aligned by a service shop that has the proper equipment. Many service shops are equipped to service certain types of radios or TV sets. As they can do these repairs quickly and at a reasonable cost, your customer will get the best repair service. The service charge to your customer will include a mark-up from your cost, to cover the pick-up and delivery of the customer's set to the specialty shop for the repair of this specific trouble.

SUMMARY

When a radio frequency carrier wave is varied in frequency by an audio signal, a frequency modulated (FM) signal is produced. The frequency varies in step with the loudness of the audio signal, while the rapidity of the change in frequency is determined by the frequencies of the audio signal. The system used to generate the center, or carrier frequency must be designed to have a high degree of stability. Any frequency shift not due to the audio modulator will cause distortion.

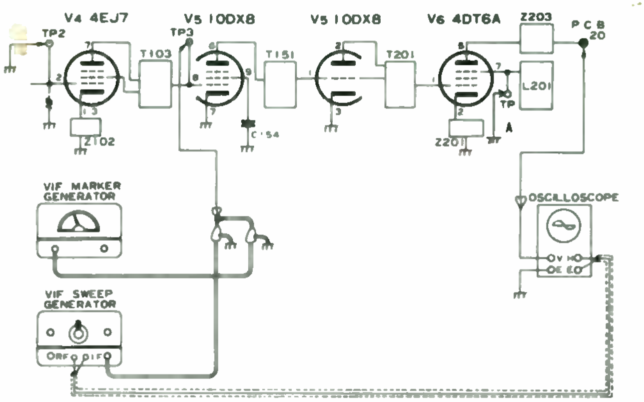
The demodulation of an FM signal requires that the wide swings of radio frequencies be converted into amplitude variations of the original audio frequencies. The relationship of the incoming radio frequency variations to the resulting outgoing audio frequencies form a characteristic S curve. The greater part of this curve should be linear, otherwise distortion will occur in the reproduced audio frequencies. Phase detection and ratio detector circuits are used as demodulators. Limiters remove any unwanted amplitude of the FM wave. Varying amplitudes of FM signals are produced by electrical noise, static, etc.

Special tubes and circuit arrangements have been developed to reduce the number of components in FM receivers and to improve the circuit characteristics. Good fidelity is a usual characteristic of FM, but all receivers, including those equipped to receive stereo FM, do not necessarily fall into the Hi-Fi classification.

Circuit diagrams are extremely helpful in tracing a signal through a receiver. Even though each manufacturer uses slightly different circuit designs, many of the troubles are similar and can be traced and solved easily after some service experience. The more difficult problems will usually require a complete service and repair manual to aid in diagnosing and correcting the difficulty.

SOUND IF ALIGNMENT

1. Connect the oscilloscope to the output of the sound detector (20).
2. Connect the sweep generator to TP-3.
3. Ground pin 2 (TP-2) of V4 (4EJ7).
4. Ground pin 7 of V6 (4DT6A).
5. Adjust the secondary of T-151 and T-201 for maximum response and the 150KC band width shown in step (A).
6. After adjustment of T151 and T201 lift the ground on pin 7 of V6. Adjust L201 to center the 4.5 Mc marker as shown in step (B).
   Lack of band width or improper slope indicates realignment of T151 & T201 is necessary.



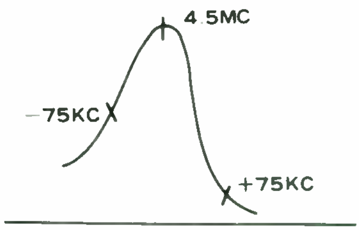
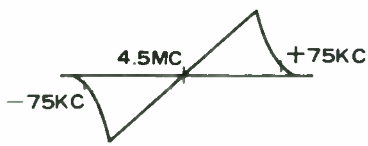
STEP	A	B
INJECTION POINT	OSCILLOSCOPE . . . . . . DETECTOR OUT P.C.B 20 SWEEP GENERATOR . . TP 3	OSCILLOSCOPE . . . . . . DETECTOR OUT P.C.B 20 SWEEP GENERATOR . . TP 3
ALIGNMENT	T151, T201	L201
RESPONSE CURVE		

Figure 20 - Sound IF alignment. Courtesy of Panasonic.

TEST

Lesson Number 36

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 52-036-1.

1. A transmitted frequency modulated signal shows
   - A. changes in frequency and amplitude.
   - B. changes in amplitude only.
   - C. changes in frequency only.
   - D. no changes at all.

2. The bandwidth of the FM signal
   - A. is the same as AM.
   - B. is much wider than AM.
   - C. is much less than AM.
   - D. varies above and below that of AM.

3. The IF frequency of the conventional FM receiver is
   - A. 456 kHz.
   - B. 10.7 kHz.
   - C. 4.5 MHz.
   - D. 10.7 MHz.

4. An FM transmitter produces frequency modulated signals
   - A. by using the audio signal to alter the amplitude.
   - B. by using the audio signal to alter the phase or frequency of the RF.
   - C. by placing the audio signal on the carrier and using the modulated signal to beat against the carrier.
   - D. by letting the RF amplifier run wide open.

5. Demodulation of the FM signal is obtained by
   A. simple rectification.
   B. filtering.
   C. ratio detectors or discriminators.
   D. using a single diode.

6. The audio section of a high quality FM receiver, as compared to an AM set, has
   A. lower gain at the low frequencies.
   B. lower gain at the high frequencies.
   C. a non-linear frequency response curve.
   D. good frequency response over the entire audio spectrum.

7. The result of limiting action is
   A. a limited number of stations being received.
   B. a limited and constant amplitude of the FM signal.
   C. to produce unwanted noise.
   D. a stereo signal.

8. One characteristic of stereophonic sound is that it requires
   A. only one audio amplifier.
   B. two tuners.
   C. only one reproducer.
   D. two audio amplifiers and two reproducers.

9. The sound IF frequency in a television receiver is
   A. 455 kHz.
   B. 10.7 MHz.
   C. 4.5 MHz.
   D. 3.58 MHz.

10. Television sound is
   A. transmitted by FM.
   B. transmitted by AM.
   C. video.
   D. characteristic of low frequency response.

Notes

Notes

Notes

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SERVICE

There are very few professions in life where you can see the results of your efforts – "Service" is one of these professions.

Too often, you lose your identity and become just a cog in a gear, never experiencing the satisfaction that comes from performing a satisfactory service job, a job profitable to you, your company, and/or customer.

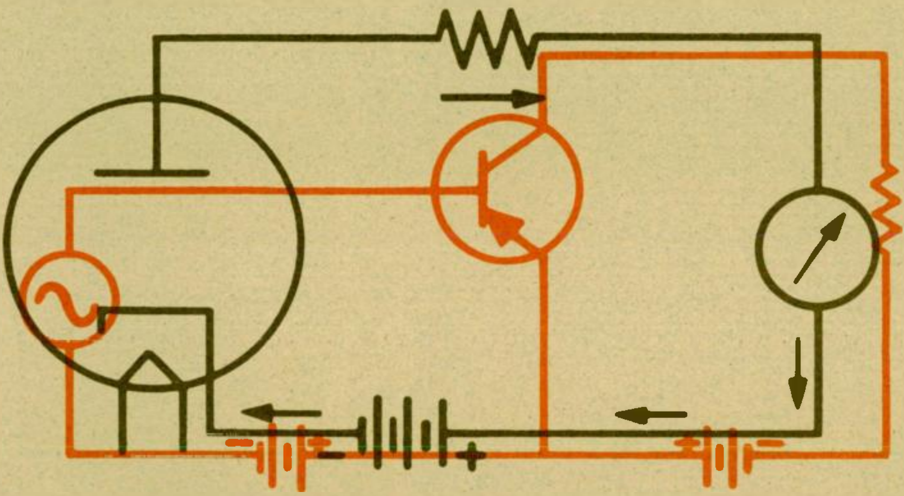
Yes, there is monetary reward for performing good service. But far more important than the monetary reward is the feeling of pride you get; the pride every professional Radio & T.V. Service Technician has as a result of your initiative, good training and good planning.

Your prosperity depends a great deal on how well you provide service and how you serve your customers. No company can prosper very long without giving courteous, reliable and helpful service. Be proud of the fact that the good service you provide plays an important part in the future of your Company and yourself.

S. T. Christensen

LESSON NO. 37

COMPOSITE SIGNALS & MULTIPLEXING



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-037

403

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CONTENTS

COMPOSITE SIGNALS AND MULTIPLEXING

INTRODUCTION

In earlier lessons we discussed how the many frequencies contained in voice and music could be impressed onto a single RF carrier and transmitted to distant points. This RF carrier, with its sidebands of sound information is handled almost as if it were a single frequency. This ability makes radio transmission possible with relatively simple equipment.

In radio transmission, variations of the RF carrier are caused by the audio signal. When wave analysis equipment became available, it was discovered that many gaps occurred in the carrier. During these intervals intelligence was not being transmitted on the carrier. It was theorized that the signal could be made more useful if information could be inserted into these gaps. Thus, a system of impressing several radiotelephone messages onto a single RF carrier was developed.

The receiver of these complex signals had to separate and route these conversations to the correct party. This required the transmission of additional information along with the elements of each conversation. The pulses or frequencies used to indicate the location of specific information appearing on the RF carrier are called *sync (synchronization) signals.*

Following the development of multiple message transmissions, a method for transmitting pictures by radio waves and telephone lines was developed. Soon, American and Europe were connected visually by the trans-Atlantic cable. This method of visual communication is known as *facsimile transmission.*

TRANSMITTING PICTURES

A study of any scene or picture reveals that, in addition to colors, the scene or picture is composed of infinite variations between pure white, through shades of gray, to black.

These variations are converted into electrical current impulses by using various strengths of current to represent various shades. Black, as an absence of light, is represented by zero signal current. Pure white, being the maximum amount of light, is represented by a maximum value of current. The current strengths representing gray shades vary between the maximum of white and the minimum of black. Thus, a picture can be impressed onto a carrier as a series of varying levels or amplitudes of current or voltage.

It is obvious that a scene cannot be viewed and transmitted as a whole any more than you can glance at a page of your text and instantly grasp its contents. Some means must be used to divide it into small portions.

A page of copy is not unlike a picture. Basically, it puts pictures into words arranged in sequential lines. To understand a word picture, a reader of English writing scans a line from left to right and interprets the various shades of meaning in the word combinations. At the end of a line the eyes travel rapidly back and down to the beginning of the next line.

A TV picture is constructed in a comparable manner. A scene is projected onto the light sensitive deposits on the face of a TV camera tube. This coating develops electrical charges throughout the projected scene with the strengths of the charges relative to the amount of light striking these deposits. In this way, the charges on the face of the camera tube coating vary in proportion to the lightness or darkness within the scene.

The face of the camera tube is scanned by an electron beam which produces an electric current proportional to the amount of charge encountered by the beam. The beam scans a narrow strip from left to right, is shut off at the extreme right and returned, shifting downward to scan a new line.

After the beam scans the last line at the bottom of the scene, the beam is shut off and returned to the upper left where it begins a new scan sequence. Each scan sequence is called a *field*.

Interlaced Scanning

The human eye retains an image for approximately 1/15 of a second. If the television frame rate (one complete picture) was 15 frames per second, motion would appear continuous but there would be an objectionable flicker. At a frame rate of 30 frames per second, the flicker is hardly noticeable. If the frame rate is increased to 60 frames per second, there is effectively no flicker. Although the television frame rate is 30 frames per second, an effect similar to 60 frames per second is produced through *interlaced scanning.* Interlaced scanning eliminates the annoying flicker associated with a lower frame repetition rate.

It was discovered that each frame (picture) could be reproduced in two parts called fields. Instead of scanning the scene completely each time, alternate lines were scanned. Thus, the beam scans all odd-numbered lines (1, 3, 5, etc.) during the first pass. On the second pass, it scans in-between these lines and displays information occurring during even numbered lines (2, 4, 6, etc.). Figure 1 illustrates lines of the first field with solid lines. The position of lines of the second field are shown with dashed lines. In the United States and Canada fields repeat at a 60-hertz rate. Since there are two fields to a frame, the frame or picture repetition rate is 30 hertz.

Figure 2 illustrates the scanning and reproduction of a bold capital letter U. The left half of the letter is purposely made lighter than the right half of the

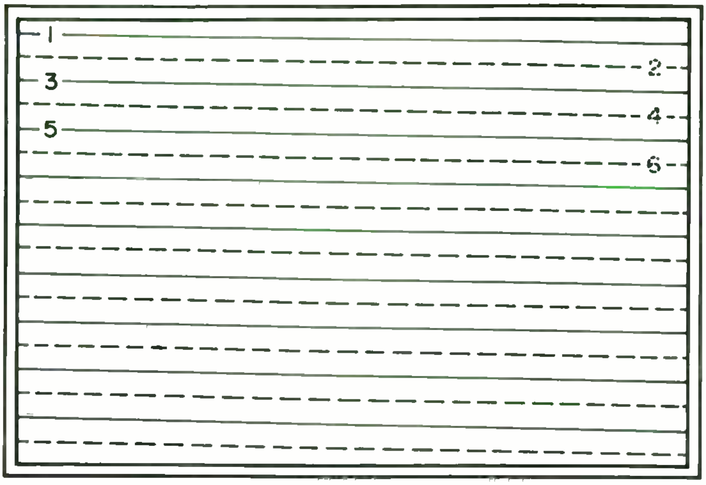

Figure 1 - Horizontal scanning to reproduce a picture on a CRT.

letter to illustrate the difference in signal strength required to reproduce it. Signal strengths relative to shade are shown to the right of the first frame.

A composite of the two fields forming a complete frame or picture is shown in Figure 2A. Although only 18 lines are used, the letter and its shades are easy to distinguish. Televised scenes are broadcast and then reproduced with more than 400 lines per frame. The total number of lines available is 525 per frame, but several occur during retraces when the beam is cut-off (blanked). Additional lines occur between fields and do not appear in the scene.

The signal levels on the odd numbered lines of the first field are shown in Figure 2B. A value of -1 has been assigned to the white background. The figure zero (0) represents black. The value for a gray shade, half-way between black and white, is -0.5, or one half the negative level for white.

There is a reason for using inverted polarity for the picture (video) portion of a TV waveform. The picture synchronizing signals always appear on the TV signal as positive pulses. Since the beam is blanked and the screen is dark for voltages above zero, the positive sync information will not cause interference in the reproduced picture.

Synchronizing Information

Figure 3 shows the three different beam movements during the reproduction of the first field. The horizontal lines of video information are shown as solid lines tracing across the screen from left to right.

The movement of the beam from the end of one scan line to the beginning of the next is called *horizontal retrace*. Horizontal retrace is indicated as dashed lines, moving from right to left (Fig. 3).

After the completion of the last line in each field the beam is moved from the bottom of the picture to the top starting position to begin reproducing the next field. This vertical retrace path is shown as a double line

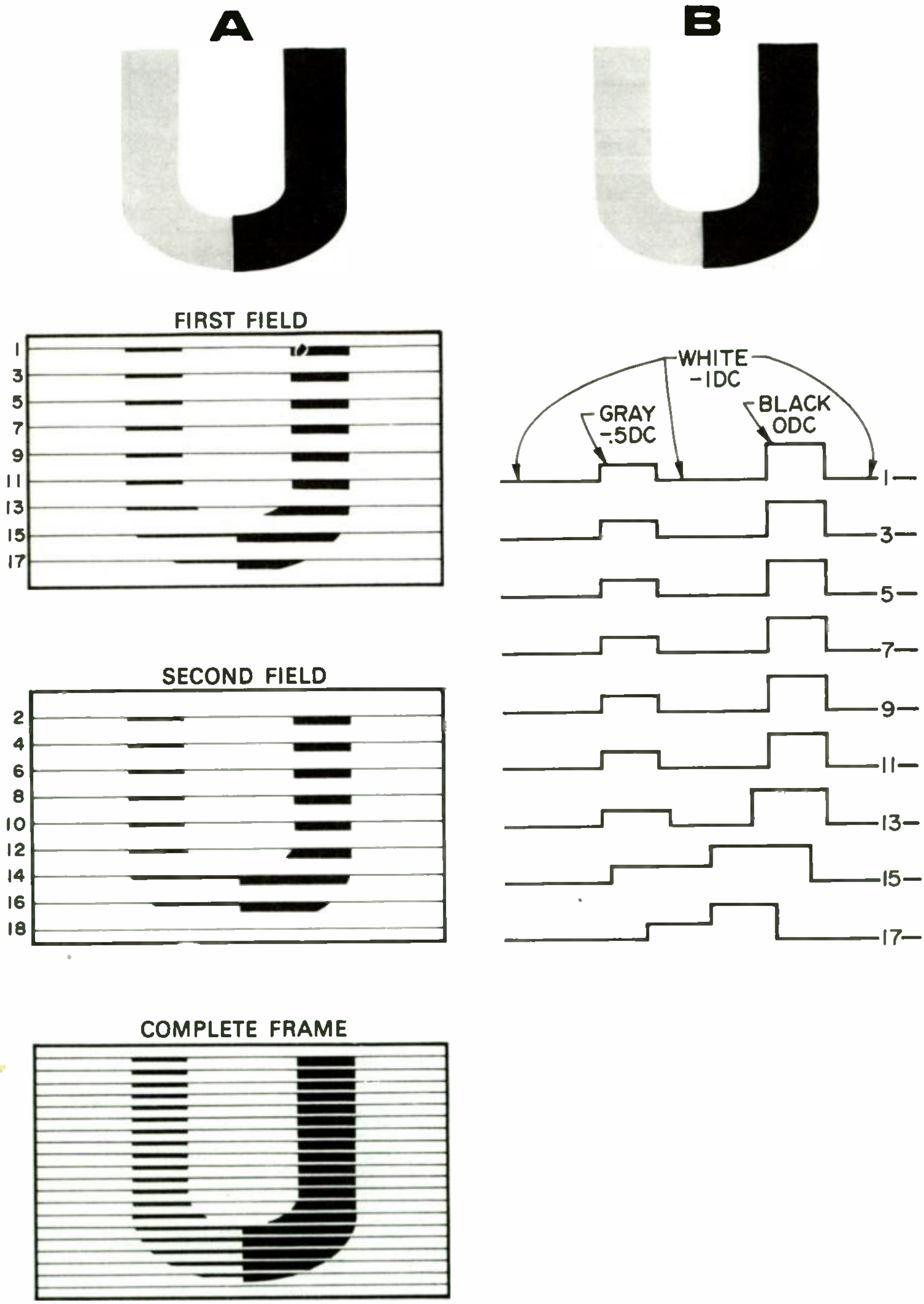

Figure 2 - A - Reproduction of the letter U by fields.
B - Signal levels associated with the letter U.

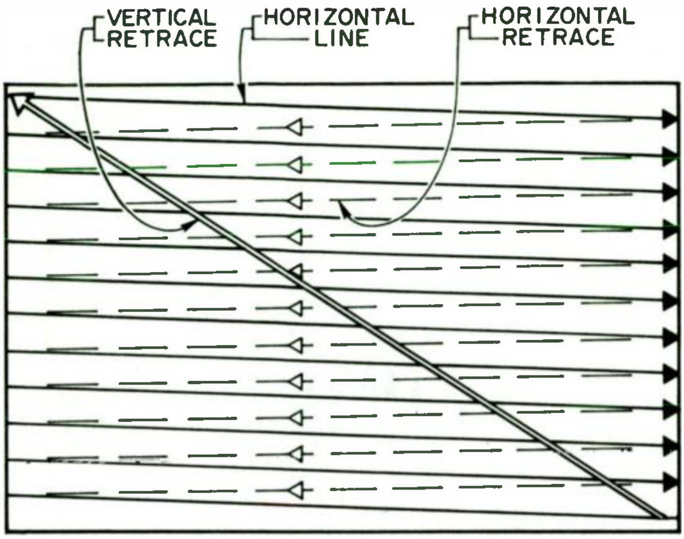

Figure 3 - Horizontal and vertical retrace.

from the lower right to upper left of the screen (Fig. 3). To begin tracing the second field, the beam positions itself between lines 1 and 3 of the first field.

Three types of sync information are present on the TV waveform. Horizontal sync pulses control the TV set's circuits to begin each horizontal retrace. Vertical sync information is present to advance the beam downward to each succeeding line and to return the beam to the beginning of each new field. The third sync signal, in addition to the horizontal and vertical sync information, is the blanking pulse. The set must be instructed to blank the beam during retrace. Unless the beam is blanked, glaring white lines will appear along the retrace path.

Figure 4 illustrates a line of video information with horizontal sync and blanking pulses. The sync pulse rides atop a broad pedestal. This pedestal is used to key the set's blanking circuitry. This pedestal is called the *horizontal blanking pulse.*

A line of video information is keyed by horizontal sync pulse 1 to begin its retrace at the end of the first line. No picture information is presented on the screen. The beam is cut off during retrace until after the trailing edge of blanking pulse 1 occurs. The beam sweeps across the screen producing light and dark segments relative to the levels on the video signal. After completion of a line of video information, the horizontal blanking pulse shuts off the beam and the horizontal sync pulse keys the set's sweep circuits to begin the retrace.

The vertical sweep circuit must sweep the electron beam down the face of the picture tube at the rate of 1 sweep in 1/60th of a second. The vertical sweep circuit must then return the electron beam to the top of the picture tube screen to await the scanning of another field. The period of a vertical sync pulse is 190 microseconds. This is approximately 3 times the period of a horizontal sync pulse, and is so long that the horizontal oscillator might lose synchronization during vertical retrace.

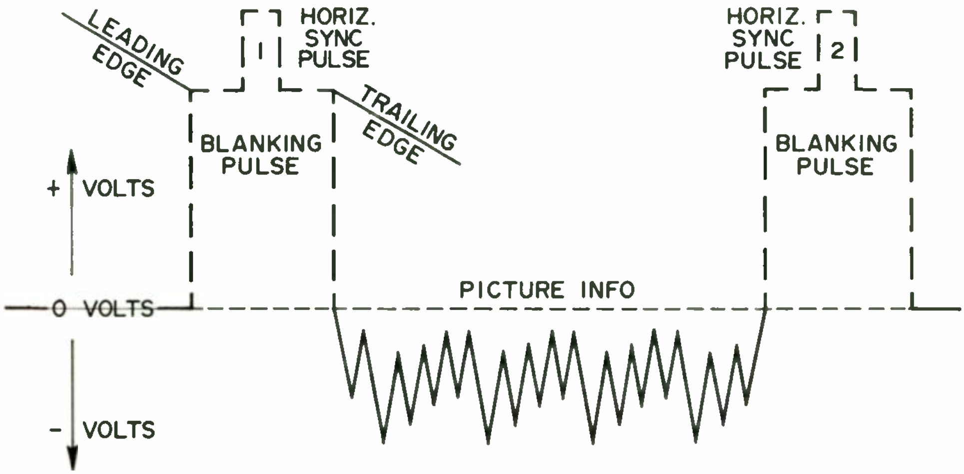

Figure 4 - Signal associated with a line of video information.

For this reason, the vertical sync pulse is serrated (cut into pieces). The vertical sync pulse is then integrated (Fig. 5) to form the required sawtooth waveform. The serrated vertical sync pulses are preceded by 6 equalizing pulses and are followed by 6 equalizing pulses as shown in Figure 6. Alternate equalizing pulses are also used to synchronize the horizontal oscillator during the long period of vertical retrace.

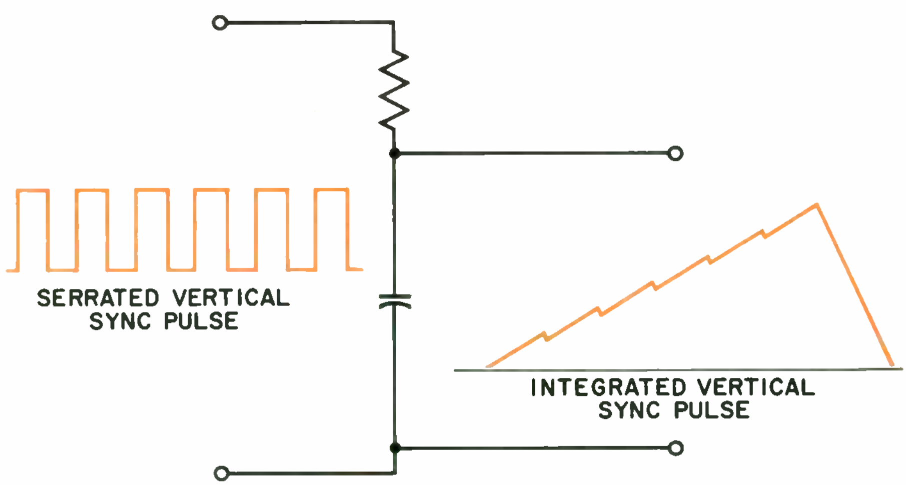

Figure 5 - Formation of the vertical sync pulse through integration.

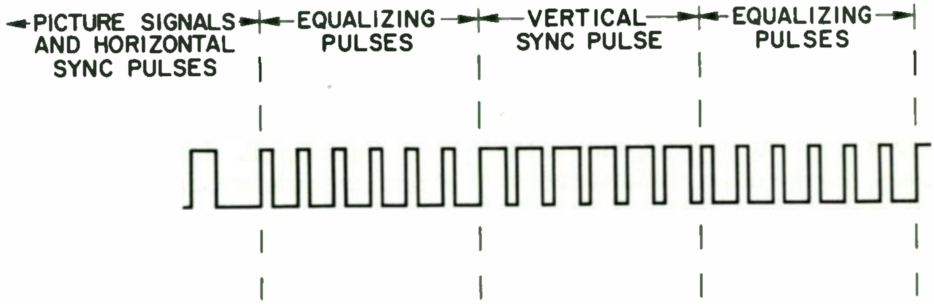

Figure 6 - Vertical sync and blanking.

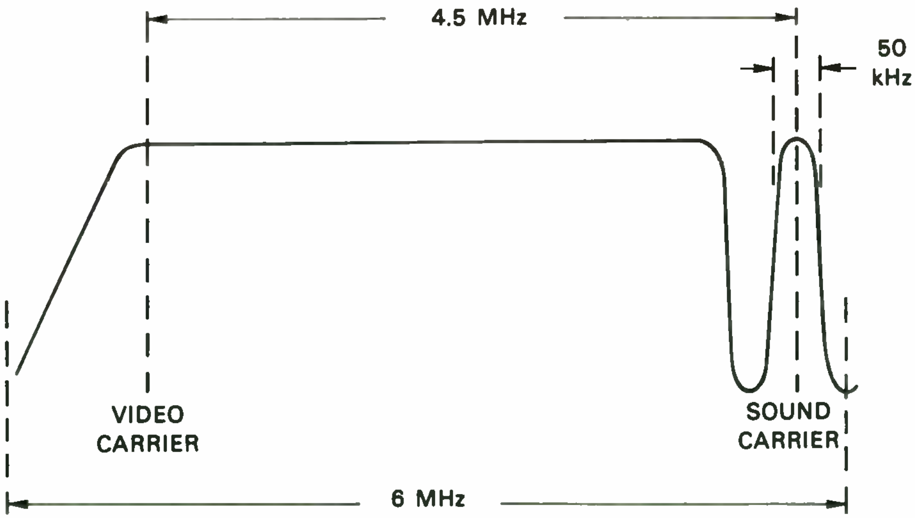

Figure 7 - Station curve for a TV channel.

The vertical blanking pulse blanks the beam for a total of 14 horizontal lines before vertical retrace occurs. After retrace, the beam remains blanked for approximately 4 lines. The group of fourteen blanked lines can be seen on your TV set by slightly misadjusting the vertical hold. Rotate the vertical hold until the picture moves slowly downward. At the end of the previous picture or immediately above the viewed picture, a broad dark stripe crosses the screen. Reduce the contrast and the individual horizontal lines become visible. Later, you will be shown how to identify some sweep problems by the appearance of this group of lines.

Video and Sound Carriers

Sound is frequency modulated onto a separate carrier and broadcast with the video and sync information. Figure 7 shows a TV channel curve with a width of 6 megahertz. The sound carrier is situated near the upper-limit channel frequency and the video carrier is 1.25 megahertz inside the lower limit frequency. The sound is separated from the video carrier by 4.5 megahertz.

Frequencies assigned in Figure 8 are for Channel 2. The FCC (Federal Communications Commission) has allocated frequencies between 54 megahertz and 60 megahertz for the broadcasting of Channel 2. The video carrier is located at 55.25 megahertz. The lower sidebands then can extend only 1.25 megahertz from the video carrier. The upper sidebands can extend to 59.25 megahertz. This permits the upper sidebands of the video carrier to extend 4 megahertz above the video carrier. The lower sidebands are attenuated gradually and then suppressed at a point 1.25 megahertz below the video carrier.

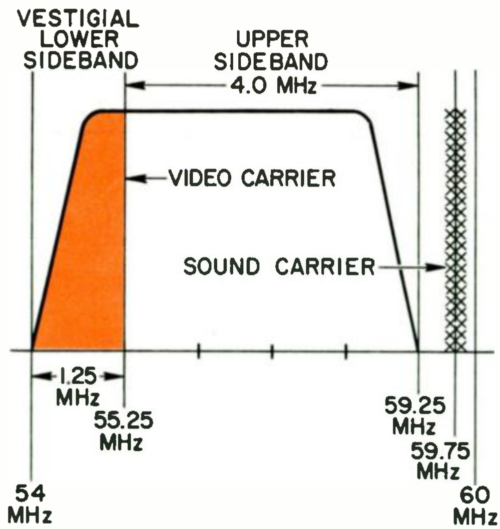

Figure 8 - RF frequencies associated with the information broadcast by Channel 2.

This method of broadcasting in which most of one sideband is suppressed is called *vestigial sideband transmission.* It permits transmission of the required information within the allotted 6 megahertz channel.

STEREO MULTIPLEXING

In the early 1960's, most FM stations began to broadcast stereo. Stereo is produced by individual microphones supplying separate audio signals from different sections of a sound production. Usually, the microphones are placed to the left and right of the production. This allows a musical group to be recorded and later reproduced with live performance sound. When listening to a stereo set, the left ear receives sounds from the left speaker and the right ear receives sounds from the right speaker. The effect is similar to facing a group of live musicians (Fig. 9). The left and right signals are abbreviated "L" and "R." The two channels of stereo sound equipment are called L and R channels.

Figure 9 shows a block system in which two mikes feed individual sounds into a stereo multiplexer. This multiplexer produces a complex audio signal that is used to modulate the RF

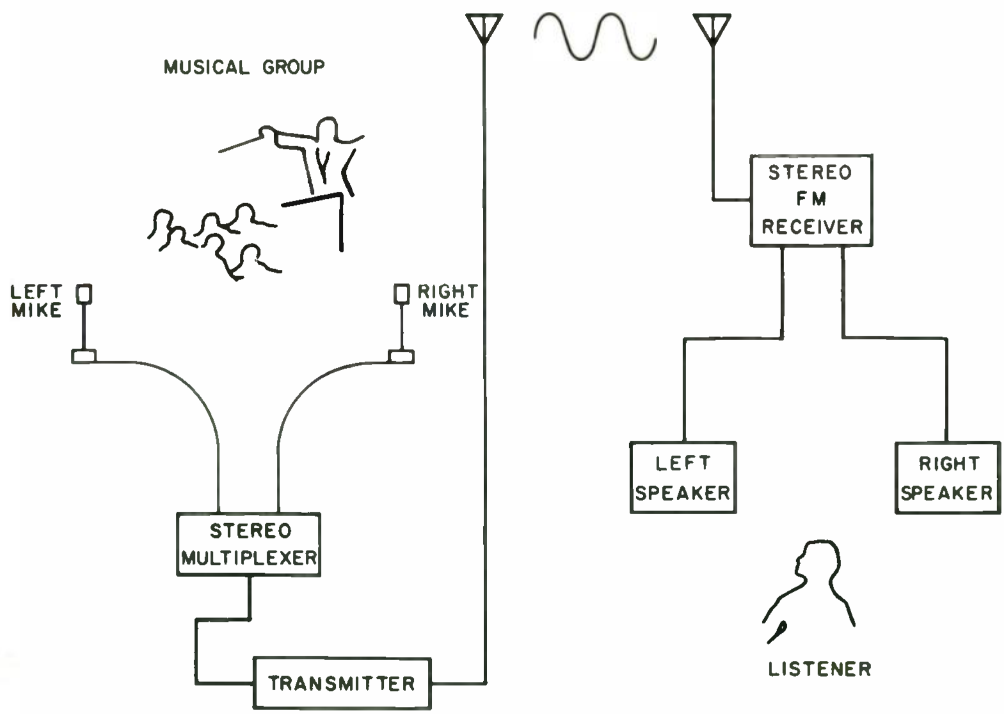

Figure 9 - Stereo FM broadcast and reception.

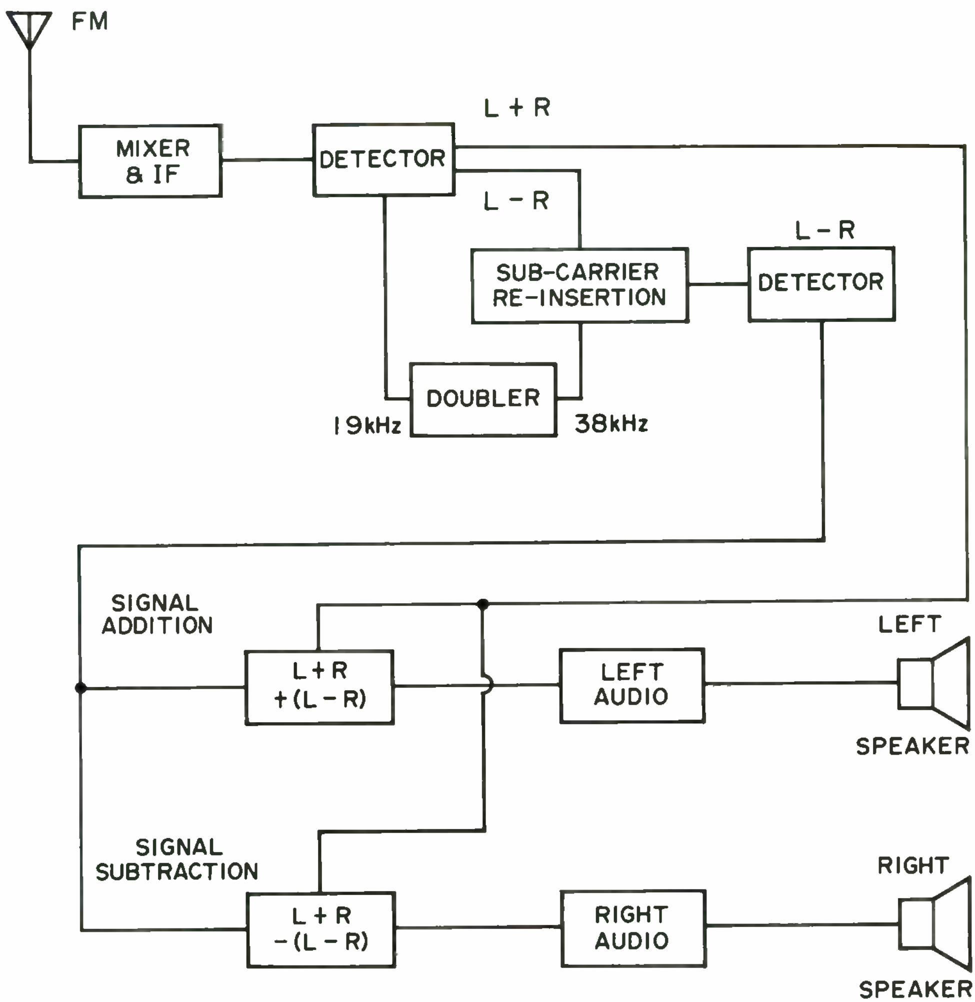

Figure 10 - Processing of L+R and L-R information in a stereo FM receiver to reproduce the right and left channels.

carrier. The signal is broadcast as if it were one group of sound frequencies. This signal can be received and processed by ordinary FM sets as single channel sound.

When a stereo set receives a stereo broadcast, it separates the sounds associated with the L and R information and presents them to L and R speakers through L and R audio amplifiers.

L−R and L+R Signals

Stereo is broadcast not as L information and R information but as sum and difference signals of the original L and R information. An L+R signal frequency modulates the FM carrier producing sidebands of + and - 15 kilohertz.

Subcarrier (38 kHz)

A difference signal (L-R) amplitude modulates a 38 kilohertz subcarrier. The subcarrier is suppressed, but its sidebands containing L-R information modulates the FM carrier. The upper and lower sidebands of the L-R information are 38-53 kilohertz and 23-38 kilohertz respectively. A 19 kilohertz pilot carrier is transmitted along with the audio information. This 19 kilohertz pilot carrier is doubled to 38 kilohertz and reinserted in the stereo receiver as the subcarrier for the L-R information (Fig. 10). The L-R information can then be amplitude detected. Combining the two signals, (L-R and L+R) the L and R information is recovered. Thus, adding the two signals reproduces the L signal.

$$\begin{array}{r} L + R \\ L - R \\ \hline 2L \end{array} \text{ (Fig. 10)}$$

Subtracting the two signals results in recovery of the R information.

$$\begin{array}{r} L + R \\ -(L - R) \\ \hline \end{array} \quad \text{or} \quad \begin{array}{r} L + R \\ -L + R \\ \hline 2R \end{array} \text{ (Fig. 10)}$$

The addition and subtraction is done by phase comparison in one case and by inversion of one signal before comparing the phase in the other case.

After extracting the L and R information, it is simple to reproduce the sounds. The R information is routed through the right audio amp and speaker and the left audio information through the left audio amp and speaker. Figure 11 shows the frequency division of the stereo FM signal. Notice that the pilot carrier is located between the L+R and L-R information. This makes it easily recoverable and free of interference.

THE COLOR TELEVISED PICTURE

At the beginning of a color televised transmission, the scene is separated into three groups of color information by the color camera. These colors are red, blue, and green. Voltage variations are produced relative to the brightness of each color. A pure white scene produces a 59% green signal, a 30% red signal, and a 11% blue signal. Percentages of color signals different from these are produced for different colors.

After the scene is reduced to the colors red, green, and blue, the signal information representing each of these

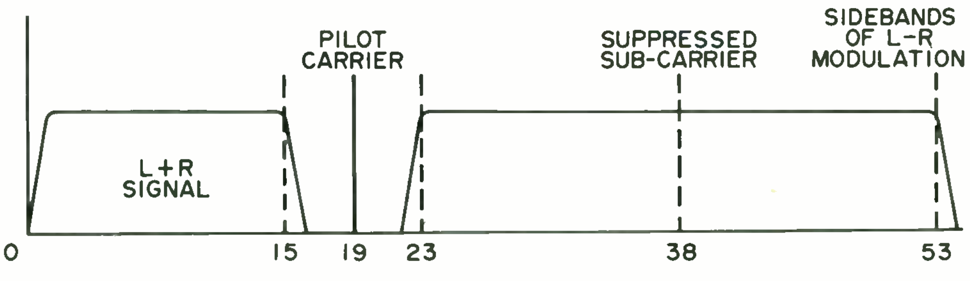

Figure 11 - L +R and L -R positions on the FM carrier.

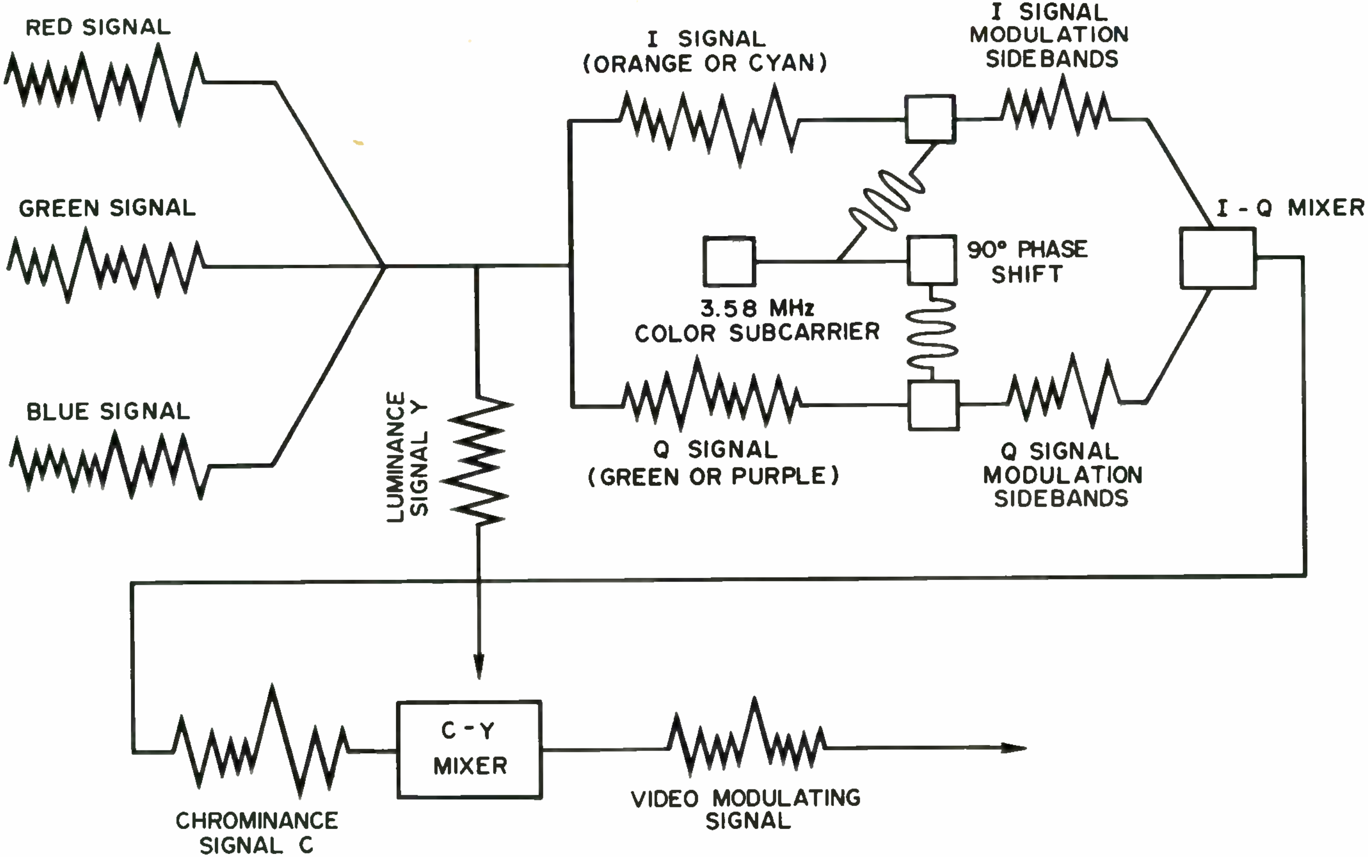

Figure 12 - Processing color information for broadcasting.

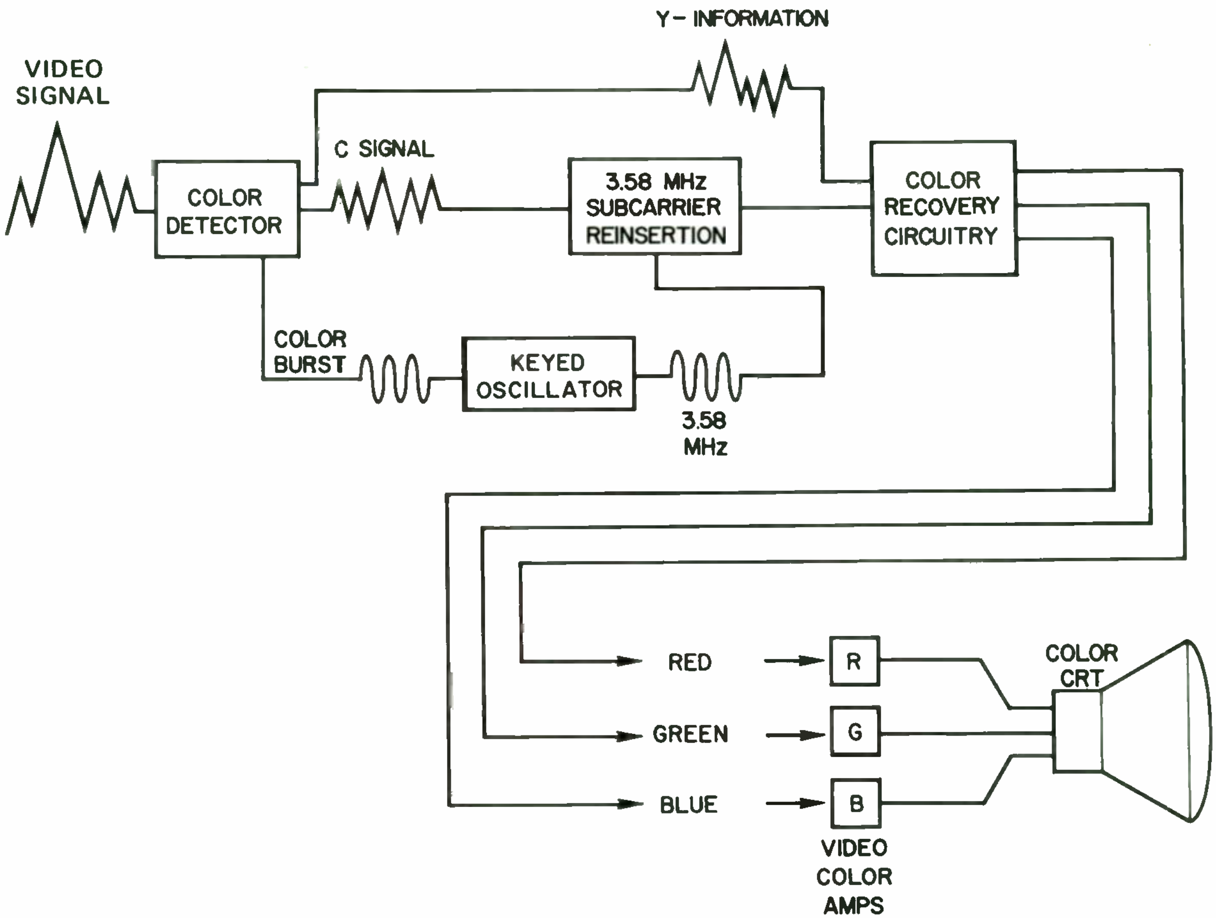

Figure 13 - Reproducing color pictures.

colors is processed individually and then combined to modulate the video carrier. They must be combined in order to keep the resulting sidebands within the allotted channel width.

Figure 12 shows color signals being processed and combined to form first two and then one signal that contains both the luminance (brightness) and the chrominance (color) information.

Luminance Signal (Y)

The signal used by the ordinary black-white receiver to reproduce a picture is an average brightness signal. In color receivers, this signal is called
10 the *luminance signal.*

Chrominance Signal (C)

By combining the three color signals, red, green, and blue, two new signals are produced. These two signals, I and Q, contain all the color information originally contained in three signals. The I signal, representing colors between orange and cyan, modulates a 3.58 megahertz subcarrier. This 3.58 subcarrier, is then shifted 90° in phase and modulated by a Q signal. The Q signal represents colors between green and purple. The two subcarriers with their modulating information are then combined and the 3.58 subcarrier frequency is suppressed. Only its sidebands are transmitted. Finally, the C (chrominance) signal is combined with the Y (luminance) signal. The result is used to modulate the video carrier.

A few cycles of the 3.58 megahertz color subcarrier are inserted onto the blanking pulse pedestal behind the horizontal sync pulse. This is called the *color burst* and it is used by the color receiver to separate groups of color information (Fig. 13).

COLOR REPRODUCTION

Luminance and chrominance signals are detected and separated in the color set. The 3.58 megahertz subcarrier is re-inserted and the I and Q informa-

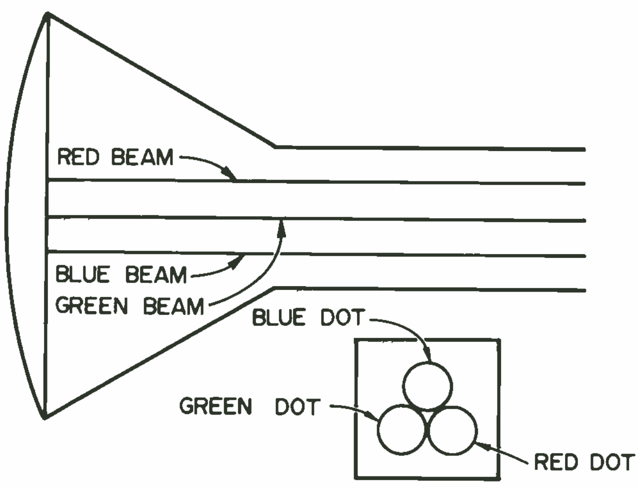

Figure 14 - Color CRT with color dots.

tion is recovered. The original color information is derived by comparing the phase differences between the I and Q signals' subcarriers. Red, green and blue signals are routed to the color CRT where they control the strength of the electron beams from red, green, and blue guns. As the three beams sweep across the CRT each one strikes its associated color dots. Thus the red beam energizes red dots, the green beam the green and the blue beam energizes blue dots. These dots are located in groups of three, one for each color (Fig. 14). The color produced by each group is a combination of the light emitted by all three.

The information presented in this lesson is intended only to acquaint you with composite waves and their uses. They will be discussed in much greater detail in later lessons along with the equipment used to process them.

SUMMARY

A picture is a combination of variations in shading between white and black. The human eye tends to blend these variations together and form a picture of an object. This natural blending action of the human eye makes television possible.

The television receiver receives a signal and rapidly scans the face of the picture tube reproducing the scene transmitted by the television station. The television receiver reproduces 30 frames per second. Using interlaced scanning, the television receiver effectively eliminates flicker. Synchronizing pulses are transmitted as a part of the composite signal to synchronize the television receiver circuits with the transmitter. This maintains the picture tube scanning circuits in synchronization with the television camera scanning circuits.

FM stereo requires a separate signal for the left channel and right channel speaker circuits. A multiplexer is incorporated at the transmitter to produce a complex audio signal that is used to modulate the RF carrier. Stereo signals are transmitted in the form of an L + R signal and L - R signal. A subcarrier is utilized to transmit the L - R signal. At the FM receiver the two signals are amplified, detected, and then fed to separate L and R audio channels.

A color television signal contains actually two separate color information signals. The luminance (brightness) signal and the chrominance (color) signal. These signals are combined in a color television receiver to reproduce a color picture. The color television picture tube uses a phosphor screen containing many red, blue, and green phosphor dots arranged in a particular pattern. These three colors, when combined in the correct percentages, can produce any visible color.

....

TEST

Lesson Number 37

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 52-037-1.

1. The pulses used to recover information from a composite signal are called ________ signals.
   A. carrier
   B. synchronization
   C. AM
   D. FM

2. Television pictures are transmitted by separating the scene into
   A. lines.
   B. blocks.
   C. circles.
   D. audio signals.

3. A method of scanning was developed for television that prevented an annoying flicker from occurring between pictures. It is called ________ scanning.
   A. vestigial
   B. sequential line
   C. field
   D. interlaced

4. Televised pictures are reproduced in two
   A. fields.
   B. horizontal lines.
   C. frames.
   D. shades.

5. A horizontal sync pulse triggers __________ after each line.
   A. horizontal retrace
   B. vertical retrace
   C. horizontal blanking
   D. vertical blanking

6. Vertical sync pulses trigger __________ after each field.
   A. horizontal retrace
   B. vertical retrace
   C. horizontal blanking
   D. vertical blanking

7. The sound carrier on a TV waveform is __________ the video carrier.
   A. mixed with
   B. modulated by
   C. not separated from
   D. separated from

8. Stereo FM is broadcast
   A. in the UHF band of frequencies.
   B. as sums and differences of right and left channel information.
   C. on two separate channels.
   D. on two subcarriers.

9. L-R stereo information modulates a 38 kilohertz
   A. carrier.
   B. second channel.
   C. pilot carrier.
   D. subcarrier.

10. Color information is contained in a mixture of two signals
   A. subcarrier and luminance.
   B. subcarrier and chrominance.
   C. luminance and chrominance.
   D. none of the above.

Notes

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LONG HOURS?

Some people gripe after working 8 hours a day and then are asked to put in an extra hour or so without pay. Many others feel that an 8 hour day is too long and when they get home just can't find time for anything but rest.

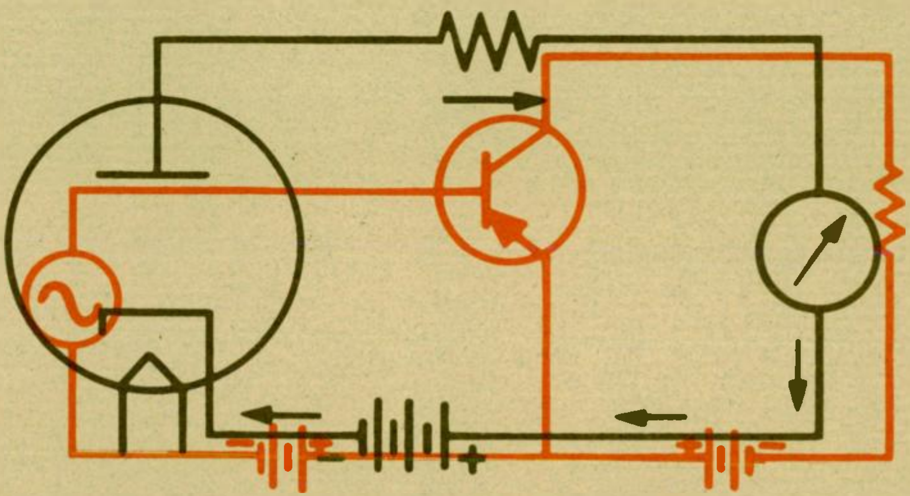
I doubt very much if you are such a person. If you were, you would not be taking this training because you would not be able to find the "time" to complete your lessons.

The time you are spending right now — reading this lesson — this paragraph — is time you are not getting paid for — at this moment. Later on, you will reap a nice return for this time. It is this self-discipline that counts. Keep it up and your rewards will be many and large.

S. T. Christensen

LESSON NO. 38

FREQUENCY CONVERSION



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FREQUENCY CONVERSION

REQUIREMENTS OF RECEIVERS

Early radio receivers were crude by today's standards. Various innovations were added to improve their performance, but they still failed to satisfy some of the major requirements for good reception. These requirements are:

1. sensitivity.
2. selectivity.
3. fidelity.

Sensitivity

Sensitivity is a measure of a receiver's ability to receive weak signals. With modern devices and techniques, adequate sensitivity ceases to be a problem; even radios costing less than ten dollars will bring in distant stations.

Selectivity

Selectivity refers to the ability of a receiver to separate stations. It is the ability to tune in a desired station or channel and exclude all others.

Fidelity

Fidelity is a receiver's ability to faithfully reproduce the sounds impressed on a radio carrier. Modern Hi-Fi sets can reproduce a full orchestra with concert hall fidelity.

Early radio receivers were mostly crude, *tuned radio frequency* (TRF) types. They passed the incoming signal through several tuned RF stages for amplification. To receive a station all tuned stages were tuned to the frequency of that station. In addition, all stages must be simultaneously adjustable to any station frequency within the band being received.

In the case of AM broadcast reception, all stages must be able to *tune* or *track* simultaneously to any station frequency between 540K hertz and 1600 K hertz. Mistuning of one or more stages at any station frequency results in poor reception. This was often the case with TRF receivers because it is almost impossible to adjust several tuned circuits to track over a broad band of frequencies.

Early in the history of communications, a system was devised that converted frequencies within a receiver's tuning range to one standard frequency. This signal was then amplified by fix-tuned stages, having high gain. The superheterodyne receiver was born from this principle: "frequency conversion by heterodyning."

HETERODYNE PRINCIPLE

In an earlier lesson, we discussed cross products of two or more frequencies. Under certain conditions, frequencies can add or subtract to form new ones. Any new frequency formed under these conditions is numerically related to those from which it is developed. The heterodyne will be either the mathematical sum or difference of the two original frequencies.

A common method of producing a third frequency is by beating two frequencies together within a vacuum tube, transistor, or diode used as a mixer. A high Q tuned circuit resonated to the heterodyne frequency follows the mixer and serves as an output load.

The chart in Figure 1 shows several examples of the results when two frequencies are combined in a mixer. The first frequency (Fig. 1A) is 1,000 hertz and the second is 700 hertz. Subtracting the second from the first

$$\begin{array}{r} 1000 \\ -\ 700 \\ \hline 300 \end{array} \text{ hertz.}$$

produces a new frequency or heterodyne of 300 hertz. Another heterodyne frequency (1700 hertz) is produced when the two add:

$$\begin{array}{r} 1000 \\ +\ 700 \\ \hline 1700 \end{array} \text{ hertz.}$$

In Figure 1B, we show the results of beating 1000 kHz with 1455 kHz. The lower frequency heterodyne is

$$\begin{array}{r} 1455 \\ -1000 \\ \hline 455 \end{array} \text{ kHz}$$

This frequency (455 kHz) is produced by the mixer stage in nearly all AM broadcast receivers. It is then amplified hundreds of times by the receiver's intermediate frequency (IF) section. The third heterodyne produced (Fig. 1C) results when 100 MHz is beat against 89.3 MHz. The result, 10.7 MHz, is the frequency amplified by the IF sections of most FM broadcast receivers.

FREQUENCY CONVERSION

The diagram in Figure 2 is a mixer tube (also called a converter stage). Input and output signals are illustrated along with an injected signal from the receiver's local oscillator. The received signal is 1400 kHz and the local oscillator has been tuned to a frequency that will produce a difference of 455 kHz between it and the input. The oscillator frequency selected is 1855 kHz.

The pentode mixer stage shown in Figure 3 is representative of those used in many receivers. Its associated components will be described in the following paragraphs and in their related figures.

Antenna Transformers

The antenna transformer shown in Figure 4A is the type used in some

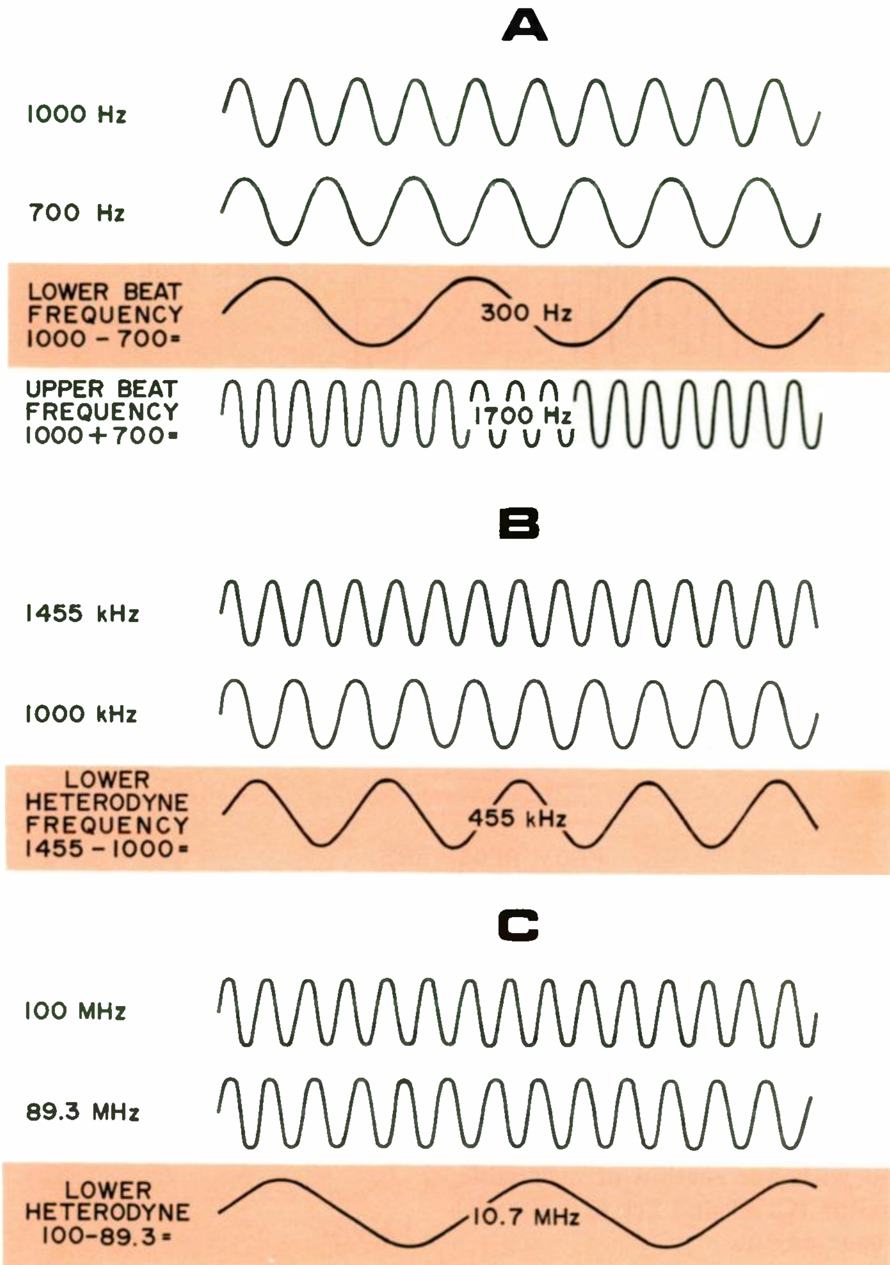

Figure 1 - Beat frequencies.

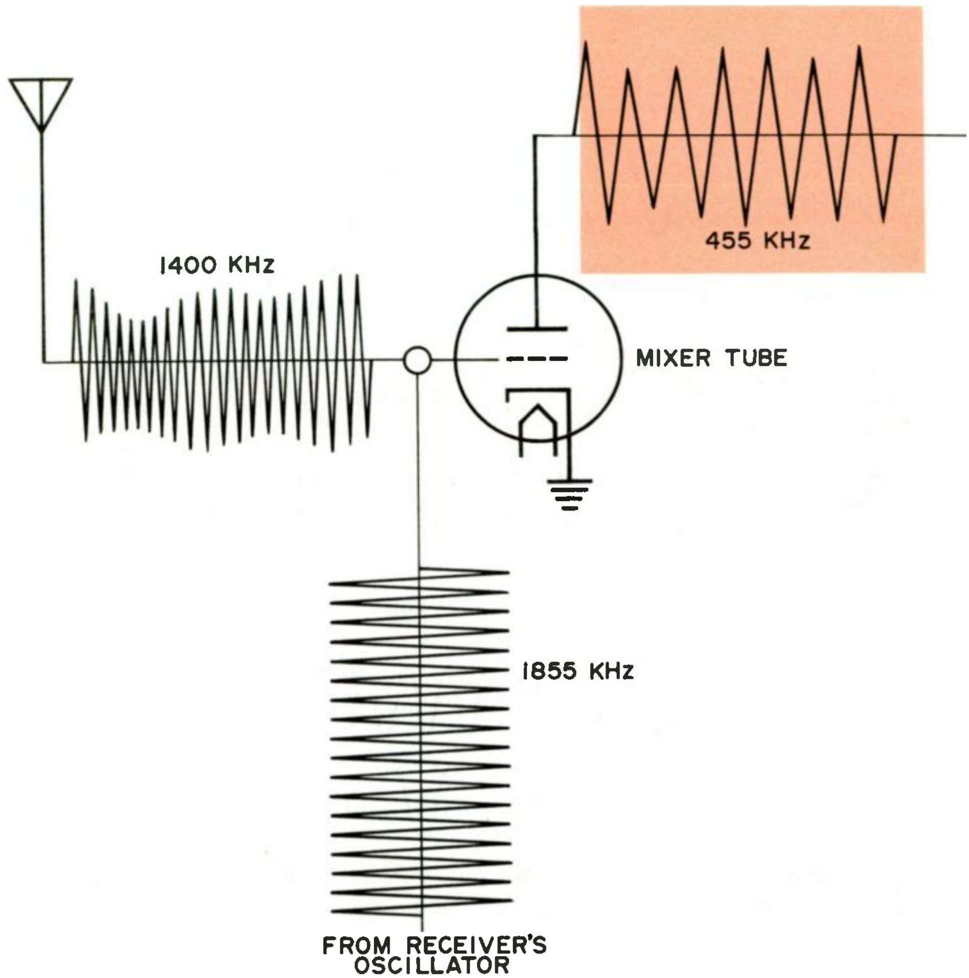

Figure 2 - Mixer stage with input and output signals.

broadcast receivers. It has an untuned primary (L1) inductively coupled to a tuned secondary (L2). The resonant frequency of the secondary can be varied with one section of a variable capacitor (C_{1A}) and act as a parallel resonant circuit.

Signal currents are induced in the antenna by intercepted radio waves. These signal currents flow through L1 to ground. Large circulating currents are induced into the secondary, the frequency of which is determined by the setting of variable capacitor C_{1A}. Signal voltages at this frequency are developed across the terminals of L2.

Mixer

The vacuum tube shown in Figure 4B with its associated components is a mixer stage. The voltage developed across cathode resistor R_K causes the control grid to be negative

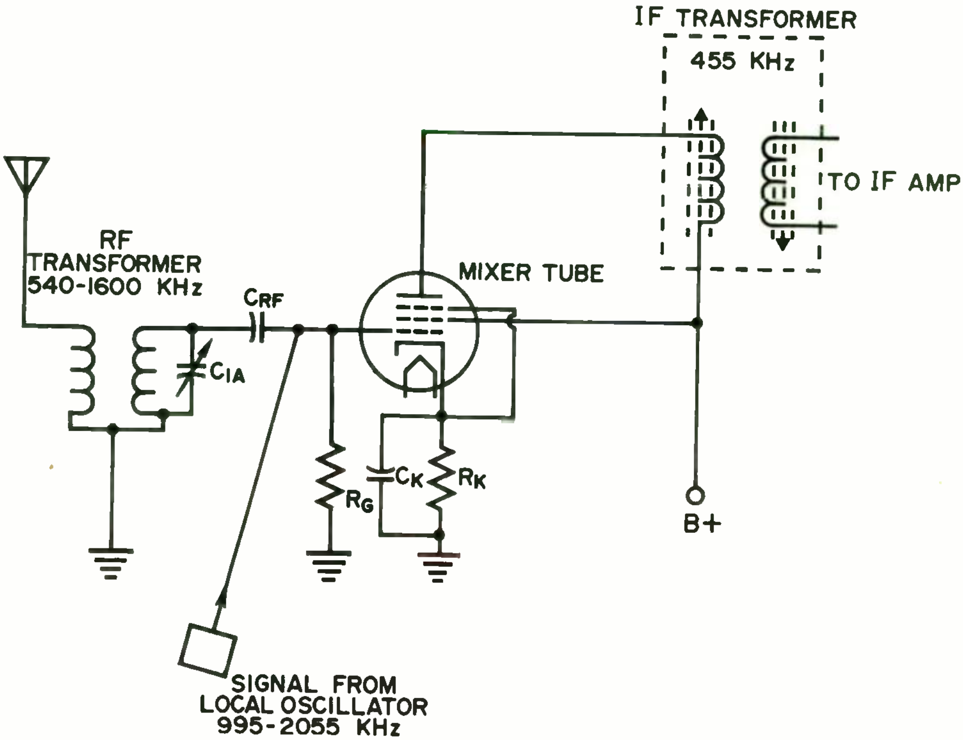

Figure 3 - Pentode mixer stage.

with respect to the cathode. This limits the "no signal" plate current and establishes an operating point for the tube. Capacitor CK serves in a by-passing function. It opposes changes at the cathode, with the result that the voltage at this point is nearly pure DC.

Oscillator signal voltage is injected into the control grid. It drives the control grid alternately negatively and positively. During the negative swing, plate current is reduced nearly to cutoff. During the positive swing, the control grid is driven positively, causing it to attract electrons from the space charge. Grid resistor RG is included to allow these electrons to leak off. Without this leakage path, the grid would become progressively more negative, and eventually it would block the tube's plate current. The upper or grid end of RG is negative with respect to the grounded end due to this leakage. This negative voltage establishes additional bias on the tube.

Because the tube operates between plate current cutoff and saturation, it is occasionally compared to a C bias detector. This is a fair comparison because the mixer is also a superheterodyne receiver's first detector.

Capacitor CRF couples the received signal into the control grid. It also

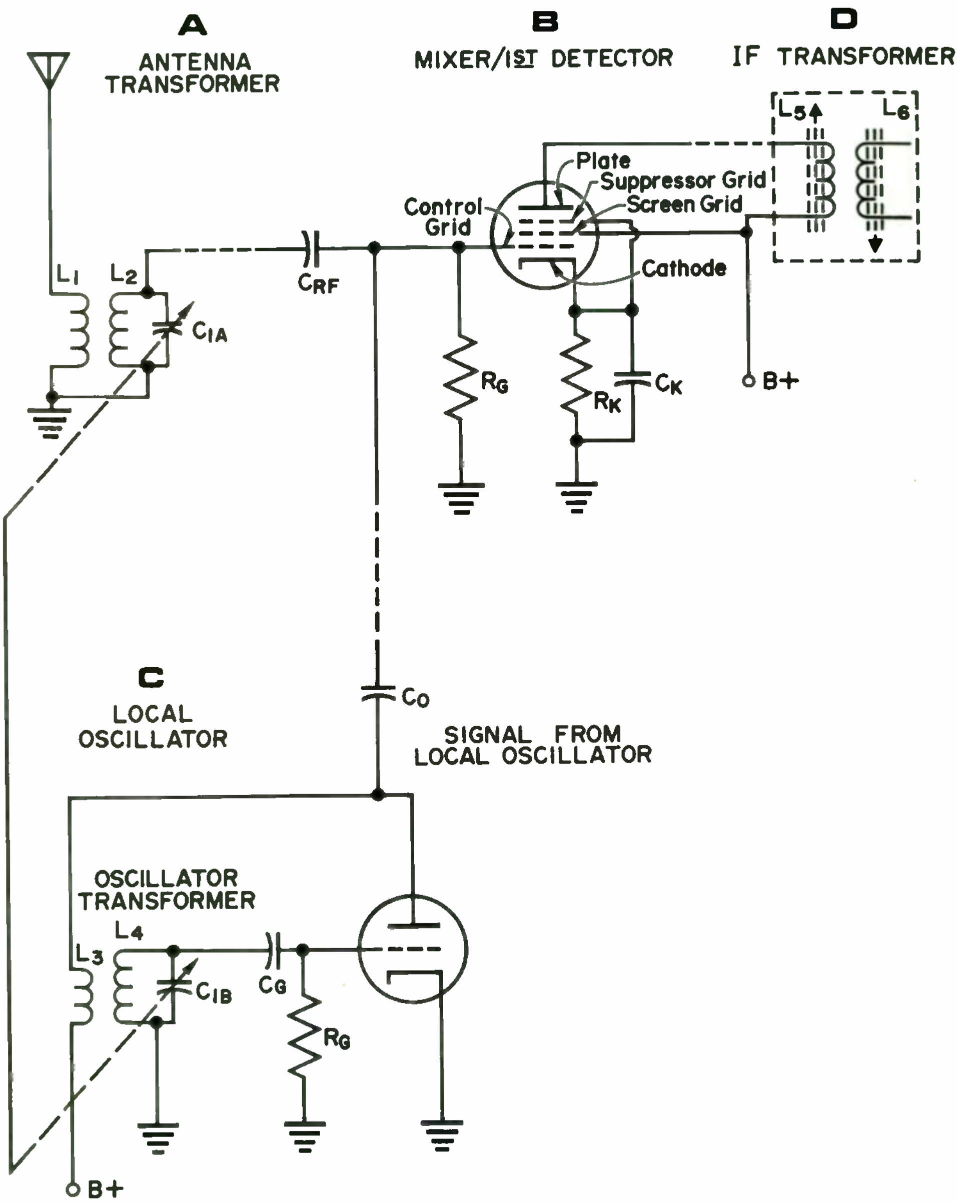

Figure 4 - Mixer and oscillator stage.

prevents the DC voltage developed across RG from being shunted to ground by the low DC resistance of L2.

When an RF signal is injected into the control grid, it too causes the plate current to vary. Since both the oscillator and RF signal are causing plate current variations, the plate current varies at rates different from either frequency. These rates are sums and differences of the input frequency and the oscillator frequency.

Local Oscillator

The circuit in Figure 4C is the local oscillator of a superheterodyne receiver. This particular oscillator uses feedback from the plate to sustain oscillations. When power is applied, current begins to build up through the tube and through L3 of the oscillator transformer. An increasing voltage is induced into L4 and is coupled to the grid through CG. This feedback voltage increases in a positive direction and causes the plate current to continue rising. Near saturation the plate current ceases to change and L3 ceases to induce voltage into L4. The negative voltage across RG (due to the electrons attracted to the grid when it was positive) causes the plate current to begin now to decrease. The decreasing plate current through L3 induces an opposite polarity voltage into L4 that causes the grid to reduce the plate current rapidly toward cutoff. Near cutoff, the plate current stabilizes and, again, no voltage is induced into L4. The grid loses control for a moment and the plate current begins to rise. The rise starts a new cycle and the process continues up and then down as plate current rises and falls in an oscillatory fashion.

The rate of change of frequency is controlled by the LC ratio of L4 and C1B. Variable capacitor C1B is connected by a common shaft to C1A as indicated by the dashed lines extending from each capacitor toward an intersecting solid line. When a station is selected by adjusting C1A the oscillator frequency is changed (to produce the proper heterodyne frequency) because C1B is also varied. The relationship is such that the oscillator frequency will always be different from the incoming station signal by 455 kHz in an AM broadcast receiver.

IF Transformer

The transformer shown in Figure 4D is a special high Q type used in intermediate frequency amplifiers. It is a highly selective unit that responds to a narrow range of frequencies. Its response is adequate to pass the necessary sidebands of the incoming carrier but limited so as not to pass an adjacent station carrier. The IF transformer is tuned to the IF frequency.

The primary (L5) is connected between the plate of the mixer tube and B+ from the power supply. Both the primary (L5) and the secondary (L6) are resonated at the time of manufacture to 455 kHz by means of adjustable cores. These are represented by dashed lines through each winding. Winding (L5) is a parallel resonant circuit that offers a very high impedance to the 455-kHz heterodyne signal. All other frequencies pass through unimpeded, into the power supply's filter section. The 455-kHz signal is induced into L6 and then applied to the IF amplifier.

TRANSISTOR OSCILLATORS

Transistor oscillators appear more complex than their vacuum tube counterparts. This is probably because of biasing arrangements necessary for transistors.

In transistor oscillators, as in nearly all electronic circuitry, two current paths exist. One is the DC path that biases or supplies power to the amplifying device. The other is the signal path. The DC path consists of resistors or inductors, which can pass DC current. The AC signal path consists of capacitors and transformers. These components pass the signal but isolate the DC to prevent it from upsetting the static bias conditions of the amplifying device.

Figure 5 shows a DC biasing arrangement for a transistor amplifier. Since an oscillator is an amplifier that supplies its own driving signal, the arrangement also applies to transistor oscillators.

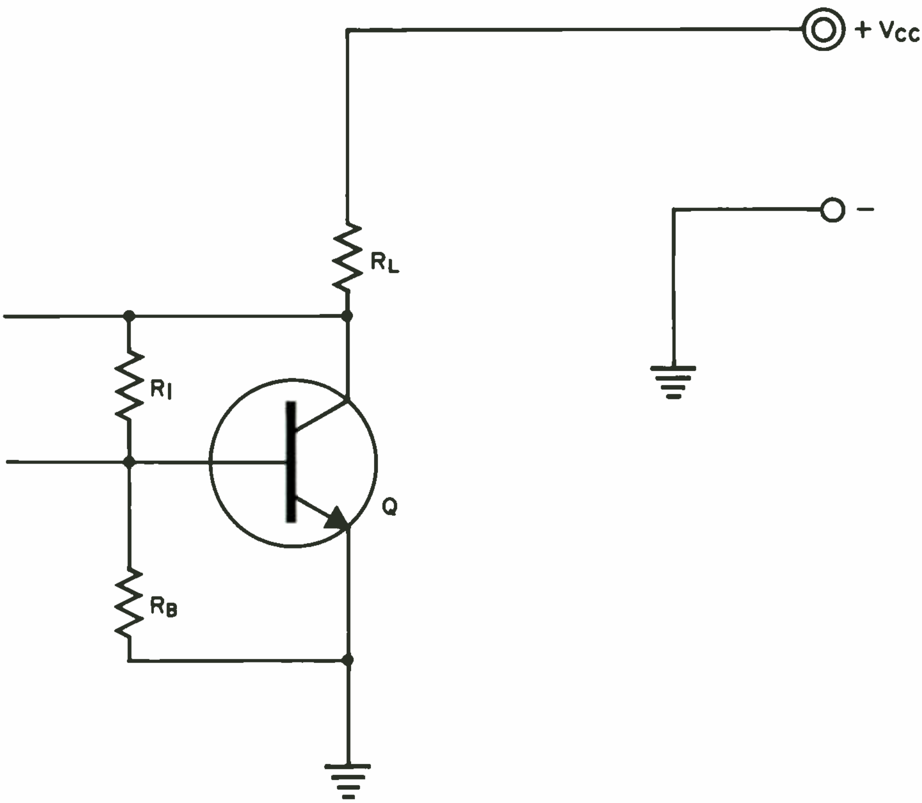

Figure 5 - Resistor bias network.

A load resistor (R_L) is shown along with a base resistor (R_B) and a base bias resistor (R1). Resistors R1 and R_B provide a current splitting path between the collector and base. Current flow into the base is adjusted by the values of R1 and R_B to cause the transistor to conduct 50% of its maximum collector current. This permits maximum signal gain because the collector current can be caused to swing between saturation and cutoff or between maximum and zero by application of an input signal. At any other bias point, the collector current swing will be unbalanced.

When the input signal current strength is such that it causes collector current saturation, the collector current cannot be further increased by application of additional signal current. Likewise, when the input signal current strength is such that collector current is cut off, the collector current cannot be further reduced by a reduction of input current.

> If the input current is still rising at saturation, the collector current cannot respond to additional changes in input occurring after saturation.
>
> Or if the signal current is still decreasing at cutoff, the collector current cannot respond to the decrease in input that occurs after collector current has been cut off.

When saturation, cutoff, or both are exceeded by the input signal, the resultant output is no longer a true reproduction of the input. This condition is called signal distortion, a condition that results in unpleasant sound from an audio amplifier.

In Figure 6 we have added a tuned circuit and two feedback capacitors to a transistor amplifier. The schematics in this figure illustrate the signal polarities during each alternation. In Figure 6A, collector current is increasing, and the increasing negative voltage forces current through L_{1A}. The increasing current in L_{1A} induces an increasing current into L_{1B}; the current in L_{1B} is coupled into the base of the transistor through C2. The base current is polarized to support the collector current and to aid its increase. This increase of signal current causes the collector current to rise to saturation. At this point the collector current ceases to change and no energy is coupled through C1 into L_{1A}. The DC bias takes over, reduces the base drive, and, as a result, the collector current.

When the collector current begins to decline, the current through L_{1A} reverses. The base current from L_{1B} also becomes opposite and tends to hasten the downward swing of the collector current. This downward swing continues until the collector current stabilizes at a point near cutoff. After the cutoff point, signal polarities again reverse and the circuit begins another cycle.

The circuit in Figure 7 includes an additional winding, L2. Winding L2 couples the oscillator signal into the mixer.

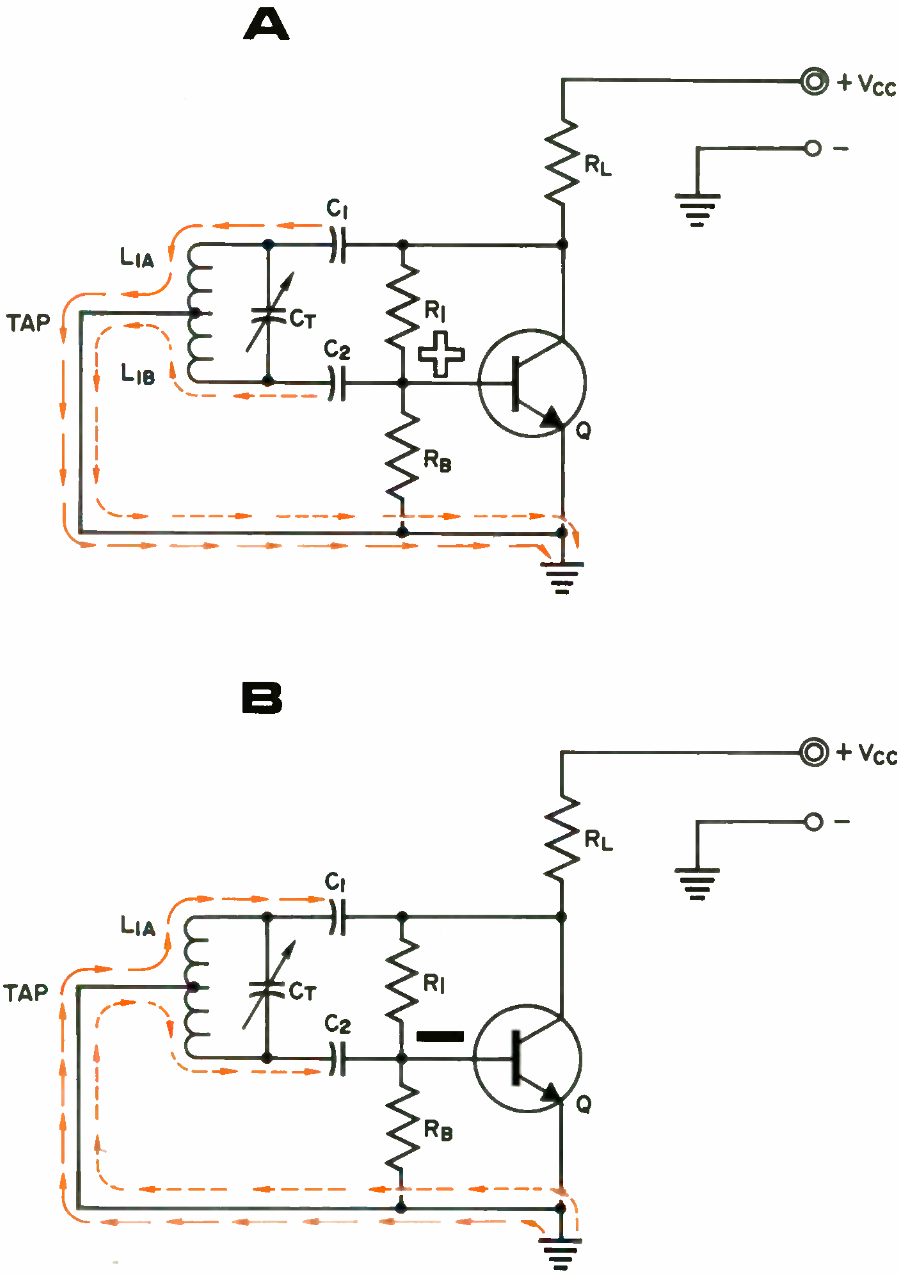

Figure 6 - Transistor oscillator showing feedback.

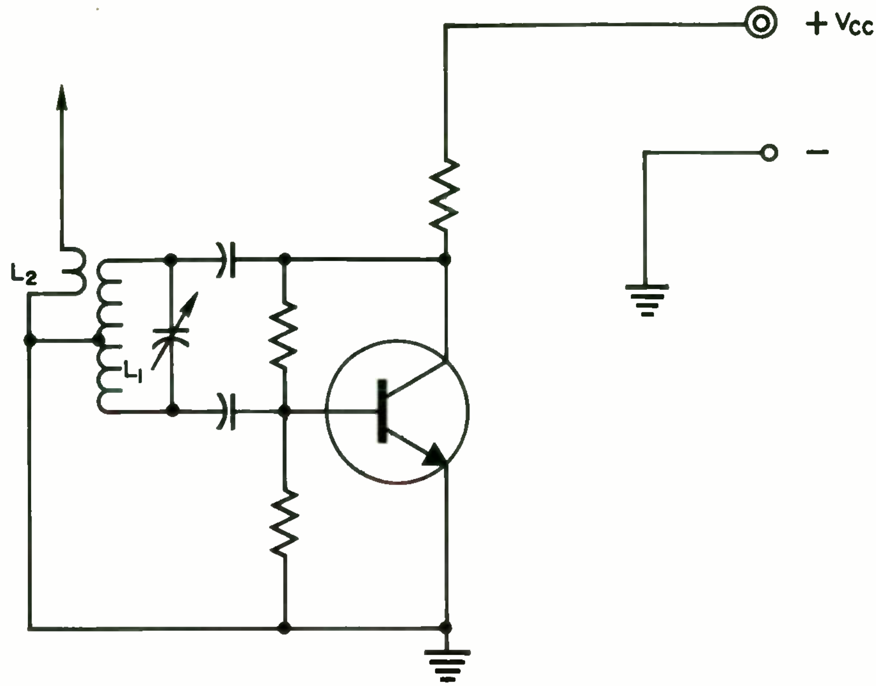

Figure 7 - Hartley type transistor oscillator.

Several other forms of oscillators are used in radio receivers. One of these is shown in Figure 8. It uses *collector* to *emitter* feedback rather than feedback from the collector to base. Feedback to the emitter must be opposite in polarity to base feedback. A negative signal applied to the emitter of a transistor has the same effect on collector current as a positive signal applied to the base. Also, a positive signal at emitter has the same effect on collector current as a negative signal at the base.

The feedback which causes an oscillator to oscillate is in phase with the input current and supports its changes. It is, therefore, called *positive feedback.*

TRANSISTOR MIXER-OSCILLATOR

Figure 9 illustrates a mixer-oscillator stage of the type used in many popular high quality receivers. The oscillator uses collector to base feedback. Resistors (R4, R5, and R6) are selected to establish correct DC bias on the transistor. Capacitor C5 by-passes signal energy to ground from the junction of R4 and R5. Without C5 the signal fluctuations appearing at this point could cause oscillation to be erratic. The take-off point for coupling the oscillator signal into the mixer is at a tap of L2.

Operating bias for the mixer is established by resistors (R1, R2, and R3). An electrolytic filter capacitor is

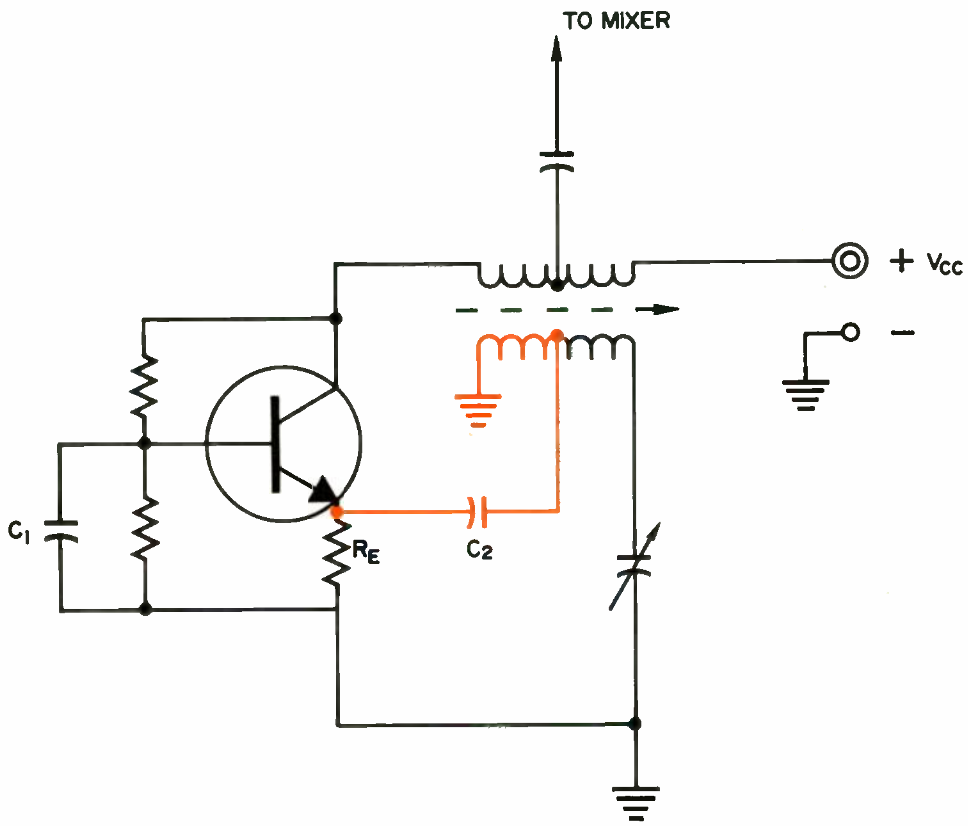

Figure 8 - Transistor oscillator with feedback to the emitter.

included at the junction of R2 and R3. This electrolytic capacitor prevents the *automatic volume control* (AVC) voltage from reacting too quickly to a change in signal strength. It also by-passes any fluctuations in voltage or current that appear at this point.

The oscillator signal is coupled into the mixer through the secondary of L1. L1 is a winding on the loop stick that also receives the induced signal from the antenna winding. Both the station and oscillator signals are injected into the base from this winding. Acting together, these two signals cause the collector current to follow frequency fluctuations that are combinations of the two signals, with the result that a 455-kHz heterodyne is produced. The primary of T1 resonates of 455 kHz and induces voltage at this frequency into its secondary. The secondary applies the 455-kHz signal to the IF stage for further amplification.

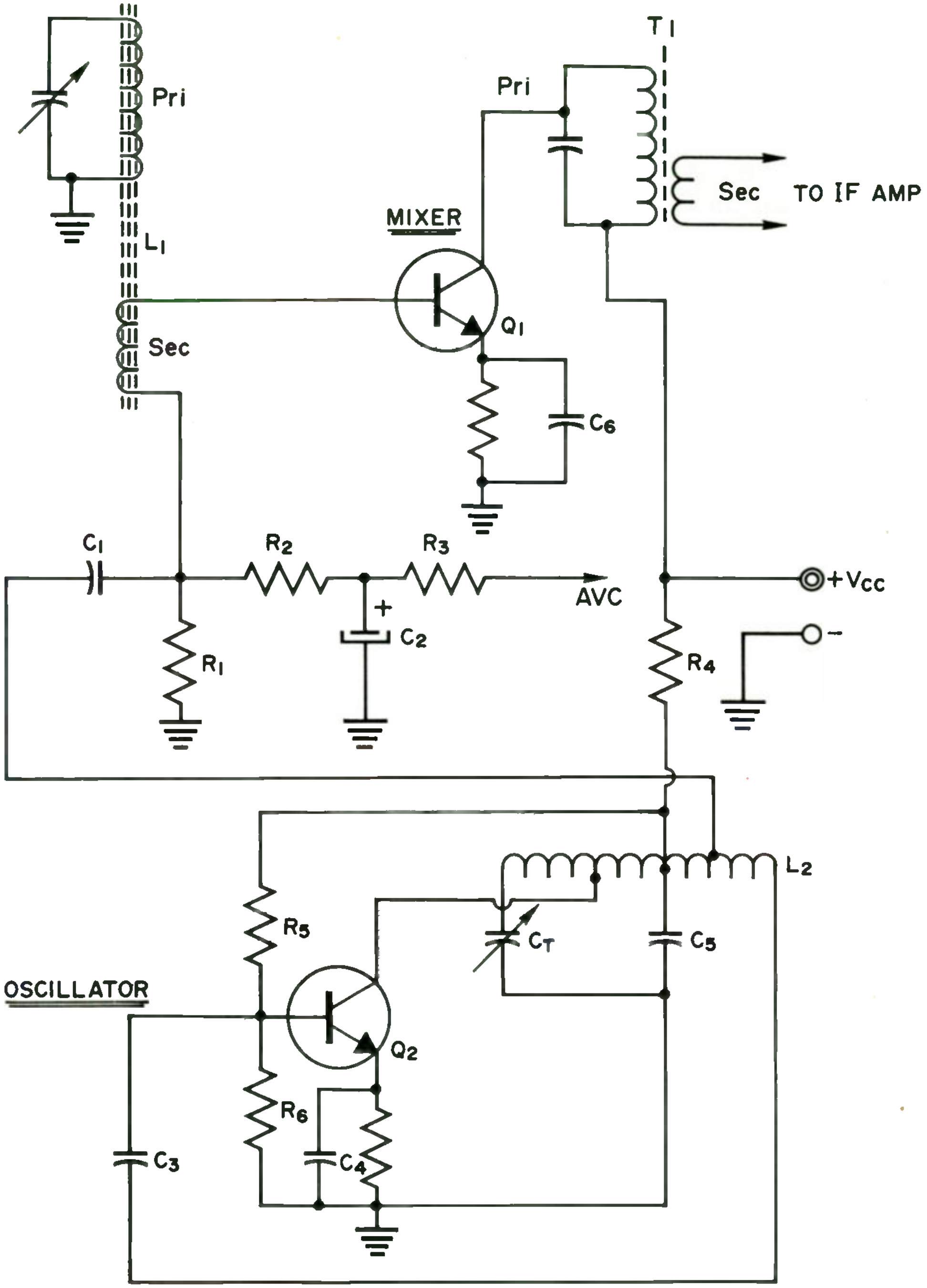

Figure 9 - Transistor mixer-oscillator stage.

CONVERTER STAGES

Some vacuum tube converter stages use a single tube to perform the functions of both oscillator and mixer. Many special purpose tubes have been developed to perform this function although ordinary pentodes can be used. In theory, the converter tube acts like two tubes in series.

The schematic in Figure 10 is representative of several commonly used pentagrid converter tubes. You will notice that the tube's elements are identified and its grids are numbered. Grid 1 is normally the control grid for the oscillator section. Grid 2 is in two parts; the first section acts as the oscillator plate and the second section (G4) is the screen grid. Grids 1 and 2 with the cathode act as the oscillator section (Fig. 11).

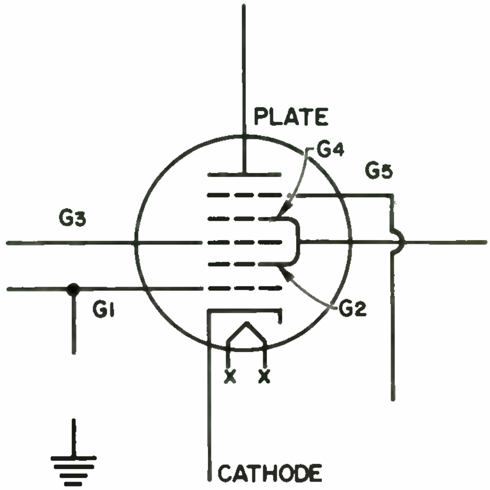

Figure 10 - Pentagrid converter tube.

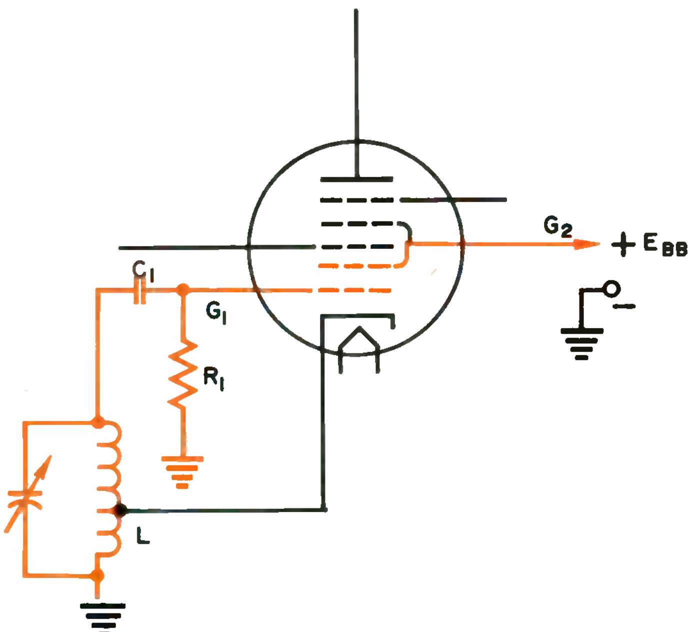

Figure 11 - Oscillator section of a pentagrid converter stage.

The schematic in Figure 12 is a pentagrid converter stage of the type used in many vacuum tube radios. L2 and C_{1B} form the oscillator tank circuit. Notice that L2 is tapped to provide positive feedback to G1, the oscillator grid. The elements *G1*, *cathode*, and *G2* comprise a triode oscillator. This triode oscillator is effectively in series with a pentode section composed of G3, G4, G5, and the plate. Fluctuations appearing at the oscillator grid G1 will also appear at the plate. Since the oscillator grid has control over the stream of electrons between the cathode and plate, oscillation coupling is said to result from electron coupling. This oscillator is called an *electron coupled oscillator* (ECO).

Signal voltage is injected into grid 3 from the tuned loop stick. (A loop stick is a ferrite core onto which the antenna is wound.) This signal also causes fluctuations in the plate current. The combination of oscillator fluctuations and signal fluctuations within the tube results in the production of a heterodyne. Transformer T1 resonates to this heterodyne frequency and inductively couples it into the IF stage for further amplification.

A single transistor can serve the functions of both mixer and oscillator. Figure 13 is the schematic of a transistor converter; it is the type used in many small portable AM broadcast radios. Oscillator feedback is from

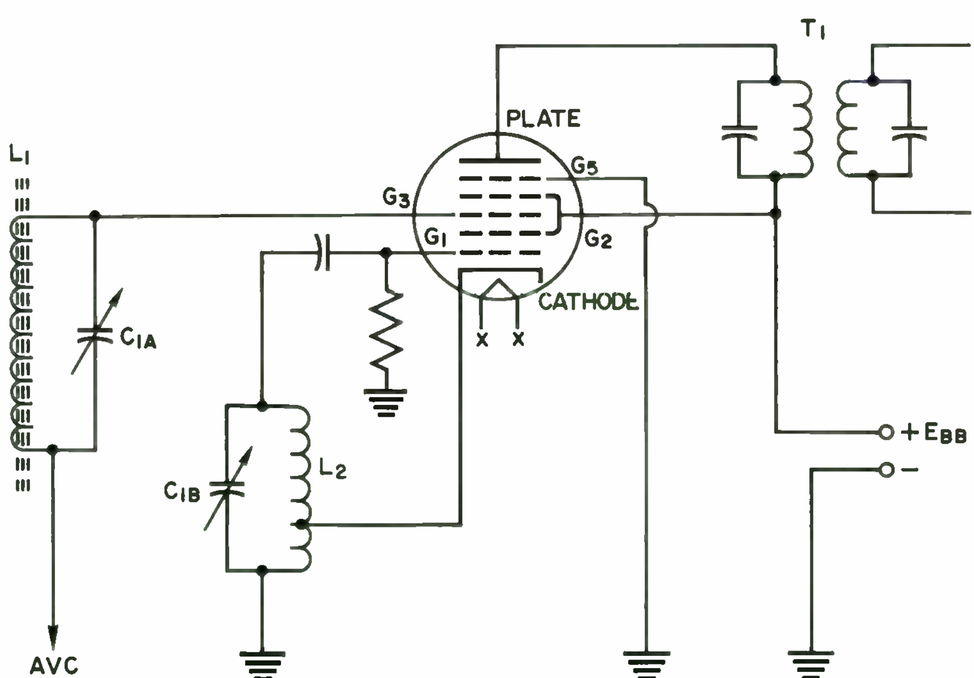

Figure 12 - Complete pentagrid converter stage.

collector to emitter with the signal being injected into the base. Both signals affect the collector current and produce a heterodyne frequency. The heterodyne (in most cases 455 kHz) is resonated by the IF transformer and inductively coupled to the IF amplifier.

SOME OTHER FREQUENCY CONVERTERS

Several types of mixer-oscillator and converter stages are shown in Figures 14 through 17. There are many variations of these used in receivers today.

The schematic in Figure 14 is a twin triode mixer-oscillator. Coupling of the oscillator signal is accomplished by connecting the cathode of the mixer section to a tap on the oscillator transformer.

The oscillator represented by the schematic in Figure 15 uses a special converter tube. This tube has separate plates and cathodes but shares a common grid, G2. The common grid acts not only as the oscillator grid; it also couples the oscillator signal into the mixer section.

Figure 16 illustrates the use of a pentode vacuum tube as a converter. In this circuit, the suppressor acts as

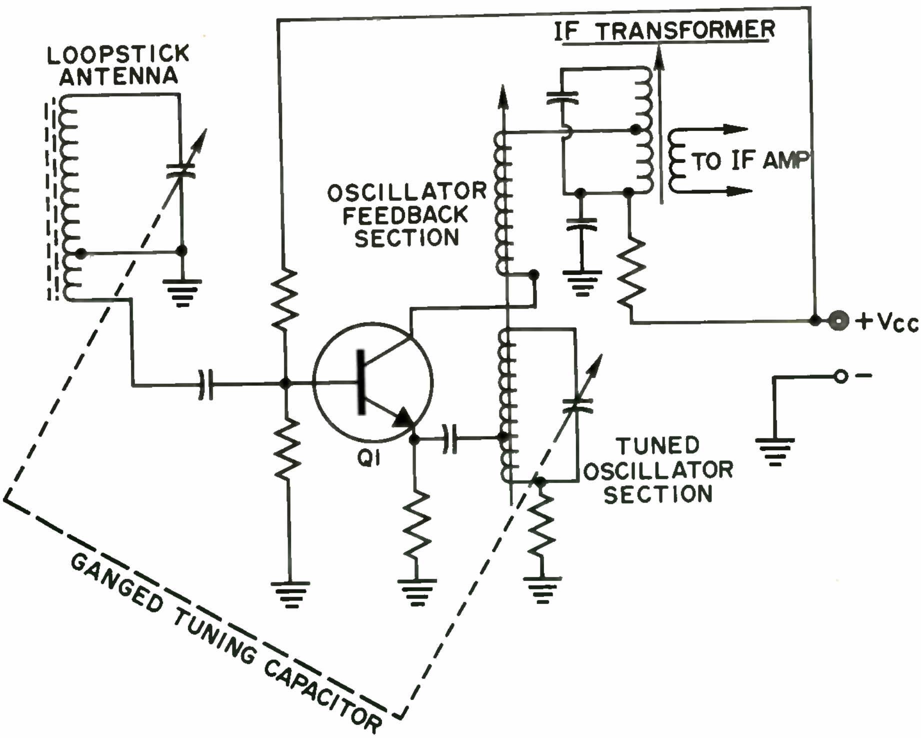

Figure 13 - Single transistor converter stage.

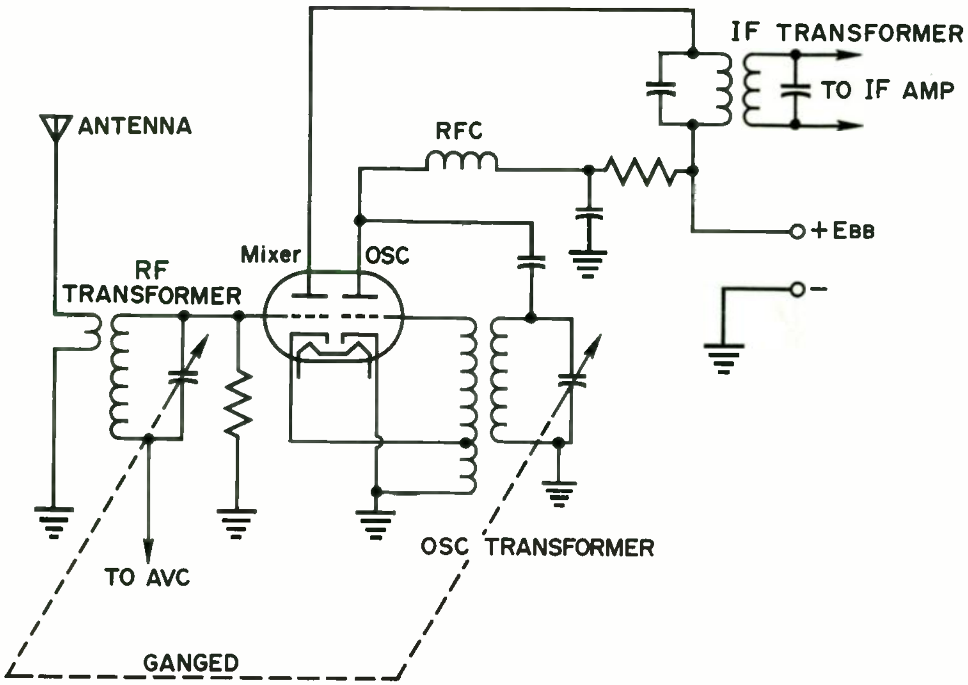

Figure 14 - Twin triode mixer-oscillator stage.

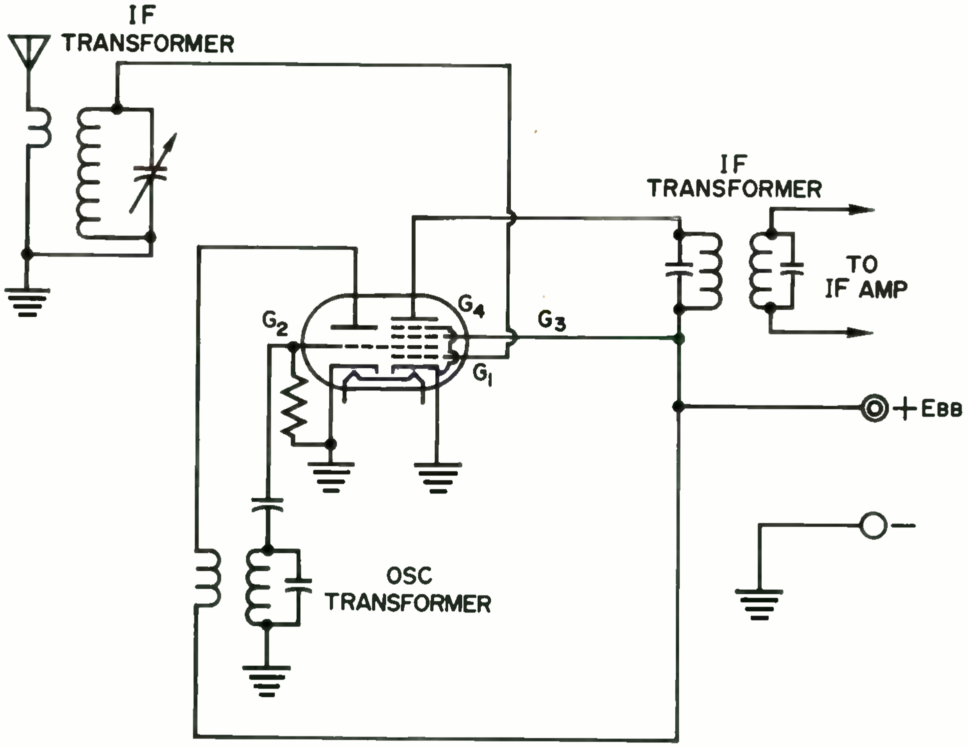

Figure 15 - Hexode tube converter stage.

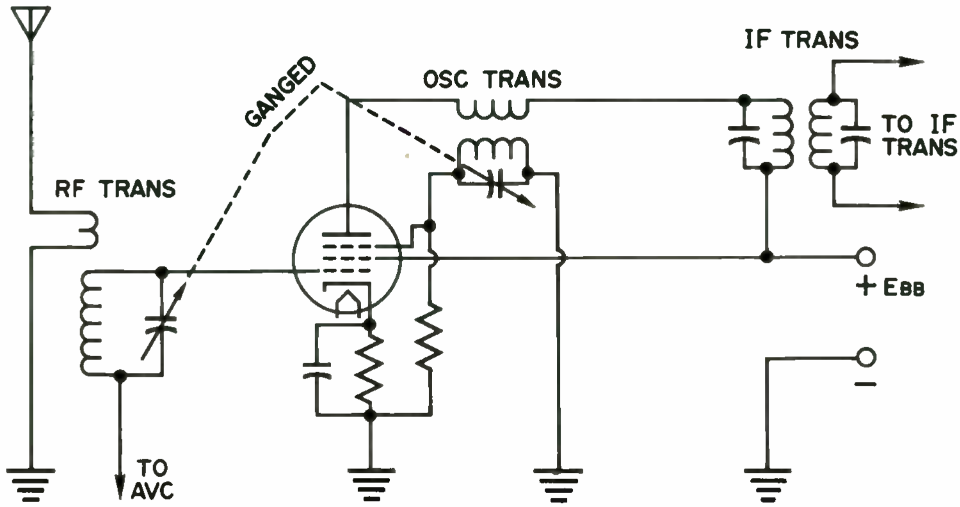

Figure 16 - Pentode tube converter stage.

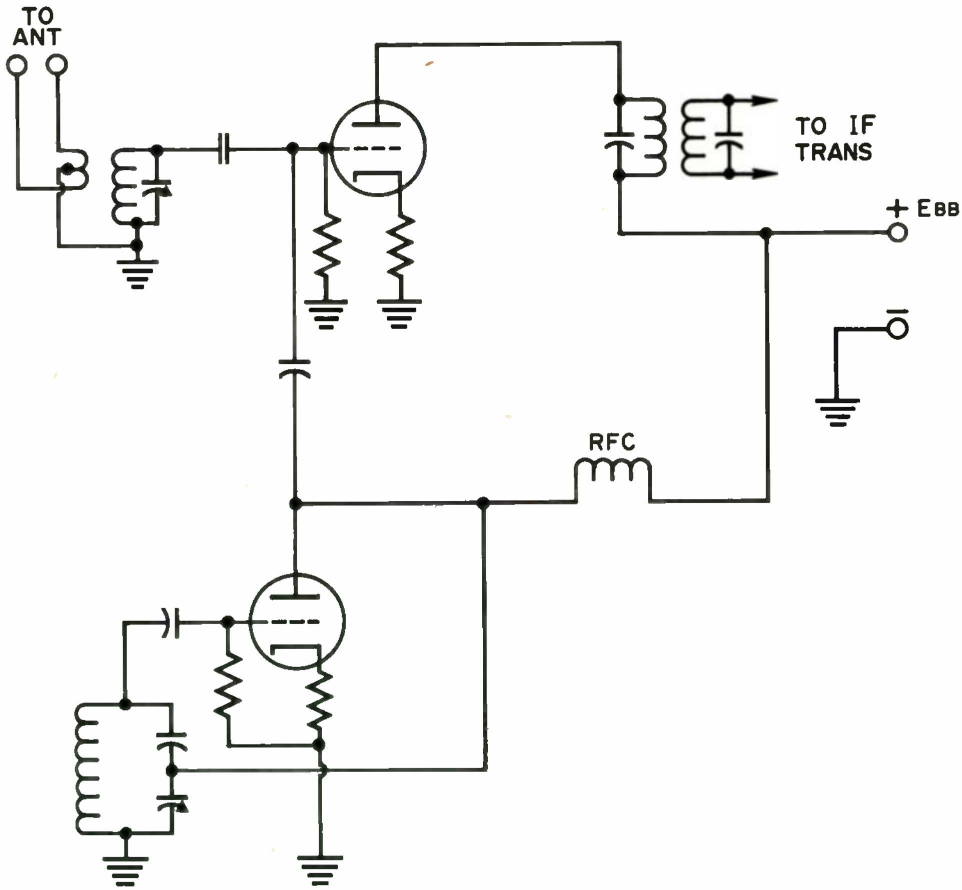

Figure 17 - Triode mixer-oscillator of the type used in some high frequency communication sets.

both oscillator grid and oscillator coupling into the mixer.

Figure 17 features a different kind of oscillator. It uses the junction of two capacitors as the feedback point. This is a Colpitts oscillator, a type noted for its frequency stability.

In Figure 18, we see a converter section using a transistorized version of the Colpitts oscillator. These are often used in high frequency radios and TV receivers because of their frequency stability.

In Figure 19, we see a base-fed transistor oscillator-mixer stage. Feedback in this case is through the secondary winding of the loop antenna. Notice the polarity reversal of V_{CC} in this circuit. This is because a PNP transistor is used instead of an NPN.

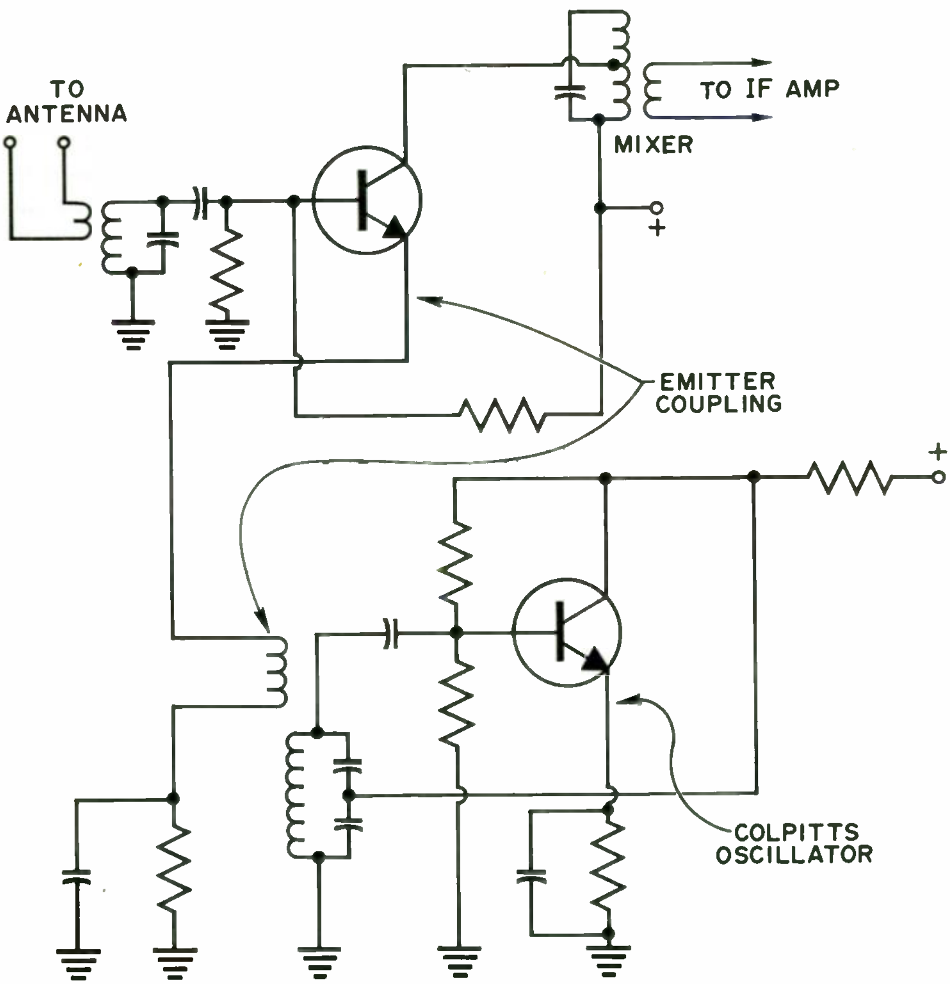

Figure 18 - Transistor mixer-oscillator with a Colpitts oscillator and emitter coupling to the mixer.

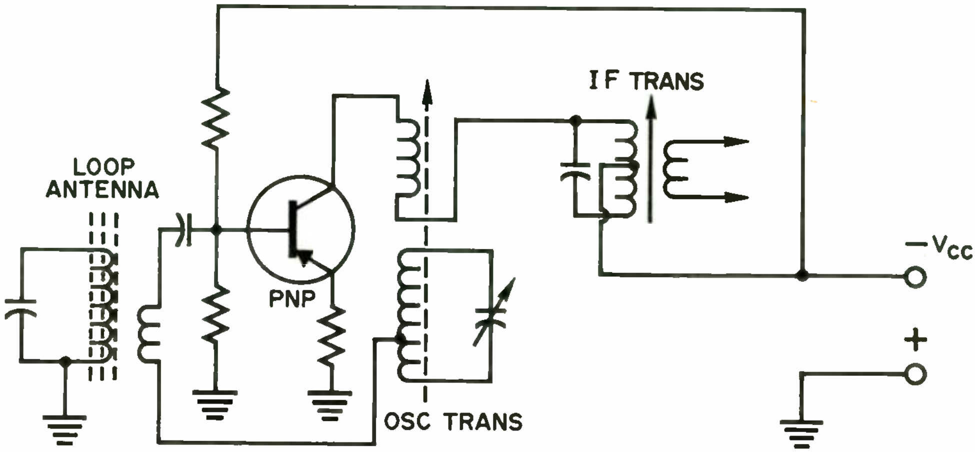

Figure 19 - Commonly used one-transistor converter stage.

FET CONVERTER

In Figure 20 we see a mixer stage that uses a FET as the active element. These devices are becoming increasingly popular in radio and TV sets. The circuit configuration resembles that of a triode mixer. Notice that the oscillator signal is injected into the source (S). The source element is similar in function to the cathode of a vacuum tube. The other two elements, gate (G) and drain (D) resemble the grid and plate, respectively, in function.

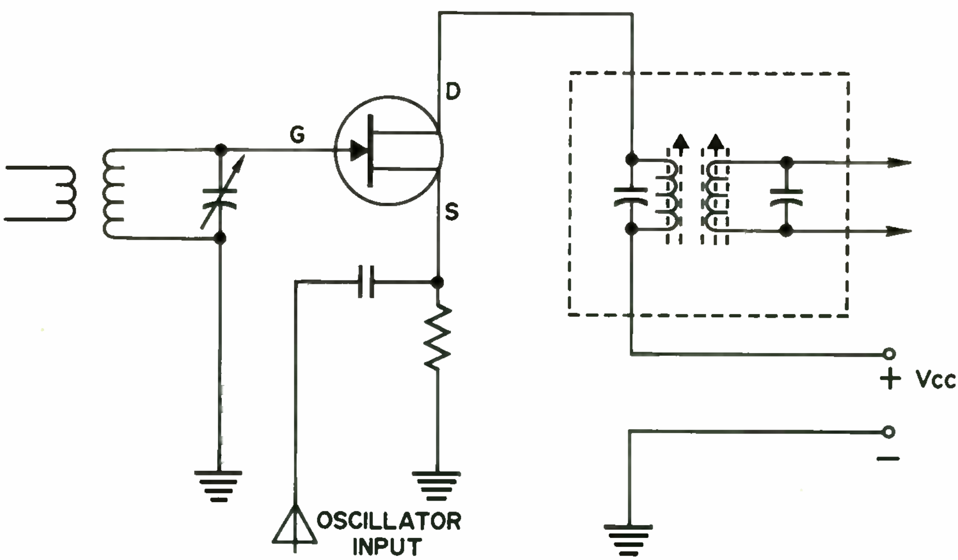

Figure 20 - FET converter stage.

THE SUPERHETERODYNE RECEIVER

Figure 21 illustrates a complete superheterodyne AM broadcast receiver, in block form. The station signal progresses from left to right, from the antenna to the speaker. Its mixer stage converts all incoming signals to a 455-kHz signal that retains the audio modulating frequencies originally impressed on the carrier at the station. This signal is amplified by the high gain IF stage (or stages) and fed to the detector.

It is the detector's function to remove the audio variations from the IF signal and present them to the audio amp for further amplification. The detector also develops a control voltage whose level is relative to the strength of the incoming signal. This DC voltage level, called automatic volume control (AVC), is used to vary the gain of the IF and mixer stages. It reduces the gain for strong signals and permits it to increase for the weaker ones. In this way, the gain of these stages compensates for signal fade and maintains a constant output signal, independent of the signal strength arriving at the antenna.

The audio signal from the detector is presented to the first audio amplifier, usually a voltage amp. Its signal voltage is increased many times before being applied to the audio power stage. In this stage, sufficient power is generated to produce sound from the loud speakers.

THE TV RECEIVER

A block diagram of a conventional black and white TV receiver is shown

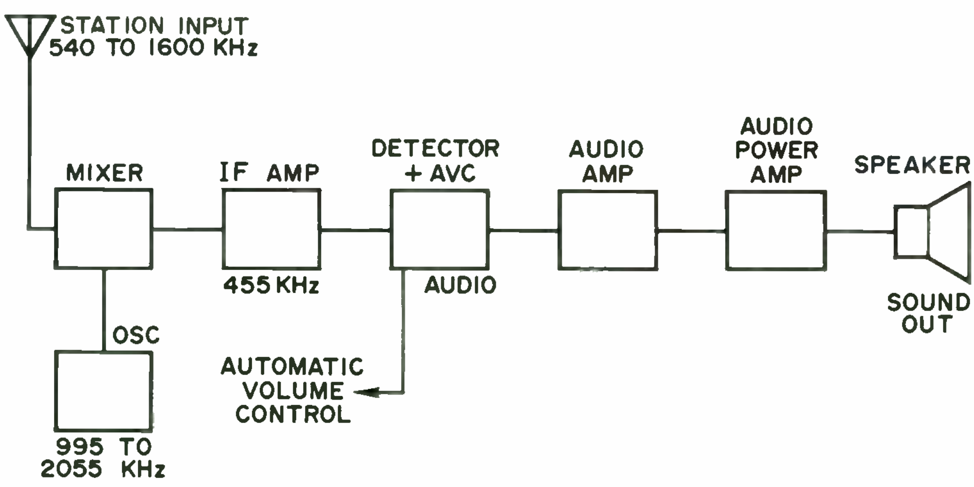

Figure 21 - Block diagram of a superheterodyne receiver.

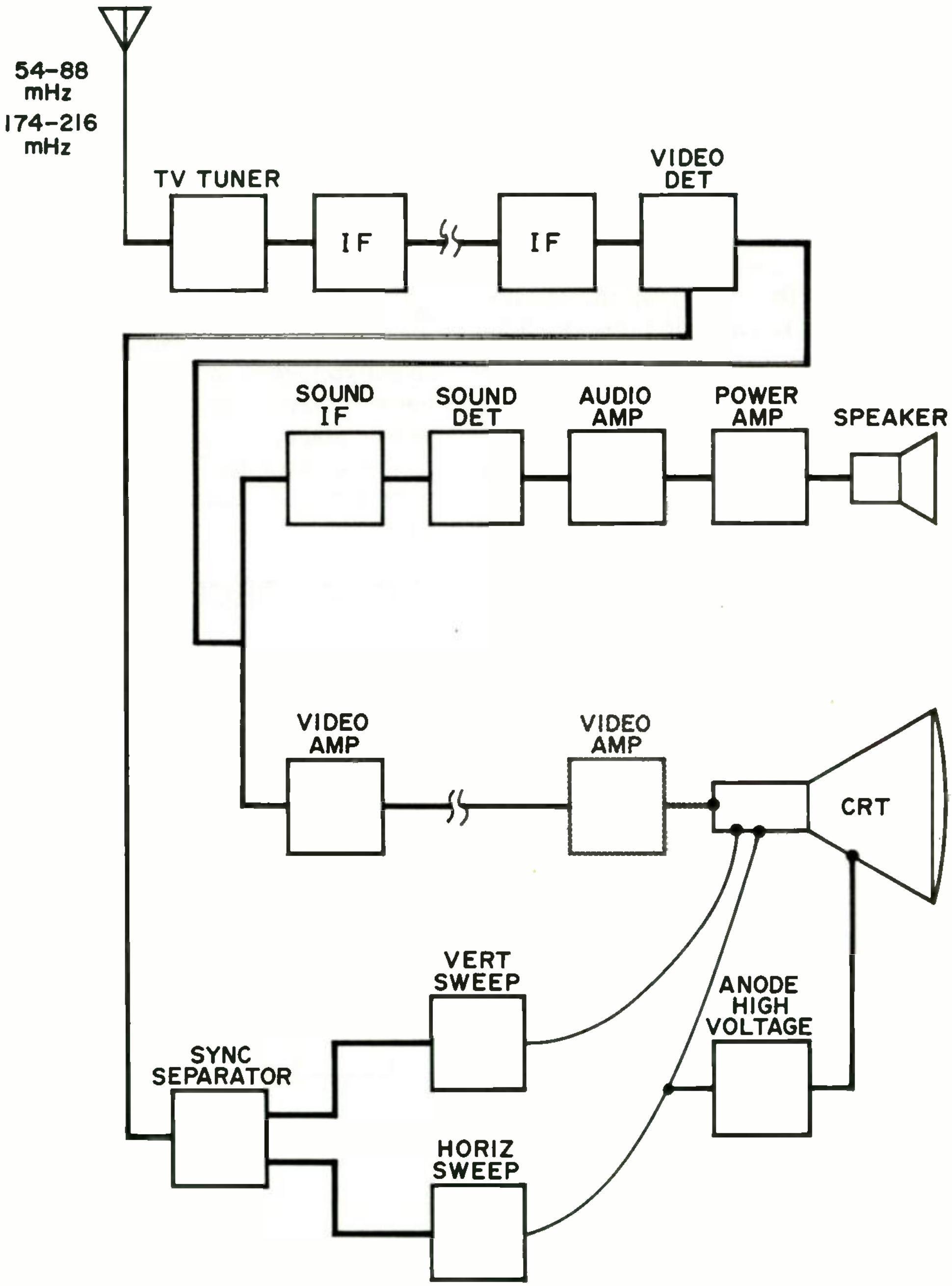

Figure 22 - Block diagram of a TV receiver.

in Figure 22. The signal from the antenna is applied to the tuner where it is amplified by an RF (radio frequency) stage and then presented to the mixer section, also in the tuner. The tuner output signal generally falls within the forty megahertz range for current TV sets.

This forty megahertz signal is amplified by two or more stages of IF and presented to a video detector. In this stage, the picture information (video), the audio information, and the synchronizing signals are recovered. The sound portion is recovered as a 4.5 MHz, frequency modulated carrier. This signal is amplified by the sound IF, detected, and further amplified before being presented to the speaker.

The video signal that causes the CRT to reproduce the light and dark portions of a scene is amplified by one or more video stages and then presented to the CRT.

Vertical and horizontal signals are also recovered by the video detector. They are applied to a sync separator which routes them to their associated sweep generating sections. A DC potential of several thousand volts is developed by the horizontal output stage and applied to the anode of the CRT. This voltage accelerates the electron beam toward the face of the CRT. The combination of audio, video and sync information causes reproduction of the televised scene, with sound.

SUMMARY

Early radio receivers were TRF (tuned radio frequency) types. In the TRF radio receiver each RF stage was tuned to another frequency each time a station was selected. The TRF receiver was difficult to adjust for the desired signal and component aging decreased performance considerably.

The superheterodyne receiver was developed to improve receiver performance. In a superheterodyne receiver, the concept of an intermediate frequency (IF) was introduced. This allowed the RF amplifier sections of a receiver to be aligned for a single frequency (the IF frequency) which improved gain, selectivity, and reliability. Normal IF frequencies for broadcast receivers are 455 kHz for AM and 10.7 MHz for FM

The superheterodyne receiver must convert the selected broadcast frequency into the receiver's IF frequency and then amplify the IF frequency to the desired signal level. The incoming RF signal is converted to the IF signal in the receiver's converter stage. The heterodyne principle is utilized in this conversion. When two frequencies are beat (heterodyned) together, two additional frequencies are produced. These two frequencies are the sum and difference of the original frequencies.

This heterodyne action occurs in the mixer stage of a superheterodyne receiver. A local oscillator that is tunable is incorporated to produce a frequency that is applied to the mixer. The incoming RF signal is heterodyned with the local oscillator frequency in the mixer and a difference frequency is produced. This is the IF frequency. When one tube or transistor functions as a local oscillator and mixer, it is called a converter.

TEST

Lesson Number 38

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 52-038-1.

1. The requirement of a radio receiver for good reception is
   A. sensitivity.
   B. selectivity.
   C. fidelity.
   D. all of the above.

2. In TRF receivers all tuned stages
   A. must tune to the station frequencies.
   B. must tune to different frequencies.
   C. were untuned stages.
   D. were band pass tuned.

3. An improved receiver was developed that was superior to previous TRF receivers, and it was named a
   A. converter.
   B. heterodyne.
   C. superheterodyne.
   D. neutrodyne.

4. In superheterodyne receivers the IF signal is produced in the
   A. mixer/converter stage.
   B. antenna.
   C. audio amplifier.
   D. none of the above.

5. A superheterodyne receiver produces a beat or heterodyne in its ________ stage.
   A. radio frequency
   B. intermediate frequency
   C. second detector
   D. mixer/converter

6. A common IF frequency for AM broadcast receivers is
   A. 700 Hz.
   B. 40 MHz.
   C. 455 kHz.
   D. 1700 Hz.

7. A common IF frequency for FM broadcast receivers is
   A. 700.0 Hz.
   B. 40.0 MHz.
   C. 1700.0 Hz.
   D. 10.7 MHz.

8. When a single tube or transistor serves as both the mixer and oscillator, it is called a
   A. converter.
   B. product detector.
   C. second detector.
   D. superregenerative circuit.

9. Local oscillators depend on ________ for their operation.
   A. degeneration
   B. positive feedback
   C. neutralization
   D. the received signal

10. An IF transformer is tuned to
   A. the intermediate frequency.
   B. all carrier frequencies.
   C. adjust the local oscillator frequency.
   D. match the antenna impedance.

Notes

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DON'T LET UP...

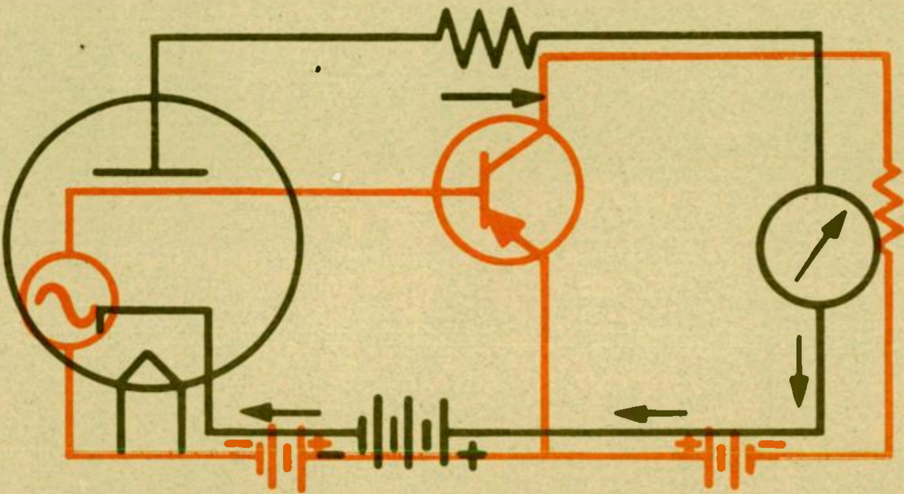
The man who thinks he has done something, has less things to do. More men are failures on account of success than on account of failures. They beat their way over a dozen obstacles, overcome a host of difficulties, sacrifice, sweat and make the impossible the possible; then along comes a little success, and it tumbles them from their perch. They let up, slip and over they go. Who can count the number of men who have been halted by recognition and reward?

You have progressed quite far with your training – don't let up for even an instant. There are three secrets to succeed as a Radio and T.V. Technician – don't let up in your studies – don't let up in your studies – don't let up in your studies.

S. T. Christensen

LESSON NO. 39

REVIEW FILM LESSONS 35-38 BOOKLET



RADIO and TELEVISION SERVICE and REPAIR

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NO. 52-039
412

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REVIEW FILM TEST

Lesson Number 39

The ten questions enclosed are review questions of lessons **35, 36, 37, & 38** 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 52-039-1.

1. The buffer amplifier in an AM transmitter is located between the crystal controlled oscillator and the

A. audio amplifier.
B. power supply.
C. RF amplifier.
D. antenna.

2. The crystal controlled oscillator, the buffer amplifier, and the RF amplifier comprise the__________section on an AM transmitter.

A. AF
B. RF
C. AC
D. DC

3. The average audio response of an AM station is

A. 100 to 5 kHz.
B. 500 to 50 kHz.
C. 50 to 7.5 kHz.
D. 20 to 20 kHz.

4. The frequency response of a FM broadcast station is
   A. 20 Hz to 2 kHz.
   B. 50 Hz to 50 kHz.
   C. 30 Hz to 15 kHz.
   D. 100 Hz to 5 kHz.

5. The higher the value of the video voltage the TV screen will become
   A. lighter.
   B. darker.
   C. snowy.
   D. none of the above.

6. The bandwidth of a TV channel is
   A. 10.7 MHz.
   B. 125 MHz.
   C. 6 MHz.
   D. 4.5 MHz.

7. A superheterodyne is a type of
   A. tube.
   B. transistor.
   C. transformer.
   D. radio receiver.

8. To receive an AM station at 1000 kHz with an IF frequency of 455 kHz, the local oscillator must be operating at
   A. 1455 kHz.
   B. 545 kHz.
   C. 455 kHz.
   D. 1000 kHz.

9. In stereo broadcasting the left and right information is broadcast as
   A. L + R and L + R.
   B. L + R and L - R.
   C. L + R and R - L.
   D. L + R and L.

10. The TV band of broadcast frequencies start at
   A. 60 MHz.
   B. 54 MHz.
   C. 107 MHz.
   D. 52 MHz.

Notes

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"Serving America's Needs for Modern Vocational Training"

IT ISN'T EASY

It's difficult to listen. In your role, as a trained Radio and TV Service Technician, your ability to listen plays an important part.

Your customer wants to be heard. Give him a chance to explain what he believes can be wrong. Listen intelligently. Don't disregard what he has to say. Sometimes his remarks may give you a clue to what to check and may save you time on your service call.

Learn these two steps to the listening process:

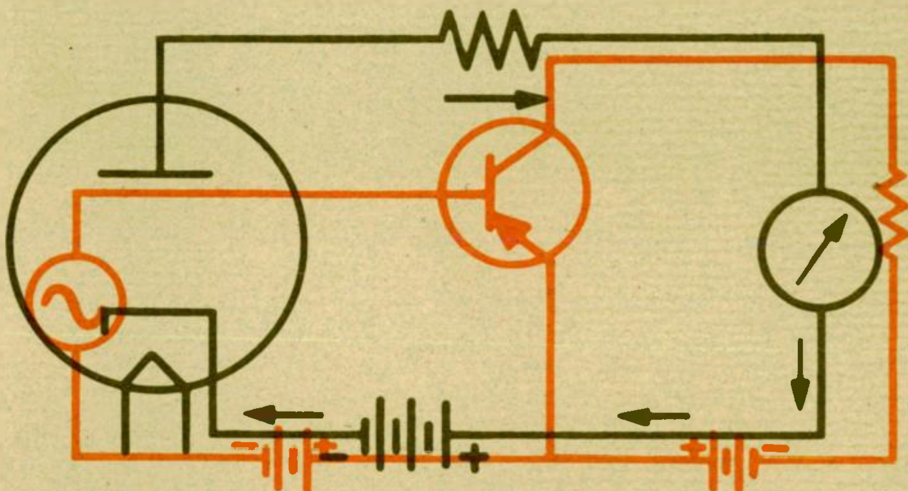
1. Listen.
2. Let your customer know you are listening.

You will be remembered long after your service job has been finished if you make sure your customer knows you listened to what he had to say.

S. T. Christensen

LESSON NO. 40

AUDIO FREQUENCY AMPLIFIERS



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-040
412

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CONTENTS

AUDIO FREQUENCY AMPLIFIERS

INTRODUCTION

The signal intercepted by a radio or TV antenna is so weak that this weak signal must be greatly increased by the radio frequency amplifiers before the signal is applied to a detector circuit. Then, the detector circuit will deliver, at its output terminals, the audio frequencies that are the voice or music as originally transmitted. This output signal from the detector, however, is still not strong enough to drive a speaker. Therefore, this weak audio signal is applied to the input of an audio amplifier where it is increased in strength. The operation of audio amplifiers and the different types of circuitry that are used in both vacuum tube and transistor amplifiers are presented in this lesson.

One of the most important items in a tube type amplifier circuit is the vacuum tube. The vacuum tube delivers a signal voltage in the plate circuit that is many times larger than the applied input signal to the grid circuit. The amount of amplification produced is known as *gain.* In addition to the gain of the tube, the gain also may be dependent upon transformer action, circuit design, or other circuit qualities.

CLASSIFICATION BY USE

Audio frequency amplifiers are divided into two general types: *voltage amplifiers* and *power amplifiers.* This lesson deals with the application of electron tubes and transistors as audio frequency voltage amplifiers. Although most references will refer to tube type amplifiers, the same mode of operation also applies to the transistor type.

Voltage Amplifiers

Voltage amplifiers are designed so that the signals of relatively small amplitude, applied between the grid and the cathode of the tube, produce large values of amplified signal voltage across the load in the plate circuit. To produce the largest possible amplified signal voltage across the plate load (which may be a resistor, an inductor, or a combination of both) the value of impedance must be as large as is practicable (Fig. 1).

The gain of a voltage amplifier is the ratio of the AC output voltage to the AC input voltage. This type of amplifier is used in radio receivers to increase the RF or IF signal to the proper level to operate the detector.

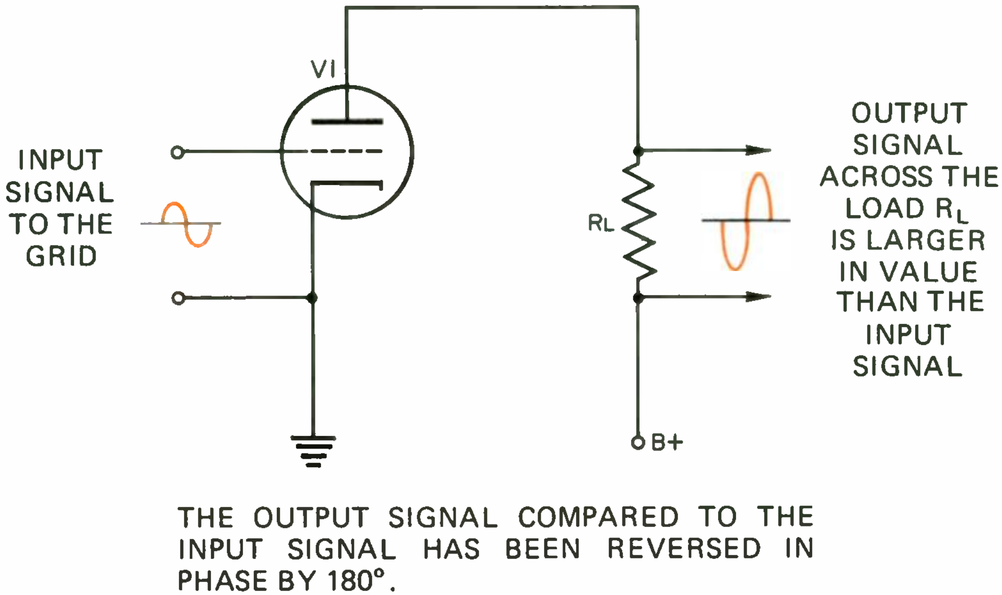


Figure 1 - Voltage amplifiers produce a larger voltage across the output load RL due to the voltage gain in the amplifier tube V1.

This lesson covers the use of tube and transistor circuits in audio amplifiers to increase weak signals to a usable level.

Power Amplifiers

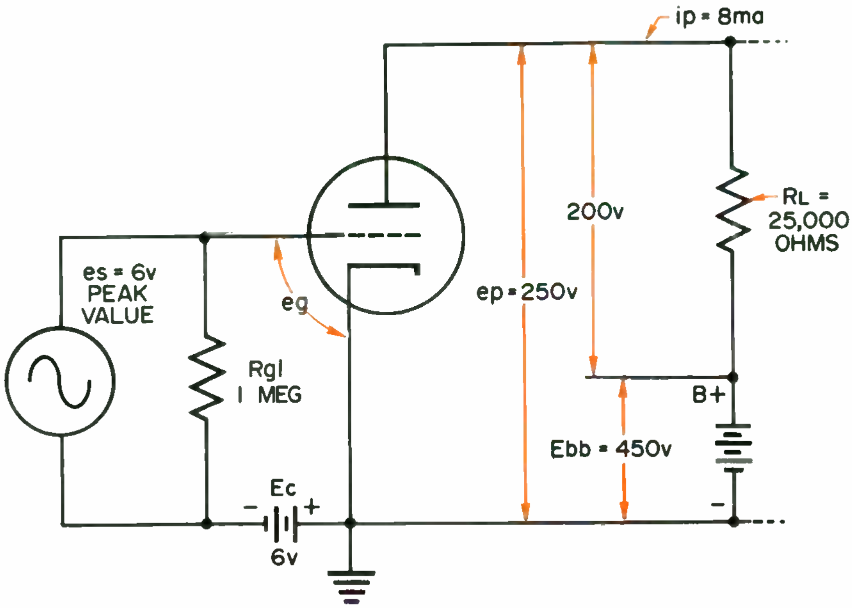
Although power amplifiers will be discussed in a future lesson, it is interesting to note that they are designed to deliver a large amount of power to the load in the tube's plate circuit. The output power handled by amplifiers of this type is so large that, not only must the tube be capable of handling the power required in the output circuit, it must also be capable of accepting a fair amount of input power in the grid circuit. Consequently, the power developed by the voltage amplifiers is generally applied to a subsequent power amplifier circuit.

BASIC VOLTAGE AMPLIFIER

A voltage amplifier is designed to accept a low signal and to raise it to a higher voltage. This higher voltage value may then be applied to succeeding stages of amplification until sufficient output energy has been developed to drive the power amplifier stages. The method used for voltage amplification can be illustrated by using a triode vacuum tube in the amplifier circuit.

Triode Voltage Amplifier

The action of a triode voltage amplifier is illustrated in Figure 2. The input signal es has a *peak* value of 6 volts AC. The AC signal swings from 6 volts negative to 6 volts positive. The plate current flow ip is 8 ma, the plate



es = AC input signal of 6 volts peak valve
eg = The voltage between the grid and the cathode
Ec = The grid bias voltage
Rgl = The grid leak resistor
ep = The voltage applied to the plate
ip = The current in the plate circuit
RL = The plate load resistor
Ebb = The plate supply voltage

Figure 2 - Triode vacuum tube amplifier.

voltage ep is 250 volts, and the voltage across the resistance RL of 25,000 ohms is 200 volts. The sum of these two voltage drops equals 450 volts. This is the value of the plate supply voltage Ebb.

The action of the amplifier is illustrated by the three waveforms present in this circuit (Fig. 3A). Beginning at the input to the grid, the AC signal acting in series with the bias voltage, swings the grid voltage from -6 volts to -12 volts. It returns to -6 volts, swings to zero volts, and then returns to -6 volts. This completes one input cycle. During this time the plate current (Fig. 3B) varies from 8 ma to 4 ma, to 8 ma, to 12 ma, and returns to 8 ma to complete the cycle. During the same time, the plate voltage (Fig. 3C) swings from 250 volts to 350 volts, to 250 volts, to 150 volts, and back to 250 volts to complete the cycle. It is the variation in plate voltage that comprises the output signal of the triode amplifier.

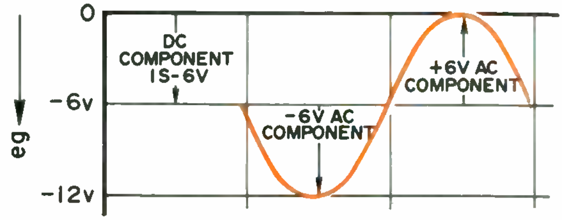
Cathode Bias

The DC bias voltage in the Figure 2 circuit is a negative 6 volts. It is supplied by battery Ec which is commonly termed a "C" battery. This voltage may also be tapped off the plate supply source.

The method used to *self bias* the grid consists of inserting a resistor in series with the cathode lead (Fig. 4)

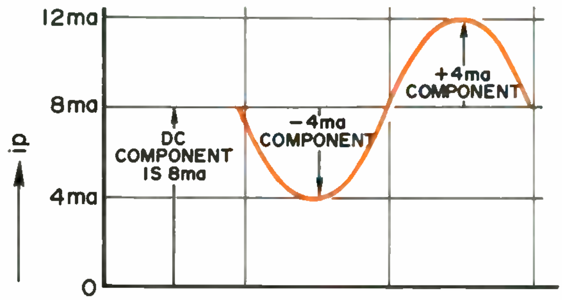
A – GRID VOLTAGE WAVEFORM

The grid is biased for operations at -6 volts. The AC input signal has a peak value of 6 volts. This AC component produces a voltage swing on the grid of the tube that is varied from zero volts to -12 volts.



B – PLATE CURRENT WAVEFORM

The plate current varies about its midpoint value of 8 ma. The grid voltage swing varies the plate current 4 ma above and below the resting plate current value of 8 ma. It is in phase with the grid voltage.



C – PLATE VOLTAGE WAVEFORM

The plate voltage is 180° out-of-phase with both the grid voltage and the plate current. With less current flowing during the negative part of the *plate current* cycle, there is less voltage drop across the load resistor RL (Fig. 2) and more voltage appears at the plate of the tube. This produces 100 volts of AC Voltage at the plate. (This is equal to 200 volts of peak-to-peak voltage.)

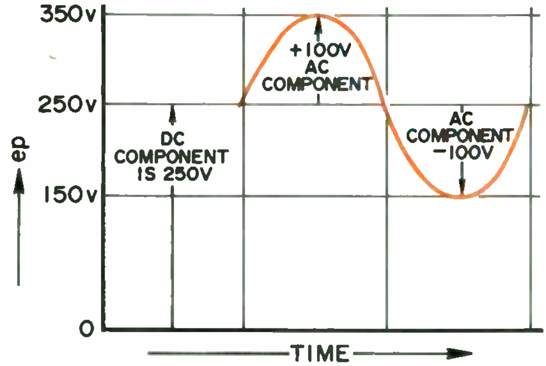


Figure 3 - Waveforms in the circuit of Figure 2.

and shunting it with a relatively large capacitor. A large value of capacity keeps the voltage across the cathode resistor relatively constant even when the plate-cathode current varies with the signal. This action establishes the *operating bias* for the triode. The grid is returned to the lower end of the cathode resistor through the grid leak resistor Rgl. The AC input signal is developed across this grid leak resistor.

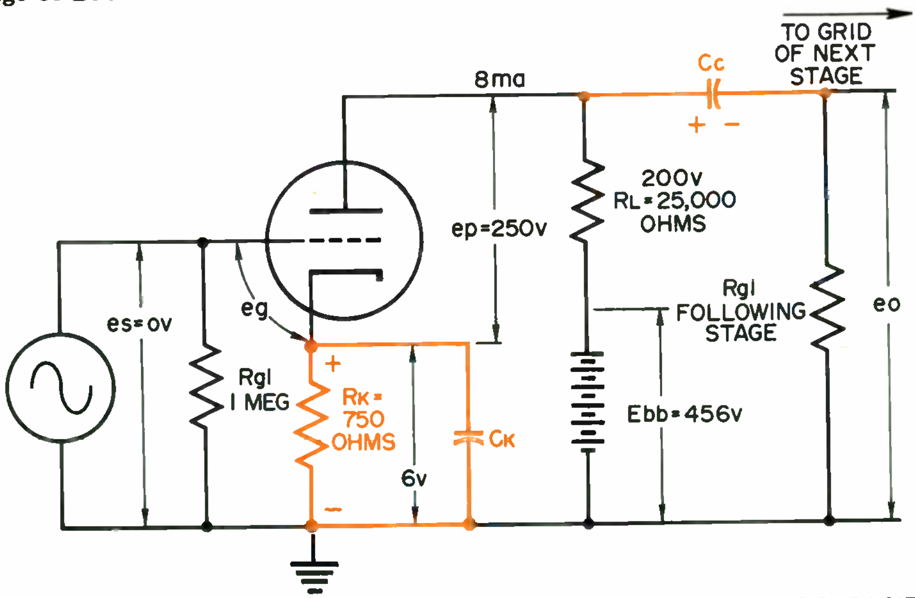
A 750-ohm resistor is connected between the cathode and the ground. This resistor carries a no-signal current of 8 ma (0.008 Amp). The voltage drop across the resistor is equal to 0.008 x 750 which is 6 volts (I· R=E). The supply voltage from the B battery must then be increased from 450 volts to 456 volts to provide the necessary 6 volts of grid bias and still be able to maintain the same no-signal plate voltage of 250 volts.

Grid Resistor

The grid leak resistor Rgl (Fig. 4) connects the grounded end of the cathode resistor to the grid. The flow of cathode current through Rk is accompanied by a negative polarity at the grid end of Rk and a positive polarity at the cathode end of Rk. Thus, Rgl conducts the bias voltage (negative charge) to the grid.

COUPLING METHODS

Normally, a single stage of voltage amplification is not sufficient for radio, TV or hi-fi equipment. To obtain the necessary gain, several stages often must be used in sequence. The output of one stage becomes the input of the next throughout the series of stages. This arrangement is called a *cascade amplifier.*



Rk = CATHODE BIAS RESISTOR
Ck = CATHODE BIAS CAPACITOR
Cc = COUPLING CAPACITOR

Figure 4 - The resistor in the cathode circuit creates a voltage drop that serves as the bias voltage. The resulting grid bias voltage exists between the grid and the cathode.

A cascade amplifier may use a number of methods to couple one amplifier stage to the next. Each method has certain advantages and disadvantages. The choice for a particular application depends on the needs of the circuit. The basic methods are:

1. resistance-capacitance coupling
2. impedance coupling
3. transformer coupling
4. direct coupling

Resistance-Capacitance Coupling

One of the most widely used methods of connecting amplifier stages together is resistance-capacitance (RC) coupling. Amplifiers coupled in this manner are relatively inexpensive, have simple circuitry, have good fidelity over a comparatively wide frequency range, and are especially suitable for use with pentodes and high-mu triodes.

A resistance-capacitance coupled amplifier, generally called an RC amplifier, can be designed to have good frequency response for almost any desired range. For instance, it may be designed to give fairly uniform amplification of all frequencies in the range from 100 to 20,000 Hz. Slight modification of the circuits may extend the frequency to a wider frequency bandwidth. Extension of the range, however, is obtained only at the cost of reduced amplification over the entire range. Thus, the RC method of coupling amplifiers gives good frequency response with minimum distortion, but it also gives lower amplification than other types of amplifiers.

A typical resistance-coupled triode amplifier and the names of the various circuit elements are shown in Figure 5. The DC and AC circuit paths are also identified. In the triode circuit the:

DC grid circuit includes
G, R1, R2, and K; the
AC grid circuit includes
G, R1, C2, and K.

There are two similar paths in the output circuit where the:

AC plate circuit includes
P, R3, C3, C2, and K; the
DC plate circuit includes
P, R3, R4, Ebb, R2, and K.

A typical resistance-coupled amplifier using pentodes (Fig. 6) has the same elements in the grid and plate circuits as in the triode amplifier circuit (Fig. 5). The only difference between the triode circuit and the pentode circuit is the addition of the components required for the screen circuit. As shown in Figure 6 the:

DC screen circuit includes
SC, R6, R4, Ebb, R2, and K; the
AC screen circuit includes
SC, C5, C2, and K.

Load Resistor

To have a large output voltage, the load resistor, R3 (Figs. 5 and 6), should have as high a value as practicable. The higher this resistance value becomes, however, the greater the voltage drop across it and the lower the voltage remaining between

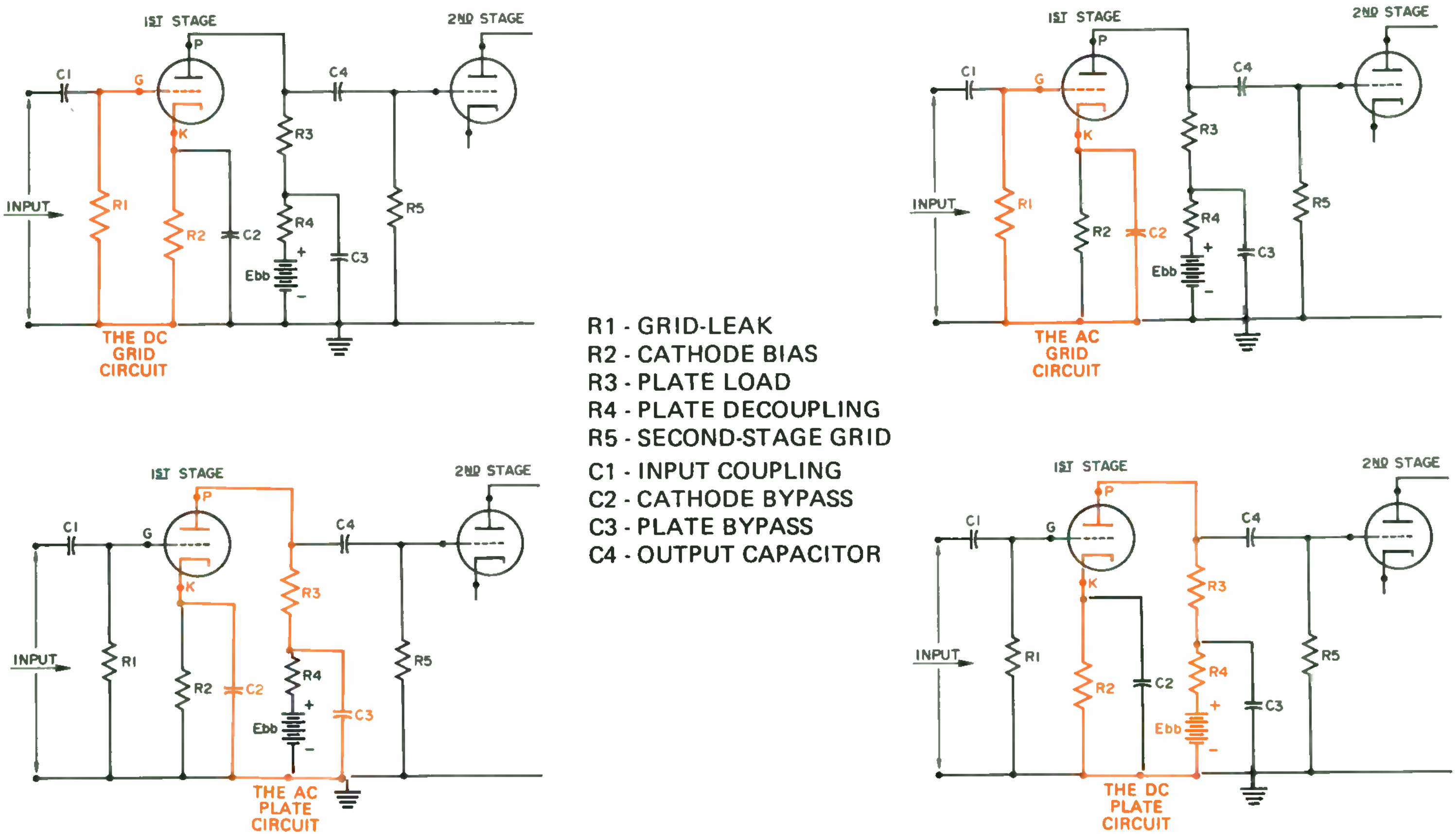
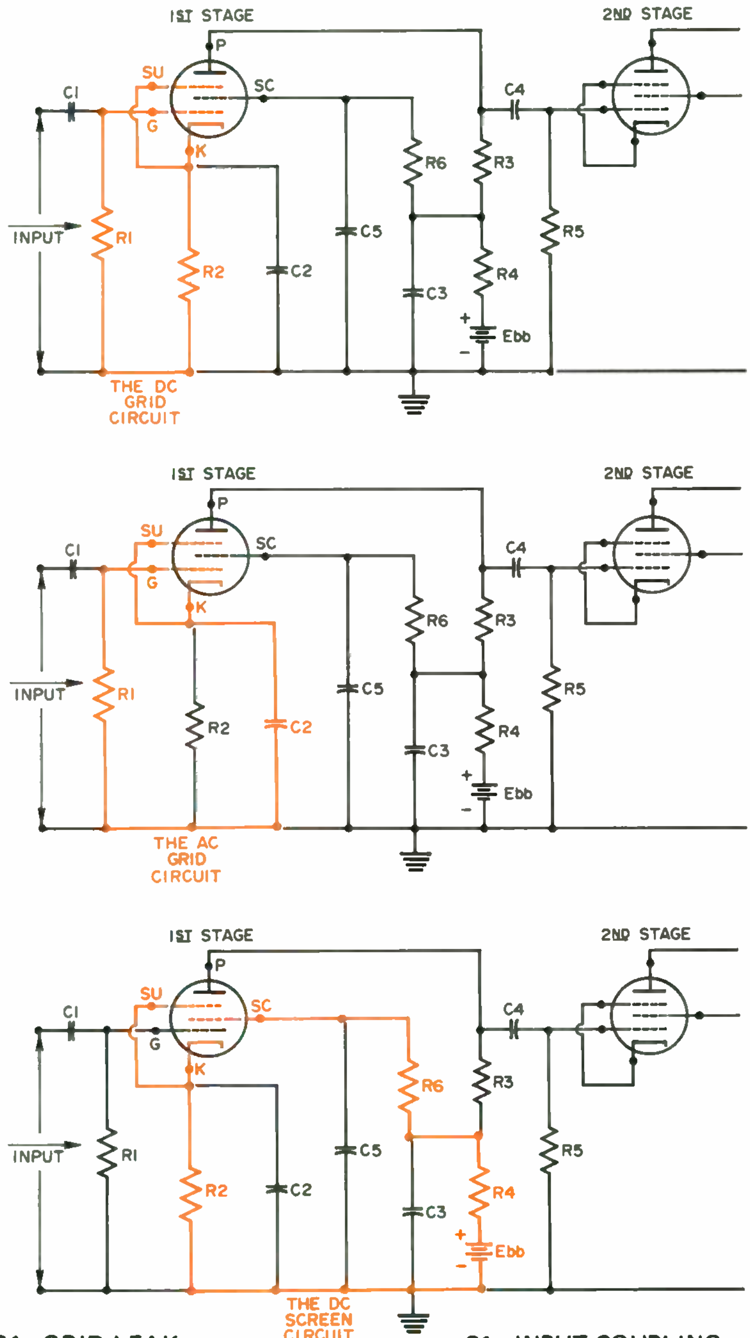


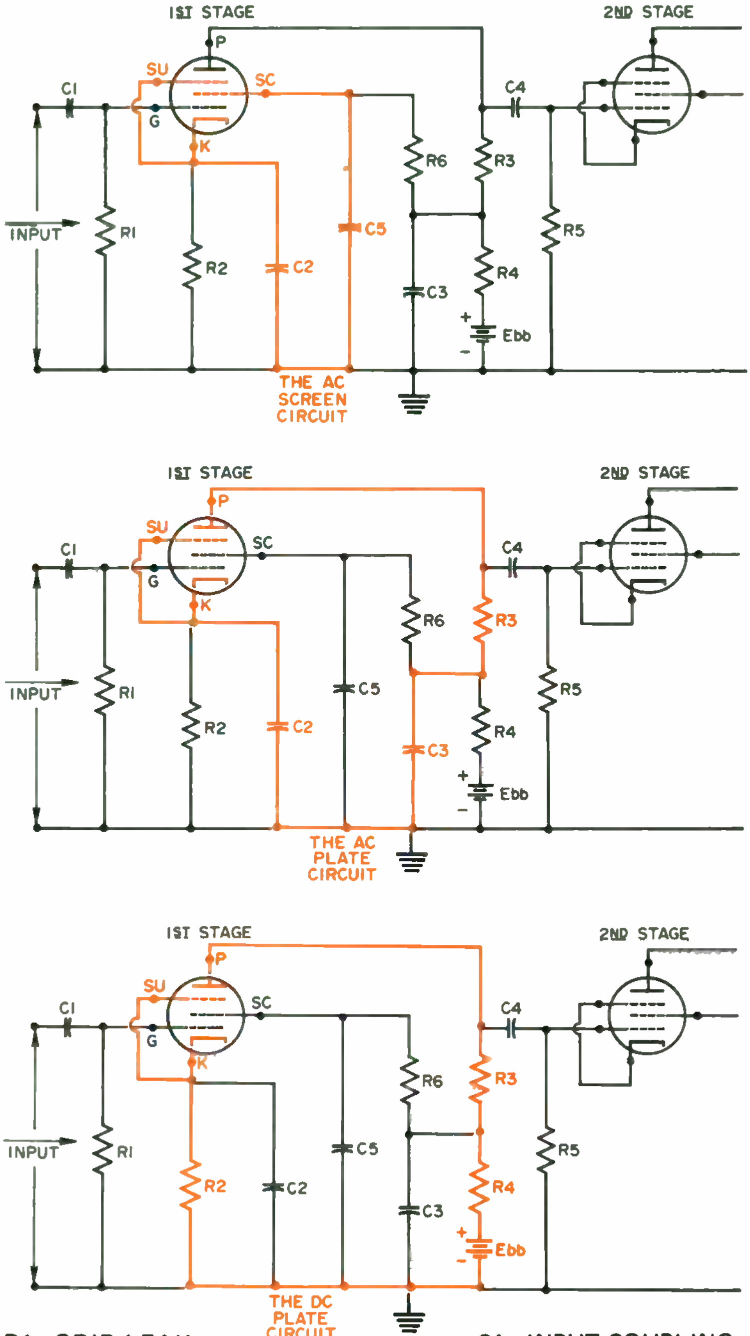
Figure 5 - Resistance-coupled amplifier circuit using a triode vacuum tube.



R1 - GRID-LEAK
R2 - CATHODE BIAS
R3 - PLATE LOAD
R4 - PLATE DECOUPLING
R5 - SECOND-STAGE GRID
R6 - SCREEN RESISTOR

C1 - INPUT COUPLING
C2 - CATHODE BYPASS
C3 - PLATE BYPASS
C4 - OUTPUT CAPACITOR
C5 - SCREEN BYPASS

Figure 6 - Resistance-coupled amplifier circuit using a pentode vacuum tube.



R1 - GRID-LEAK
R2 - CATHODE BIAS
R3 - PLATE LOAD
R4 - PLATE DECOUPLING
R5 - SECOND-STAGE GRID
R6 - SCREEN RESISTOR

C1 - INPUT COUPLING
C2 - CATHODE BYPASS
C3 - PLATE BYPASS
C4 - OUTPUT CAPACITOR
C5 - SCREEN BYPASS

Figure 6(continued)

the plate and cathode of the tube. To determine the required effective plate voltage, the voltage drop across the load resistor is subtracted from the plate supply voltage. There is a practical limit to the size of the plate load resistor if the plate is to be supplied with its rated voltage. If a larger plate resistor is necessary, the only alternative is to increase the plate supply voltage.

There is a practical limit to the amount that plate voltage may be increased. An example of the DC voltage distribution around the plate circuit is shown in Figure 7. The plate current is 6 ma and the voltage across the 30K ohm load resistor is 6 x 30 which is 180 volts. The voltage drop across the 500 ohm cathode resistor is 0.006 x 500 which equals 3 volts. These 3 volts provide the grid bias for the tube. The plate-cathode voltage ep, is the supply voltage Ebb, less the voltage drop across RL and RK, or 300 - 180 - 3 = 117 volts.

Screen Voltage

The screen resistor R6 (Fig. 6) has the required voltage drop across it. When this voltage drop is subtracted from the supply voltage Ebb, the rated screen voltage is applied to the screen grid. The value of the cathode resistor R2 is determined by the amount of grid bias required and the no-signal plate and screen currents.

Frequency Response

Low Frequency

For the range of audio frequencies to be amplified, the cathode by-pass capacitor C2 (Figs. 5 and 6) has a low reactance to the AC component of plate current compared to the resistance of R2. The decoupling, or filter, circuit C3R4 greatly reduces the AC component of plate current flowing through the plate voltage supply, because R4 offers a high series resistance and C3 offers a low shunt

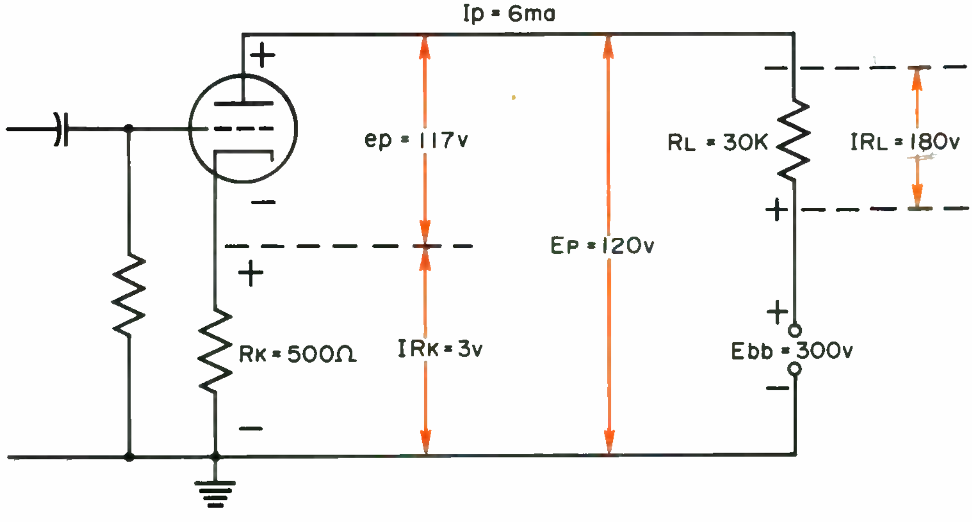


Figure 7 - Distribution of voltages around the plate circuit.

reactance to the AC signal component.

Typical frequency response curves for an RC coupled audio amplifier are shown in Figure 8. The response is measured in terms of the amplifier voltage gain over a range of frequencies. The voltage gain is the ratio of the output voltage eo to the input signal voltage es (Fig. 4).

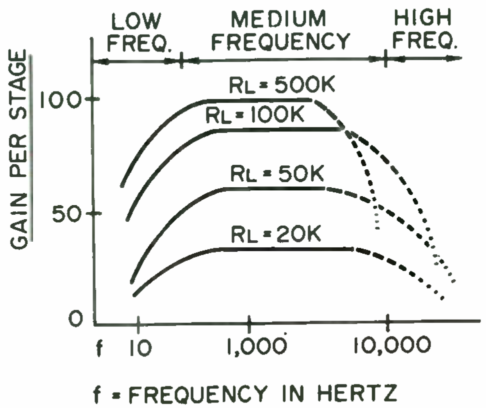


Figure 8 - Frequency response curves show how the gain of an RC amplifier varies with the frequency. The larger the load resistor, RL (Fig. 7), the greater is the voltage developed across it, but with a consequent loss of frequency response.

The gain falls off at very low frequencies because of the increase in the reactance of capacitor C4 (Figs. 5 and 6). It must be remembered that the reactance Xc of the capacitor C4 varies in a manner opposite to the change in the frequency f, according to the formula

$$X_C = \frac{1}{2\pi\ f\ C4}$$

When the frequency is low, the value in ohms of the reactance Xc is very large. As the voltage drop E across a reactance is determined from $E = IX_C$, the voltage drop E will be large when Xc is large at low frequencies (Fig. 9). As capacitor C4 acts in series between the source and the load, it develops an increasing amount of signal voltage across itself as the frequency decreases.

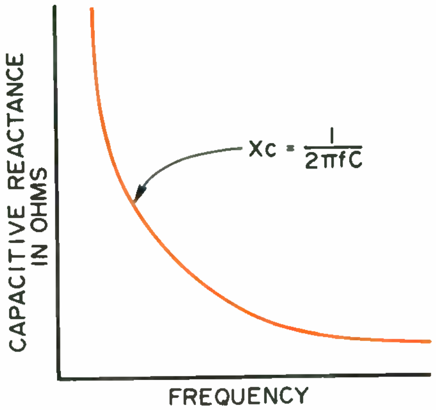


Figure 9 - The reactance of a capacitor varies inversely with the frequency.

Medium Frequency

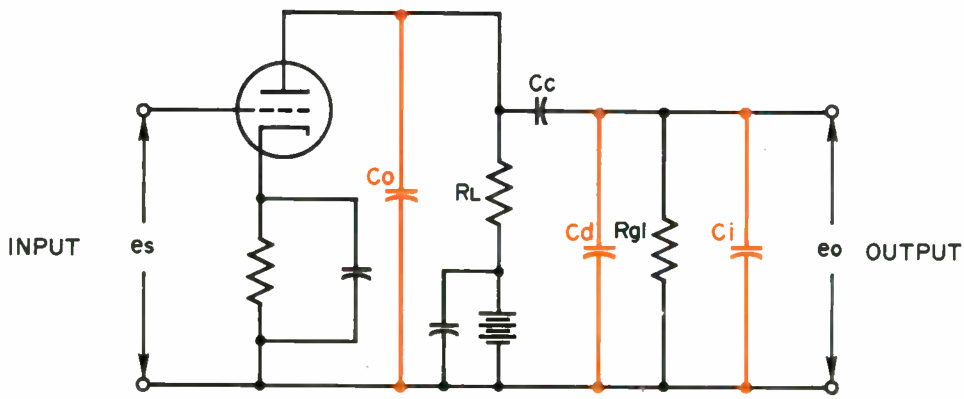
When the frequency f is increased to the middle frequency range, the reactance Xc of the capacitor C4 is decreased. This decrease reduces the voltage drop across the capacitor C4, thus allowing most of the voltage that has developed across the load resistor R3 to be applied to the grid of the succeeding stage. The purpose of each stage of amplification is to develop a higher voltage across the load resistor in the plate circuit compared to the input voltage. Then, this higher voltage is applied to the grid of the succeeding stage for additional amplification.

High Frequency

As the frequency increases, the capacitive reactance Xc of C4 becomes lower and the voltage drop across it is also decreased. This action should have the effect of having a higher voltage applied to the grid of the succeeding stage, but at higher frequencies another action takes place in the circuit. This other action occurs because of the shunting effect of the capacitance in the circuit (Fig. 10).

The total shunt capacitance is a combination of the fixed capacitors in the circuit and stray capacitance. The stray or distributed capacitance is created by the wiring, circuit components, and the proximity of the chassis ground.

The reduction in gain at higher frequencies is caused by the shunting effect across the load resistor RL of the output capacitance Co of one stage, the input capacitance Ci of the next stage, and the distributed capacitance Cd of the coupling network. The combined effect of these capacitances is to decrease the output voltage, eo.



Co - Output Capacitor or equivalent, distributed capacitance
Cd - Distributed Capacitance of the Coupling Capacitor Cc
Ci - Input Capacitance of the next stage

Both the fixed and stray capacity shown by the colored lines affect the higher frequencies. The reduction in gain due to capacitance is shown by the dotted line portion of the gain curves in Figure 8.

Figure 10 - The distributed capacity acts as a shunt capacitor reducing the voltage available at the output of the amplifier stage.

Amplifiers used to amplify a wide band of frequencies have many RC coupled stages. Each stage has a relatively low gain per stage, uses large coupling capacitors between each of the stages, and low shunting capacitors across the input.

Impedance Coupling

Impedance or inductive coupling is obtained by replacing the load resistor R_L of a normal RC coupled amplifier with a choke or inductor L (Fig. 11). To obtain as much amplification as possible the inductor is made as large as possible. To avoid undesirable magnetic coupling a closed-shell type inductor is used. Because of the inductor's low DC resistance, only a small DC voltage is developed across it. Thus, the tube operates at a higher plate voltage.

The degree of amplification is not as uniform as it is with the RC coupled amplifier because the load impedance Z_L varies with the frequency. The impedance Z_L varies according to the formula:

$$Z_L = \sqrt{R_L^2 + X_L^2}$$

because the resistance is constant for the inductor. Z_L may be considered to vary directly as the reactance X_L varies. Thus, if we consider Z_L to be equal to $2\pi fL$, the impedance in ohms of L will be low when the frequency f

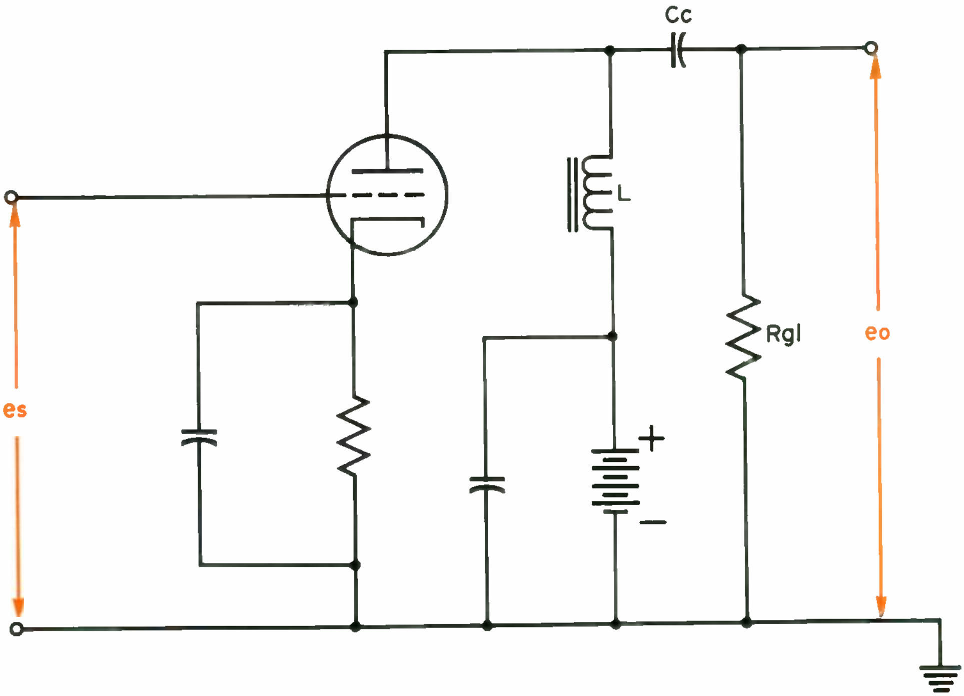


Figure 11 - An impedance coupled amplifier is similar to a resistance coupled amplifier. The frequency response of this amplifier is not as uniform across the frequency range as the RC amplifier.

is low. Conversely, when the frequency f is high, the impedance of the inductor L in ohms will be high.

Since the output voltage appears across Z_L, the voltage gain increases with the frequency until the shunting capacitance limits it (Fig. 12). The shunting capacitance includes, not only the interelectrode and distributed wiring capacitances found in RC coupled amplifiers, but also the distributed capacitance associated with the turns of the inductor. The distributed capacitance between the turns of the coil greatly increases the capacitance to ground and plays a part in limiting the use of this coupling method at the higher audio frequencies.

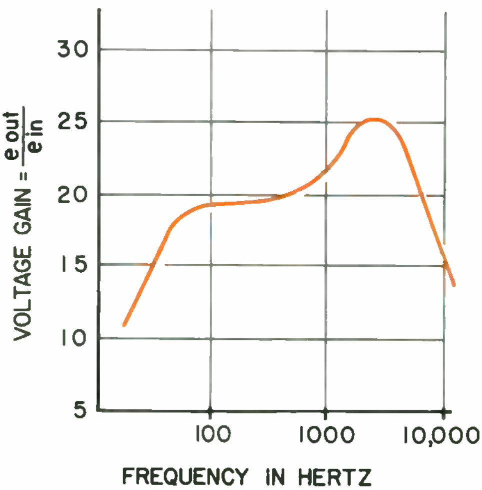


Figure 12 - A typical response curve of an impedance coupled amplifier plotted on semi-log graph paper. The vertical scale has equal spacing for the numbers along its length, while the horizontal scale, the log scale, has *unequal* spacing. These horizontal scale spacings are always 10 times greater in *value*.

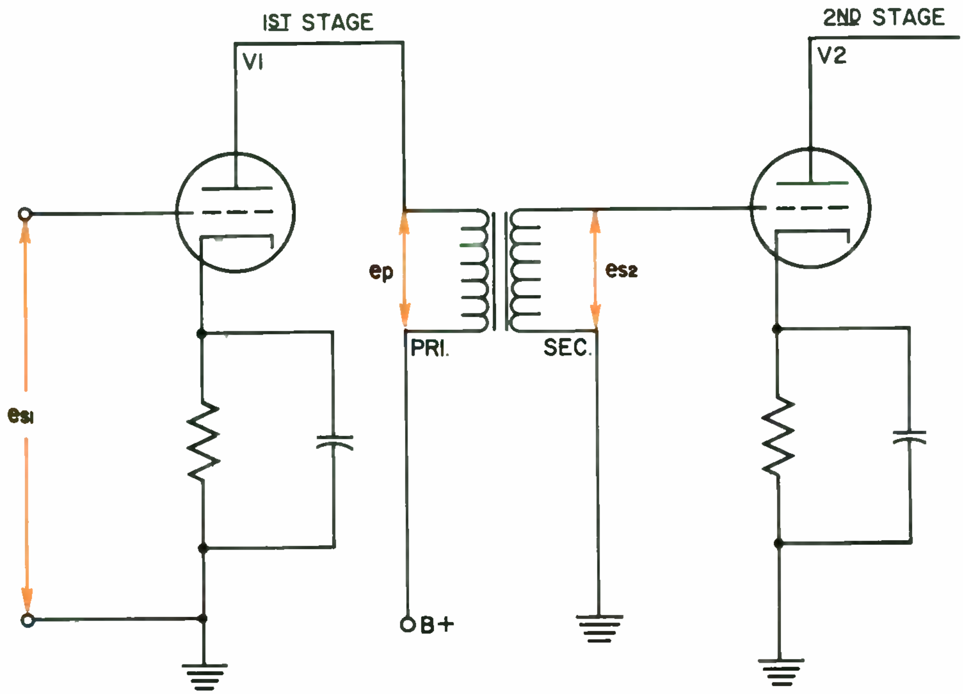
Transformer Coupling

Transformer coupled stages have certain advantages over other types of coupling. The voltage amplification of the transformer coupled stage may exceed the amplification of the tube if the transformer has a step-up turns ratio (Fig. 13). Direct-current isolation of the grid of the next tube is provided without the need for a blocking capacitor. Also, the DC voltage drop across the coupling resistor, necessary when RC coupling is used, is avoided. This type of coupling is also used to couple a high-impedance source to a low-impedance load, or vice versa, by choosing a suitable turns ratio. Also, it may be used as a simple means of providing phase inversion for a push-pull amplifier without the use of special phase inverting

The disadvantages of transformer coupling are greater cost, greater space requirement, the necessity for greater shielding, and the possibility of poor frequency response at the higher and lower frequencies. The voltage gain as a function of frequency throughout the audio range is shown in Figure 14. The curve shows that the transformer coupled voltage amplifier has a relatively higher gain and a uniform frequency response over the middle range of audio frequencies. But, it has a poor response for both low and high audio frequencies.

Direct Coupling

In each of the coupling circuits that have been discussed, the coupling device isolated the DC voltage in the



es1 - Input signal
ep - Signal voltage across the primary of the audio transformer
es2 - Signal voltage across the secondary of the audio transformer

Figure 13 - A circuit showing how a transformer coupled amplifier couples the signal from the first to the second stage.

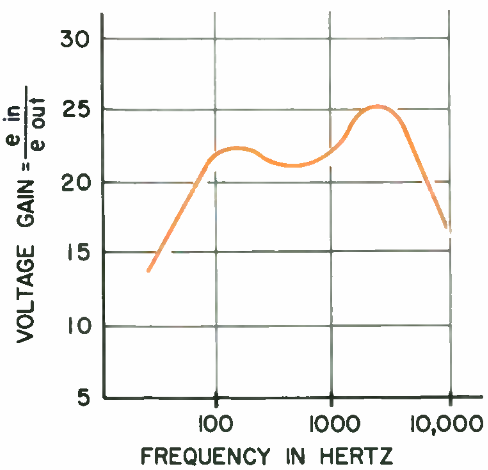


Figure 14 - A typical response curve of a transformer coupled amplifier shows that the response is generally flat in the middle frequency range, but has a poor response at the low and high frequencies.

plate circuit of one tube from the grid circuits of the next tube. These circuits are designed to couple the AC component of the signal to the next stage with a minimum of attenuation.

In a direct-coupled amplifier, the plate of one tube is connected directly to the grid of the next tube without going through a capacitor, transformer, or similar coupling device. This arrangement, however, presents a problem of voltage distribution. Because the:

plate of a vacuum tube must have a *positive* voltage with respect to its *cathode*, and the

grid of the next tube must have a *negative* voltage with respect to its *cathode*, it follows that the cathodes of the two tubes cannot operate at the same potential. Proper voltage distribution is obtained by a voltage divider, as shown at points A, B, C, D, and E in Part A of Figure 15. There are two versions of the same circuit drawn in Figure 15 (Parts A and B). Part A is the more conventional form of the schematic drawing. This same circuit is redrawn in Part B to show how the supply voltage is distributed among the various elements in the amplifier.

In this direct coupled amplifier, the plate of V1 is connected directly to the grid of V2. The grid of V1 is returned to point A through Rg1. The cathode bias of V1 is developed by the voltage drop between points A and B of the voltage divider. The plate of V1 is connected through its plate load resistor RL to point D on the divider. Load resistor RL also serves as the grid resistor for V2.

Since the plate current from V1 flows through RL, a certain amount of the supply voltage is developed across RL. The amount of voltage developed across RL must be considered in choosing point D on the divider. Point D is located so that approximately half of the available voltage is applied to the plate of V1. The plate of V2 is connected through a suitable output load R to point E, which is the most positive point on the divider. Since the voltage drop across RL may place too high a negative bias on the grid of V2, it may be necessary to connect the cathode of V2 at point C which is negative with respect to point D. This lowers the bias on the grid of V2, because the voltage drop across RL and across the resistor from C to D are in opposition. Point C, together with the value of R, determines the proper voltage for V2.

Resistance Network

The entire circuit in this direct coupled amplifier is a complex resistance network that must be adjusted carefully to obtain the proper plate and grid voltages for both tubes. If more than two stages are used in this type of amplifier, it is difficult to achieve stable operation. Any small change in the voltages of the first tube is amplified and thus makes it difficult to maintain proper bias on the final tube connected into the circuit. Because of the instability encountered, direct-coupled amplifiers are almost always limited to two stages. Furthermore, the power supply voltage must be twice the voltage requirement for one stage.

One method of supplying the needed range of voltage is to use a power supply which provides approximately equal amounts of both positive and negative voltages with respect to ground. This method allows cascading without necessitating excessively high plate supply voltages. In Figure 15, either point C or point D may be properly tied to ground potential.

When the tube voltages are properly adjusted to give class A operation (described in a later lesson), the circuit serves as a distortionless amplifier with uniform response over a wide frequency range. This type of

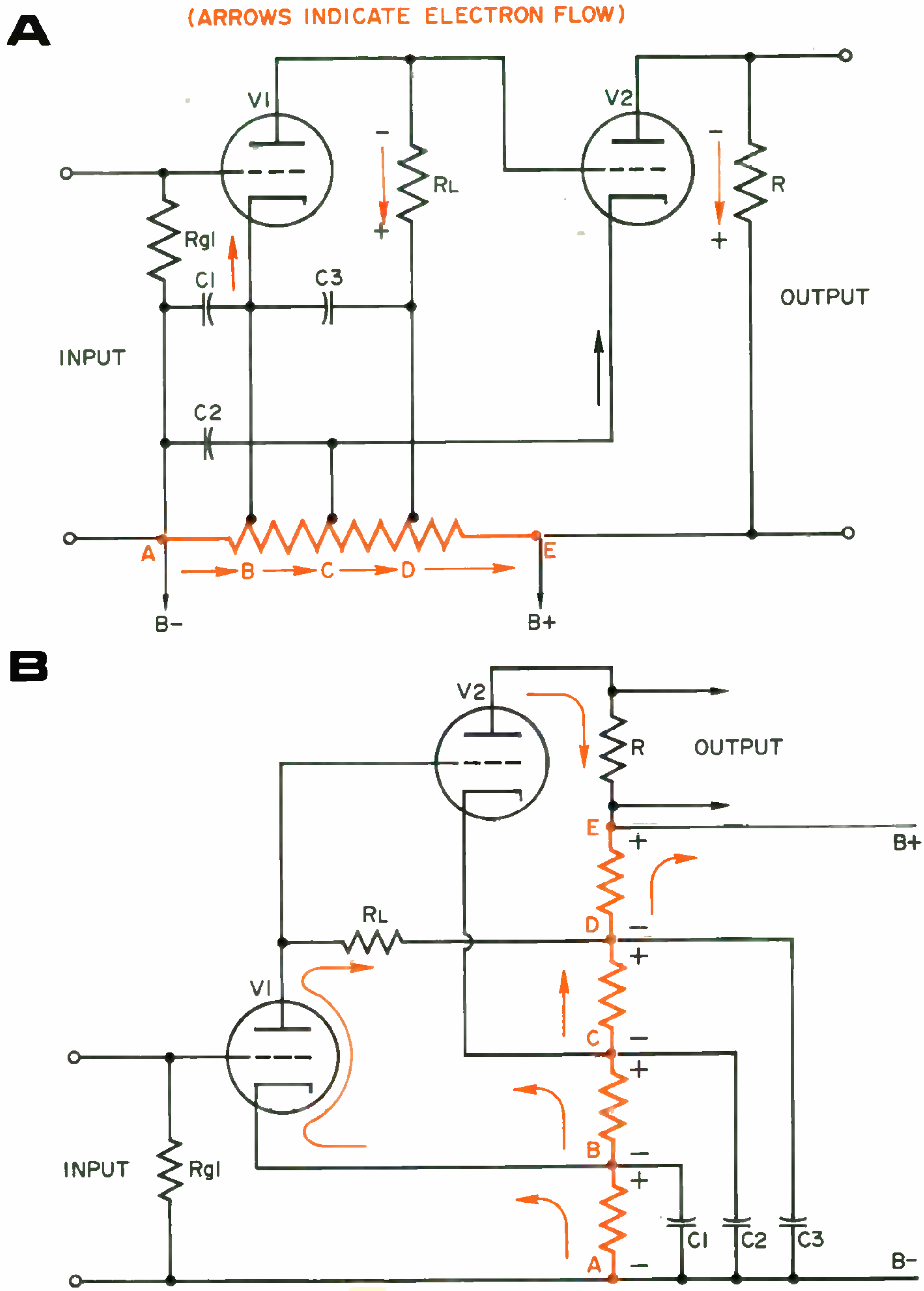


Figure 15 - A direct coupled amplifier must have the proper distribution of voltages to obtain the required polarities.

amplifier is effective especially at the lower frequencies because the impedance of the coupling elements does not vary with the frequency. Thus, a direct-coupled amplifier may be used to amplify voltage variations of very low frequencies. Because the response is almost instantaneous, this coupling is useful for amplifying pulse signals where all distortion (caused by the coupling elements) must be avoided.

FEEDBACK CIRCUIT

A feedback circuit is one in which some portion of the output voltage is fed back to the input portion of the circuit. When this principle is applied to a *feedback amplifier*, it means that the amplifier has transferred some voltage from the output of the amplifier back to the input. If the signal being fed back is in phase with the input signal it is called:

Positive,
Direct, or
Regenerative feedback;

because it *adds* to the input voltage. If the signal fed back to the input is 180° out of phase with the applied signal, it is called:

Negative,
Inverse, or
Degenerative feedback;

because it *subtracts* from the input voltage. Positive feedback is used in oscillators. Negative feedback is used in amplifiers. This negative feedback prevents self-oscillation and provides a more uniform output with the changes in tube characteristics.

The basic principle of feedback is diagrammed in Figure 16. Some of the output is added in series with the input. Depending on the polarity, this additional voltage acts to increase or

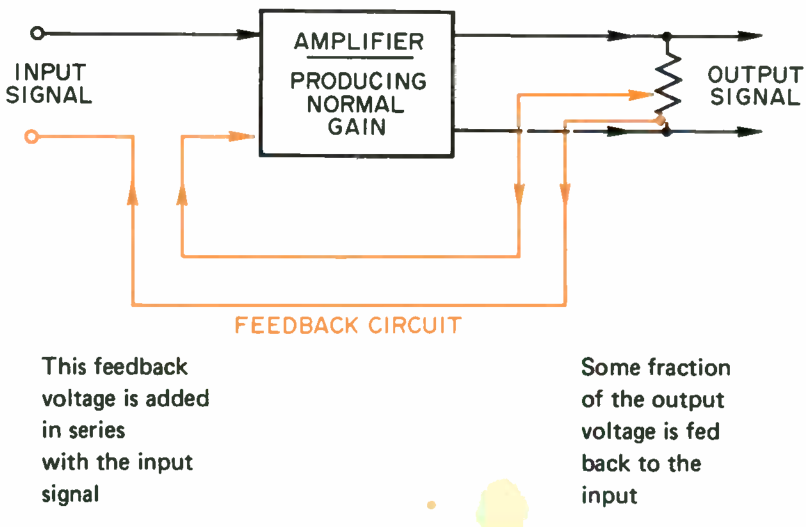


Figure 16 - Basic principle of a feedback amplifier.

decrease the resultant voltage applied to the amplifier's input terminals. If the signal is in phase, the input voltage is *Positive* (Regenerative). If the signal is 180° out of phase it is *Negative* (Degenerative).

Advantages of Feedback

Negative feedback may be used to reduce any nonlinear distortion produced in the tube circuit. Negative feedback can make the output waveform similar to the input waveform by reducing nonlinearities produced within the amplifier tube. There is a decreased amount of distortion due to a definite action in the amplifier stage.

The input signal applied to the grid of an electron-tube amplifier is amplified by an amount determined by the amplification factor of the tube. Any nonlinearities introduced within the tube are not amplified. If a portion of the output signal is fed back 180° out of phase with the input, the distortion component of this feedback voltage is amplified along with the input signal.

The amplified distortion component tends to cancel the distortion component introduced within the tube. The output may be practically free of nonlinear distortion. To separate the distortion from the desired signal, the distortion must occur in the plate circuit of the stage in which negative feedback is to be applied.

The overall gain of the desired signal is also reduced. Increasing the number of stages compensates for this reduction. Distortion caused by the flow of grid current cannot be corrected by negative feedback because this distortion occurs at the source and *not within* the amplifier tube.

Feedback in Tube Amplifiers

Negative feedback in vacuum tube circuits may be obtained in a number of ways. The feedback system may return the signal over one or two stages. Only in certain instances are more than two stages involved. A basic tube circuit (Fig. 17) uses a voltage divider network consisting of C1, R1, and R2. In this circuit, a part of the output voltage that exists across the primary of the output transformer T3 is used as the feedback voltage.

An understanding of the action in the circuit may be obtained by assuming that the input signal causes the grid voltage to swing in a positive direction. With the grid becoming positive, the current in the plate circuit increases. This causes the voltage at the plate to decrease. As the voltage decreases, the capacitor C1 discharges through R1 and R2 creating voltage drops across both resistors. The voltage drop across resistor R2 creates a polarity making the top end of R2 negative with respect to its grounded end. The voltage across R2 is in phase opposition with respect to the secondary voltage of T2. Therefore, the grid-to-cathode signal is equal to the difference between the secondary voltage of T2 and the feedback voltage across R2.

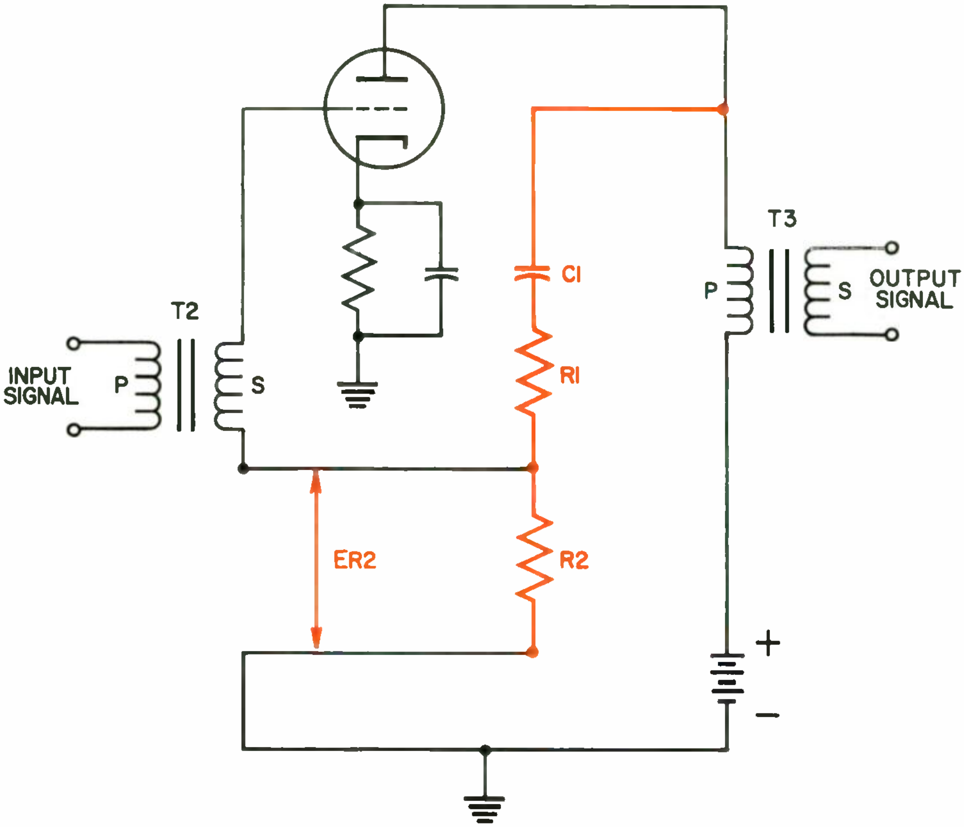


Figure 17 - A tube circuit that uses a portion of the total voltage developed across the primary of the output transformer. The feedback voltage is ER2, which is in series with the secondary winding of the input transformer.

Another method of obtaining negative feedback employs current feedback (Fig. 18). Here, the bypass capacitor across the cathode resistor has been omitted, producing a degenerative action that may be analyzed as follows. Assume that the input signal swings the grid voltage in a positive direction. The increase in plate current causes an increase in the voltage drop across Rk. Since Rk is not bypassed, the signal current in the plate circuit flowing through Rk adds to the bias produced by the no-signal component. The grid-to-cathode voltage on the positive half cycle is equal to the difference between the input signal and the drop across Rk. The magnitude of the grid voltage swing in a positive direction is not as great as it would be without feedback because the voltage drop across Rk is increased.

Similarly, on the negative half cycle the input signal swings the grid voltage in a negative direction and decreases the plate current. The decrease in current through Rk causes a decrease in the voltage across Rk. During this half cycle the grid-to-cathode voltage is equal to the *sum* of the input

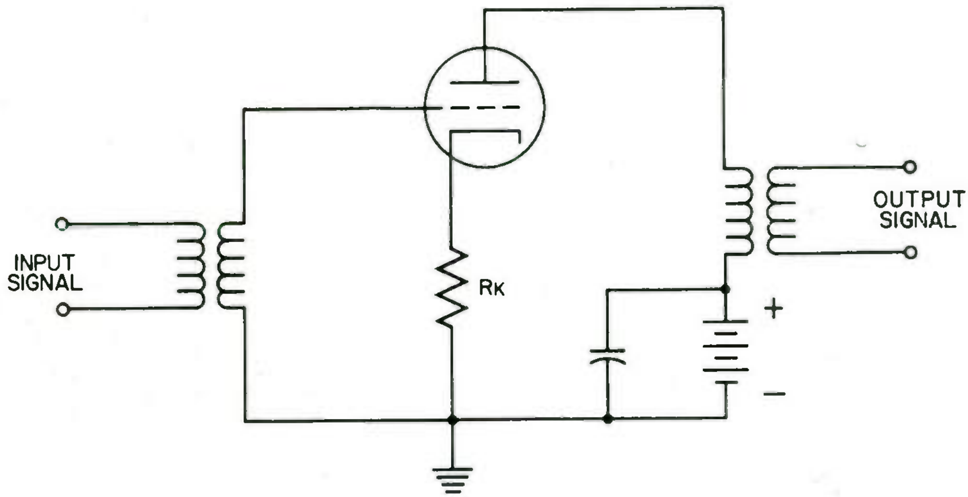


Figure 18 - A tube circuit that uses the variation in voltage developed across the cathode resistor RK. An increase in current flow in the plate to cathode circuit develops a greater voltage drop across RK. This effectively increases the value of the grid bias, and reduces the resultant input signal.

voltage *plus* the drop across Rk. The magnitude of the negative swing of grid voltage is less than it would be without feedback because the drop across Rk is less.

The output voltage developed across an unbypassed cathode resistor is used in designing cathode followers and phase inverters. These circuits are considered in later lessons.

If proper phase relations are established, negative feedback involving more than one stage may be used. Figure 19 shows a two-stage negative feedback amplifier using voltage feedback. In this case, special attention must be paid to the phase relations throughout the circuit.

Assume that at a given instant the input voltage makes the grid of V1 less negative. Plate current then increases in V1 and the plate voltage decreases. This causes the grid of V2 to become more negative. At the same time, the plate of V2 becomes more positive because of the reduction in plate current. This increase in potential causes an increase in the charge of C1. The charging current flows from ground up through R2 and R1 to the left plate of C1, making the top end of R2 more positive with respect to ground. The increase in voltage across R2 acts, in series with the input and the bias across Rk, to reduce the magnitude of the positive-going signal impressed on the grid. In short, the grid input signal is reduced by the amount of the feedback voltage because these two voltages are 180° out of phase. Various kinds of feedback circuits may be employed to satisfy specific requirements. Thus, a circuit using feedback applied to both the grid input circuit and the cathode circuit may be employed.

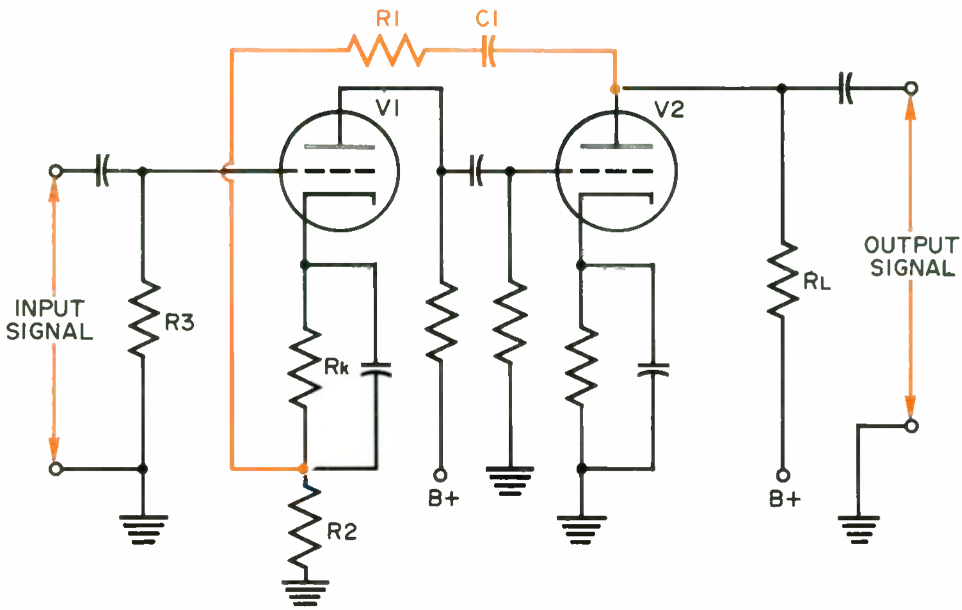


Figure 19 - This two-stage tube amplifier takes an output from the second stage and feeds it into the input circuit of the first stage.

TRANSISTOR AMPLIFIERS

A solid stage device having three elements is known as a transistor. It may be named more exactly as a *Transistor Triode.* Transistors, like electron tube triodes, are amplifiers. Although electron tube circuits are similar to transistor circuits, the two circuits have different characteristics. It is not possible to substitute a transistor for an electron tube without changing both the bias and the plate supply voltages. For example, the transistor in some circuits is a current amplifier having a low input resistance. The corresponding electron tube amplifier has a high input resistance. As previously stated, the transistor has a:

collector terminal that functions like the plate of a vacuum tube triode, a

base terminal that corresponds to the triode grid, and an

emitter terminal that corresponds to the triode cathode.

The similarity between a triode vacuum tube and a transistor may be seen by comparing the basic amplifier circuit used with each one (Fig. 20). The grounded-emitter configuration used to illustrate a simple transistor amplifier (Fig. 20B) is one of the more commonly used forms. The transistor may be of either type. With the polarities shown in this circuit, however, the only transistor that may be used is the PNP type.

Phase Relationships

The phase relationships between a grounded-cathode triode vacuum tube (Fig. 21) and the two grounded

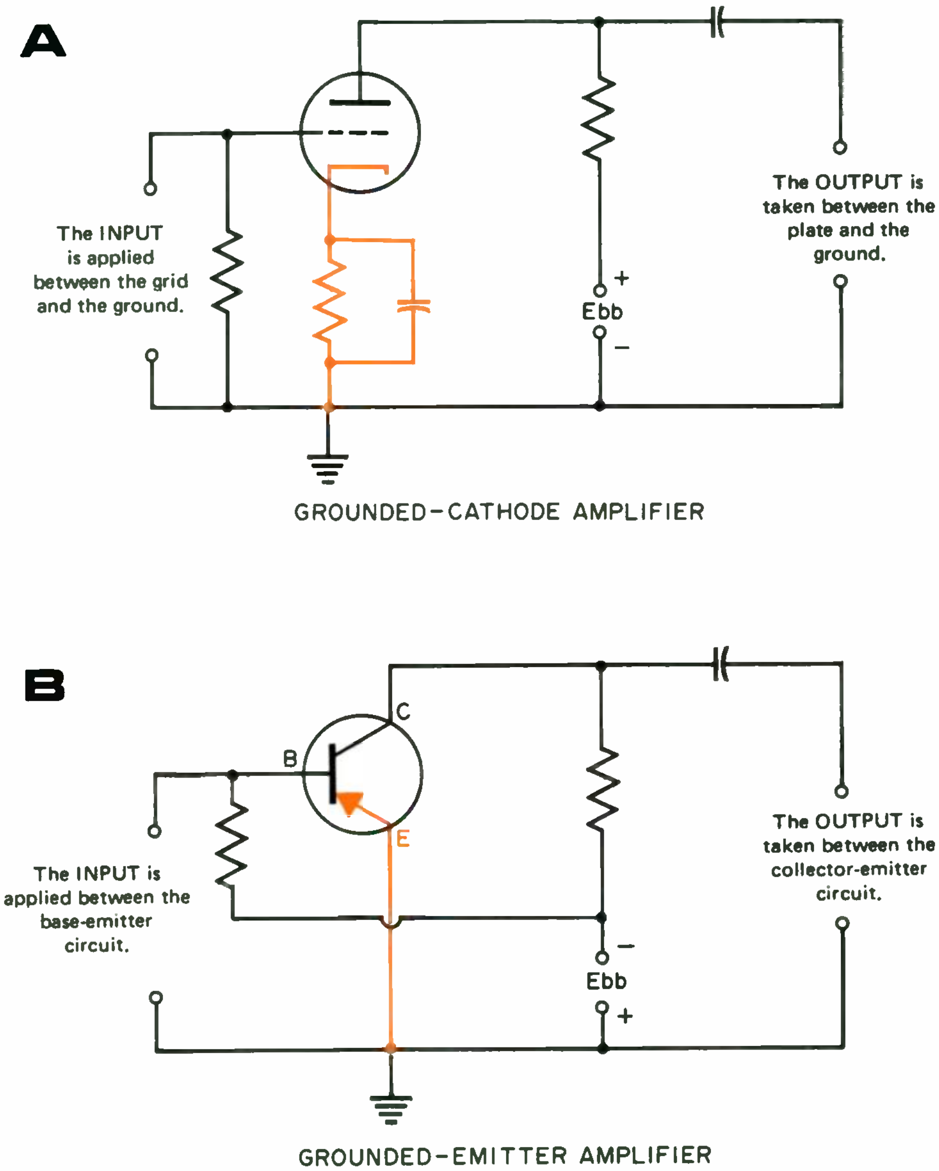


Figure 20 - The similarity between a triode type, vacuum tube amplifier circuit and a PNP type transistor amplifier circuit.

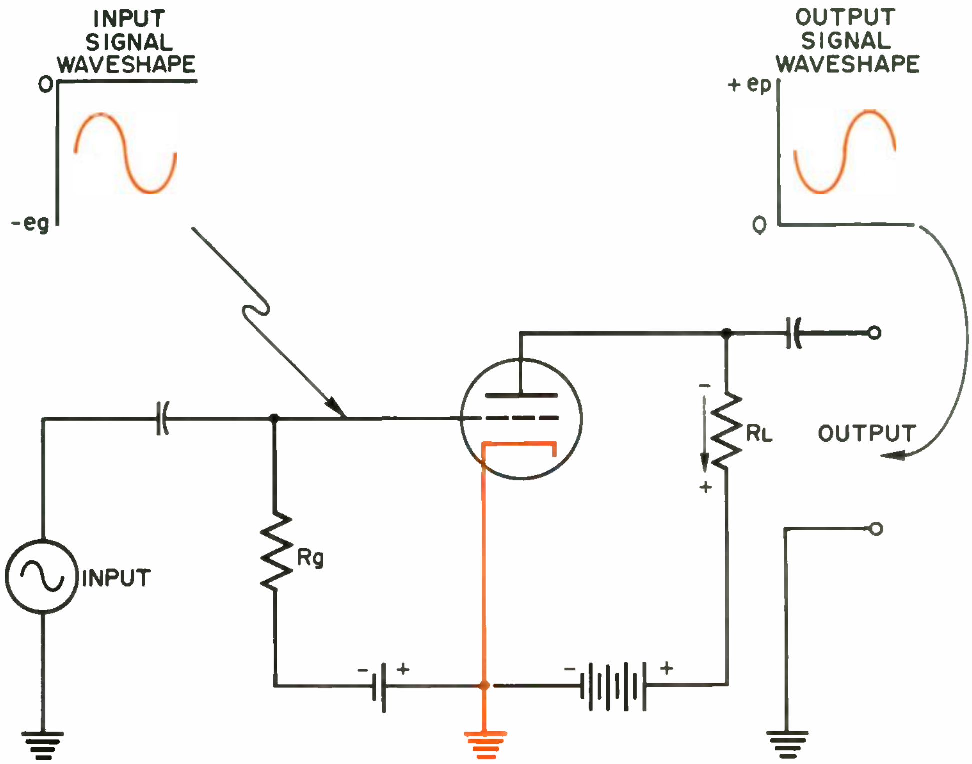


Figure 21 - A grounded cathode vacuum tube amplifier.

emitter transistor circuits (PNP and NPN types) are helpful in understanding their operation as amplifiers (Figs. 21, 22, and 23). The phase between the input and the output in all three circuits is shifted 180°. The reason for the shift will be described when the circuits are analyzed.

Triode Input Signal

The triode input signal (Fig. 21) is developed across the grid resistor Rg in series with the bias voltage between the grid and the cathode. The output signal of the triode is developed between the plate and the ground. The average grid voltage depends upon the magnitude of the grid bias supply voltage. The average plate voltage depends upon the magnitude of the plate supply voltage.

Transistor Input Signal

The input signal to the PNP transistor (Fig. 22) is developed between the base and emitter in series with the bias voltage in the circuit. The bias polarity is in the forward, or low-resistance, direction of the base-emitter junction. The output signal of the transistor is developed between the collector terminal and ground.

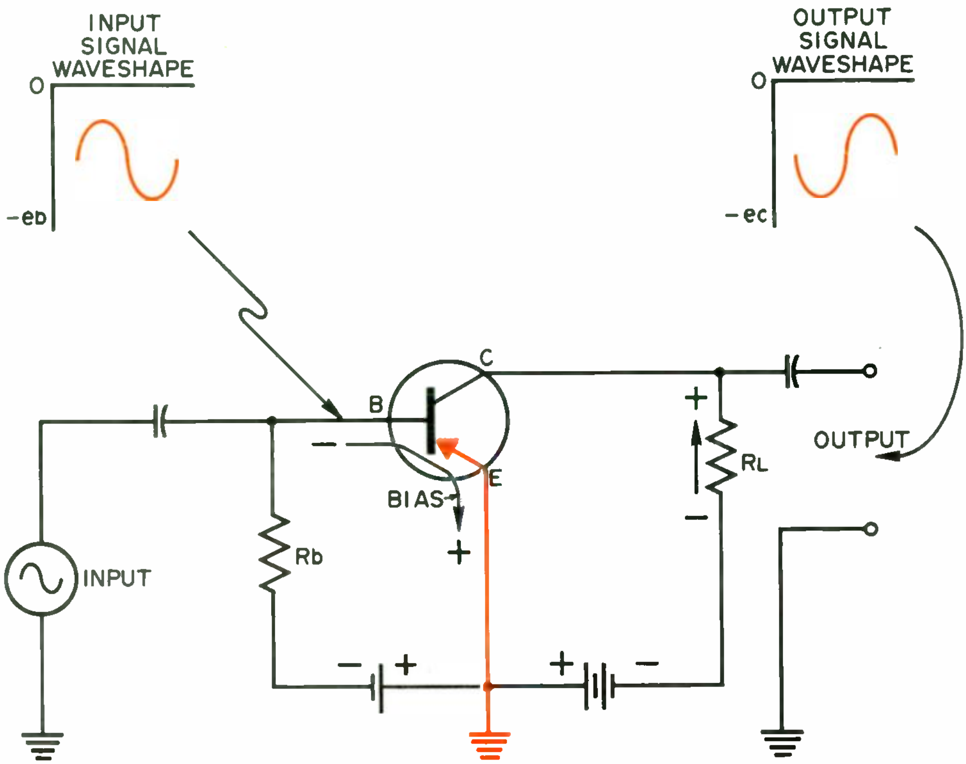


Figure 22 - A grounded emitter PNP type transistor amplifier.

The average base voltage, compared to the emitter, depends upon the magnitude of the bias voltage in the base-emitter circuit. The magnitude of the bias current determines the transistor's mode of operation (or *class of operation* which will be discussed in a later lesson).

The average collector voltage depends upon the magnitude of the collector voltage supply. In many instances, the magnitude of the collector voltage has only a small effect in determining the collector current. The collector current is primarily a function of the bias current in the input circuit.

When a signal is applied to the input circuit of the transistor, the bias current varies about an average or no-signal value. This action causes the collector circuit current to vary through a much greater amplitude across the load impedance, which is connected in series with the collector voltage supply and the collector terminal of the transistor.

Due to this sequence of actions, a phase shift of 180° occurs between the input and output signals. First, a positive-going input signal (Fig. 22) opposes the base-emitter bias and decreases the base-emitter current. This action decreases the collector

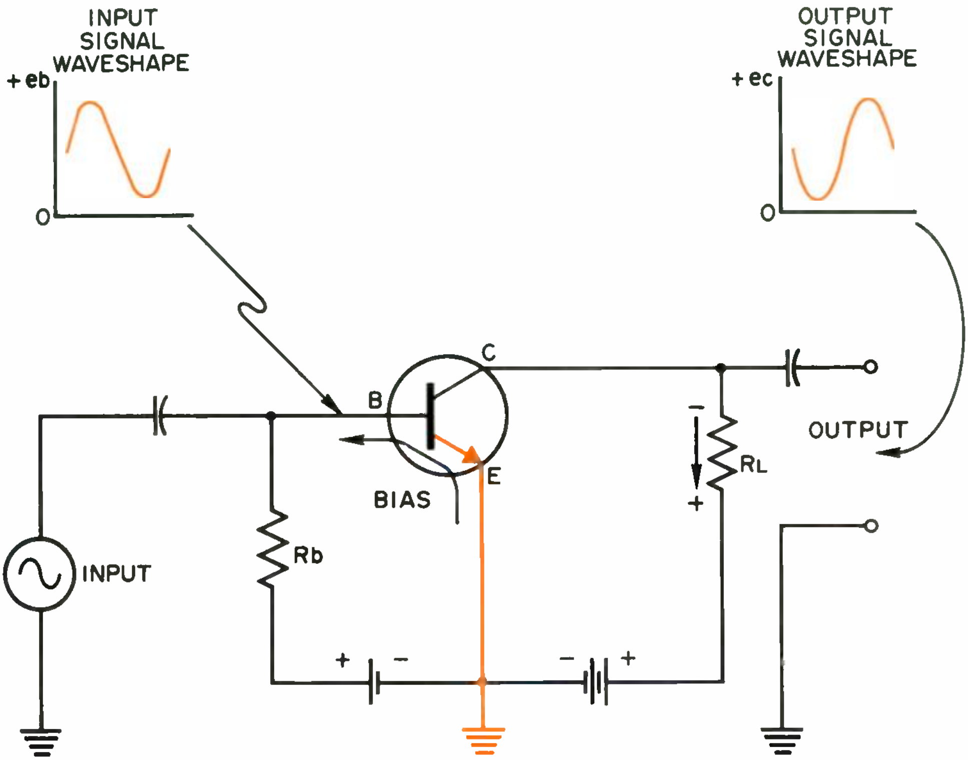


Figure 23 - A grounded emitter NPN type transistor amplifier.

current and the voltage drop across the load impedance, resulting in an increase in collector-to-ground output voltage. Because the collector is negative with respect to ground, a positive-going input signal results in a negative-going output signal.

A positive-going input signal to the NPN transistor (Fig. 23) causes an increase in base-emitter current. This develops a corresponding increase in the collector current and the voltage drop across the load impedance. Because this drop subtracts from the collector voltage, the output signal is less positive. Therefore, it is equivalent to a negative-going output signal. The latter action is similar to that occurring in the plate circuit of the triode with a positive-going signal at the grid. Remember that an increase in plate current causes an increase in voltage drop across the plate load impedance which results in a decrease in the plate-to-ground voltage. A decrease in the positive plate voltage is equivalent to a negative-going output signal. This is shown by the waveforms in Figure 3.

Transistor Input Impedance

The grounded-emitter transistor has a medium input impedance. For junction transistors, this value may be

1 K ohm. For point contact transistors, the value may be 35 K ohms.

The output load impedance of the grounded-emitter transistor may have either the same or slightly higher magnitude as the input impedance.

Figure 24 combines the three previous schematic diagrams (Figs. 21, 22, and 23) to provide a comparison of the circuits.

TRANSISTOR COUPLING METHODS

A single stage of amplification seldom provides enough undistorted gain. This necessitates the use of two or three amplifiers connected in series, with each stage amplifying the output of the preceding stage. An amplifier consisting of a number of stages is sometimes called a *cascade amplifier*.

Previous studies of vacuum tube amplifiers have shown that some type of coupling method must be used between the stages. The coupling between stages is accomplished by using resistance-capacitance networks, impedance networks, or audio transformers. The stages may be directly coupled by connecting the output element of one stage to the input element of the succeeding stage. The first circuit of these four basic amplifiers is illustrated in Figure 25.

Because all coupling networks are somewhat frequency responsive, some coupling methods afford better results than others for a particular circuit configuration. Generally, 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. Direct coupling provides the maximum economy of parts with excellent low-frequency response and DC amplification.

Resistance-Capacitance Coupling

The RC coupling (Fig. 25) utilizes two resistors and a capacitor to form an interstage coupling device. This device 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. 25) is the collector load resistor for the first stage. Capacitor C_{CC} is the DC voltage-blocking and AC signal-coupling capacitor. R_B is the input-load and DC return resistor for the base-emitter junction of the second stage.

Because the input resistance of the second stage is low (1,000 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. This attenuation is due to a large signal drop across the coupling capacitor and is achieved by using a high value of capacitance. Thus, values of 10 to 100 microfarads or more are used for low audio frequencies.

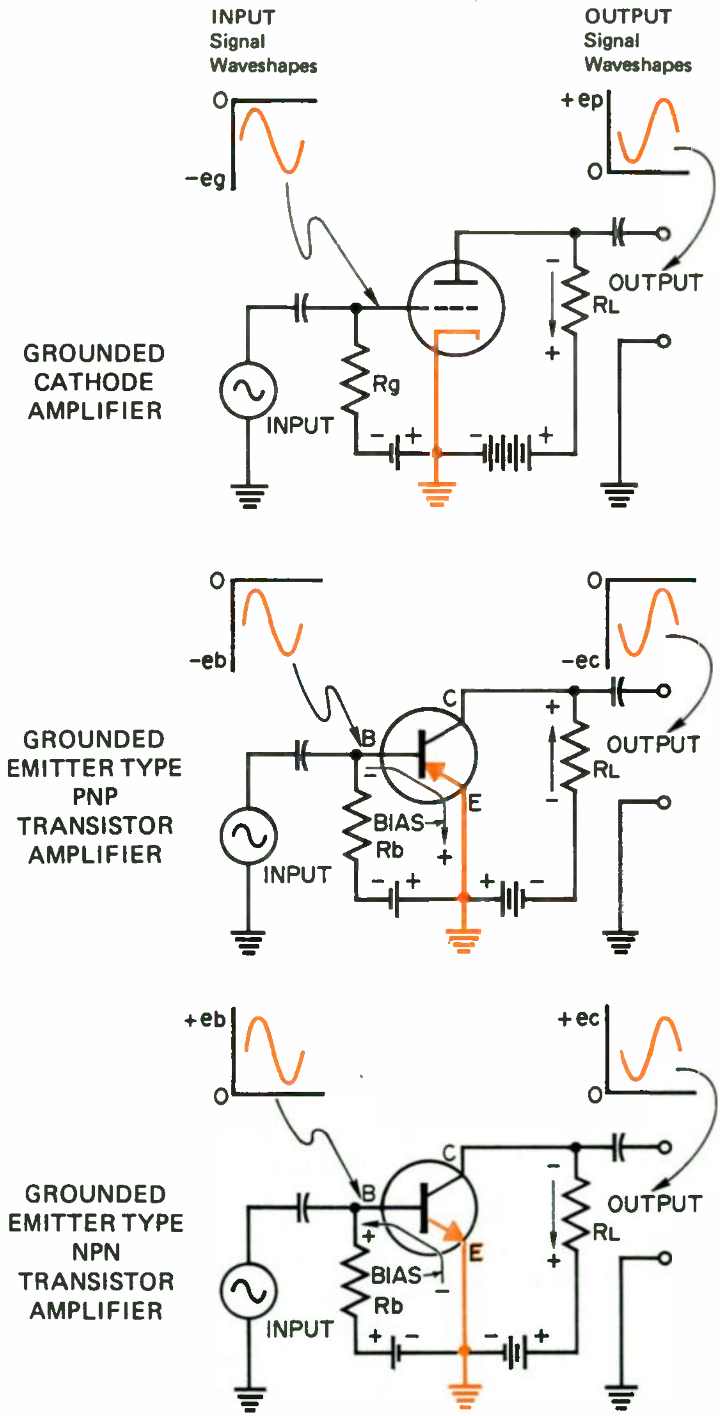
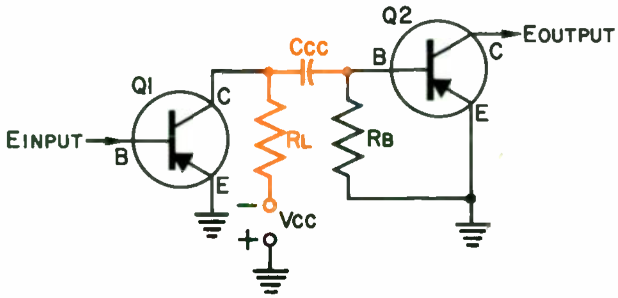


Figure 24 - A comparison of basic tube and transistor amplifiers.



RC coupling uses relatively few parts and provides good gain capabilities and a broad frequency response.

Figure 25 - Resistance-capacitance (RC) coupling.

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.

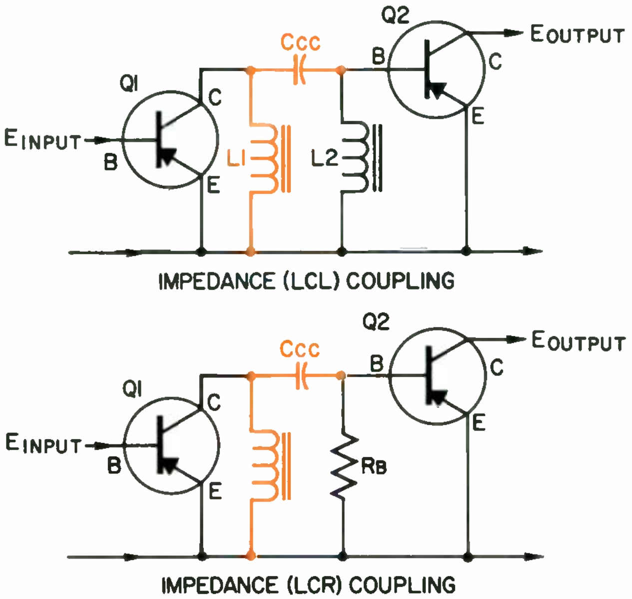
The high-frequency response normally is limited by the stray circuit capacitance plus the input and output capacitance. Hence, the transistor itself is usually the limiting factor. The low-frequency response is normally limited by the time constant of the coupling capacitor C_{CC} and the base return (input) resistance R_B. For good low-frequency response, the time constant must be long in comparison to the lowest frequency to be amplified.

Impedance Coupling

The impedance coupling network is a network in which one or both resistors of the RC network are replaced by an inductor (Fig. 26). 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 effective as that of resistance coupling, it is much better than that of transformer coupling because there is no leakage of reactance effects. The high-frequency response of the impedance coupler is limited by the collector output capacitance. The low-frequency response is limited by the shunt reactance of the inductor L1. The efficiency of the impedance coupler is approximately the same as that of the transformer-coupled circuit.

Transformer Coupling

Transformer coupling (Fig. 27) is used extensively in cascaded transistor stages and power output stages. It provides good frequency response and

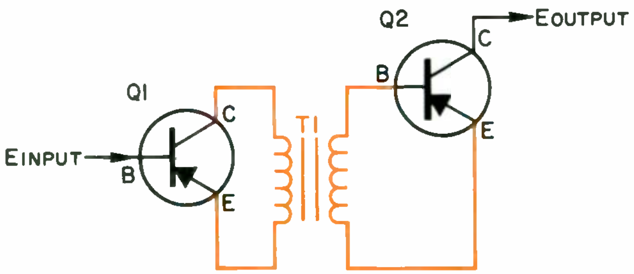


Impedance coupling can provide higher power output, but it does not have as good a frequency response as the RC amplifier.

Figure 26 - Two types of impedance coupling.

proper matching of input and output resistances with good power conversion efficiency. It is more costly 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 by the mutual inductive coupling of the primary and secondary windings. Because 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 which minimizes collector current losses and allows a lower



Transformer coupling requires more costly parts than the RC amplifier, and its frequency response is not as good as the two amplifiers in Figures 25 and 26. But it can provide excellent impedance matching.

Figure 27 - Transformer coupling.

applied collector voltage for the same gain as other coupling methods. The primary winding also presents an AC load impedance which includes the reflected input (base-emitter) impedance of the following stage. The secondary winding also completes the DC return path of the base and provides better thermal stability because of its low DC resistance. Because the transistor input and output impedance may be matched by using the proper turns ratio, maximum available gain may be obtained from this coupling method.

Like the impedance coupler, the shunt reactance of the transformer windings causes the low-frequency response to drop off. The high-frequency response is limited by the leakage reactance between the primary and secondary windings and by the effect of collector capacitance. Because of the low DC resistance in the primary winding, the power efficiency approaches the maximum amount. No excess power is dissipated.

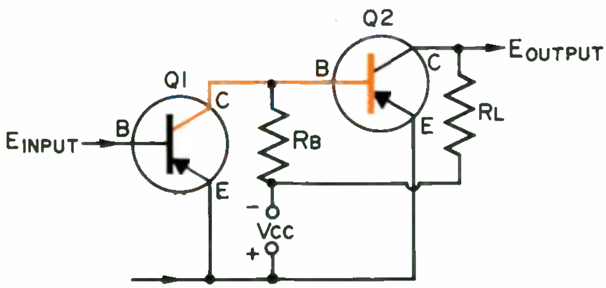
Direct Coupling

Direct coupling is used for amplification of DC and for very low frequencies. As in electron tube circuits, this method of coupling is limited to a few stages because all signals, including noise, are amplified. 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. (This will be discussed later.)

Figure 28 shows a basic direct-coupled amplifier utilizing two PNP transistors. When a signal is applied to the base of Q1, the amplified output is directly applied to the base of Q2 from the collector of Q1. The output is taken from load resistor RL of Q2.

Frequency Compensation

Like the electron-tube coupling networks, transistor coupling networks may also be compensated to



Direct coupling is used to amplify DC and very low frequencies, but its use is limited to a few stages, as it amplifies electrical noise along with the signal.

Figure 28 - Direct coupling.

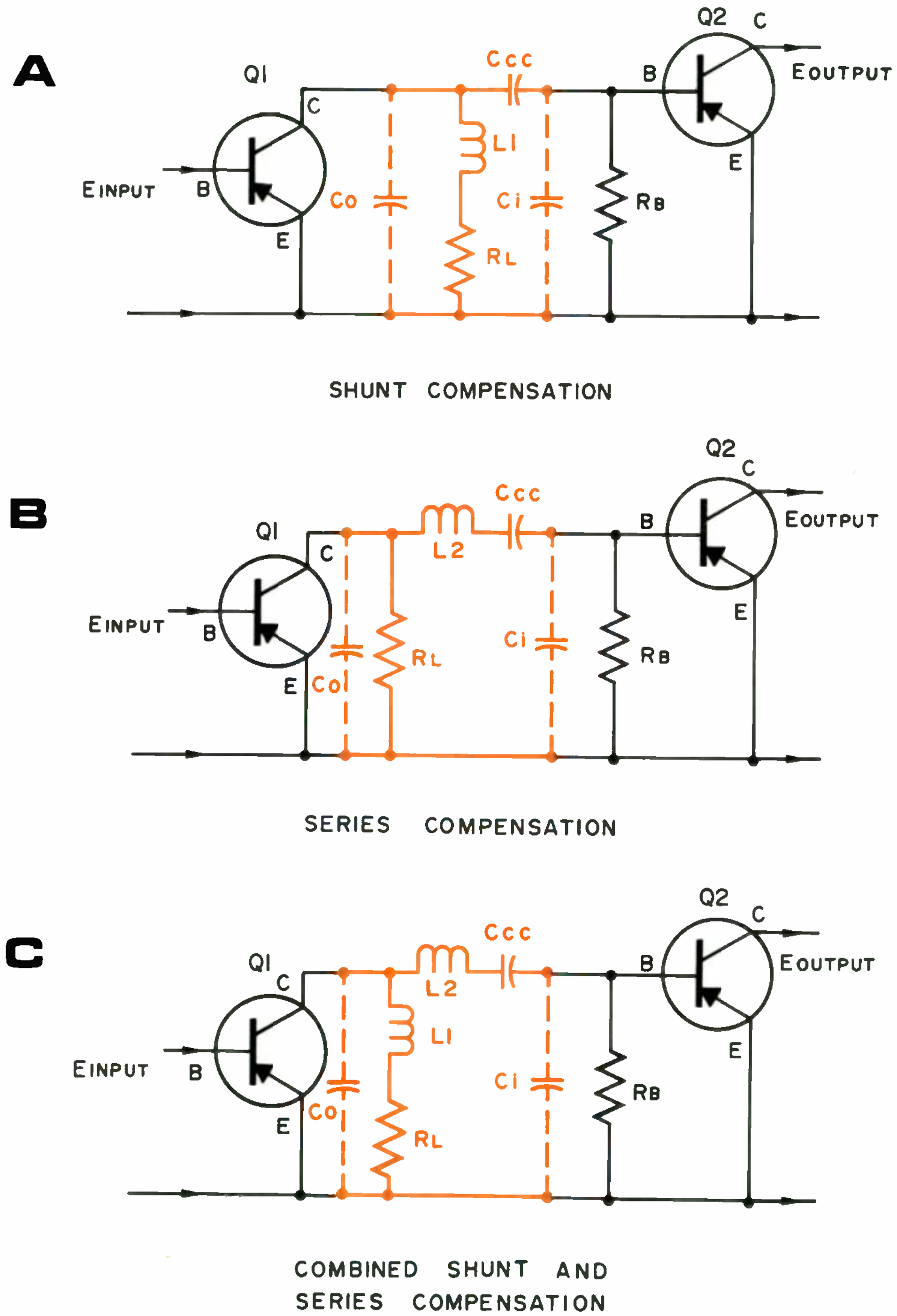


Figure 29 - Compensation circuits that improve the high frequency response characteristics of an amplifier.

increase frequency response. Figure 29 shows the basic equivalent circuits for three types of compensation. The insertion of series inductor L1 (Fig. 29A) produces a parallel resonant effect with output capacitance Co and input capacitance Ci. It improves the high-frequency response about 50 percent. A shunt circuit that produces a specific peak of frequency is sometimes called *shunt peaking.*

Note: Co refers to the output capacitance of Q1. Ci refers to the input capacitance of Q2.

Insertion of inductor L2 (Fig. 29B) in series with Ccc produces a series resonant circuit with input capacitance Ci. It further increases the high-frequency response about 50 percent over that of shunt peaking. Using the effect of both series and shunt peaking provides a gain about 80 percent greater than that of the series peaking circuit alone (Fig. 29C).

Figure 30 shows a typical low-frequency compensation circuit. With resistor R1 inserted in series with RL, the collector load is increased at those frequencies where the resistance of R1 is effective. As capacitor C1 parallels R1, the higher frequencies are bypassed around R1. However, as the capacitive reactance of C1 increases with a decrease of frequency, the lower frequencies pass through R1. Thus, the load resistance for low frequencies is increased and so is the output at these frequencies. The combination of C1 and R1 is chosen by the circuit designer to provide the desired frequency compensation. This type of compensation also corrects phase distortion which is usually more prevalent at the lower frequencies.

TRANSISTOR BIAS STABILIZATION

The designer of an audio amplifying circuit must determine an operating

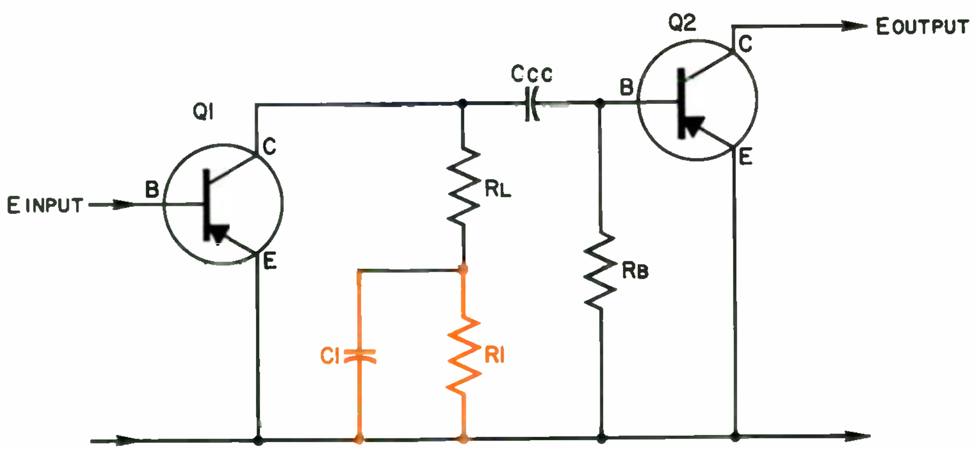


Figure 30 - A low frequency compensation circuit.

point for the transistor he has selected. This operating point is determined by the value of the chosen base bias current. In turn, this bias current establishes the values of DC current and voltage in the collector load when no AC signal is present at the input terminals.

Effect of Temperature

The temperature usually increases around an electronic chassis when it is in operation. This additional heat affects all of the components. Because transistors are more sensitive to changes in temperature than vacuum tubes, provision must be made to compensate for the effect caused by the increase in temperature. Larger sized transistors have heat sinks slipped onto their protective cases to dissipate as much heat as possible, and thus, maintain the chosen operating point.

An increase in the temperature at the base-emitter junction usually results in additional current flowing through the collector-emitter circuit. This increase in collector current increases the temperature of the transistor. If this increase is large enough, it will shift the operating point of the transistor. This shift may cause distortion in the output signal. Any method that maintains a given value of base bias or automatically shifts the bias closer to its chosen value is called *bias stabilization.*

An increase in temperature at the junction of the base and the emitter (resulting in additional current flow) is due to the negative temperature characteristic of this junction. Most devices increase their resistance as they become hotter and they are said to have a *positive temperature coefficient.* But transistors react in an opposite manner, and are said to have a *negative temperature coefficient* because their resistance decreases as they become hotter.

Swamping Resistor

Placing a large value resistor, called a *swamping resistor*, in series with the emitter (Fig. 31) is one means of reducing the effect of the negative temperature coefficient of the transistor. 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 swamps (overcomes) the junction resistance. Thus, the variation of emitter-base resistance with temperature is such a small portion of the total series resistance in the emitter circuit that it has little effect on the collector current.

Voltage Feedback

Another method of compensating for emitter-base resistance change with temperature is to reduce the forward bias of the emitter-base as the temperature increases. A reduction in the value of the forward bias voltage — with an increase in temperature — may be accomplished by using a bias stabilization arrangement.

Feedback bias stabilization circuits compensate for emitter-base resistance

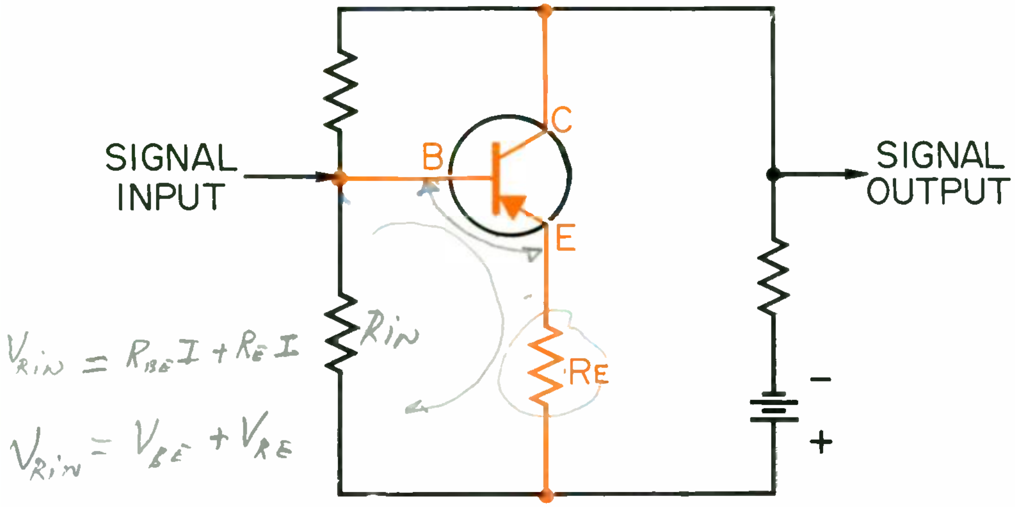


Figure 31 - The resistor RE in the emitter circuit is much larger in value than the resistance across the junction of the base and the emitter. Thus, the greater portion of a voltage change occurs across RE.

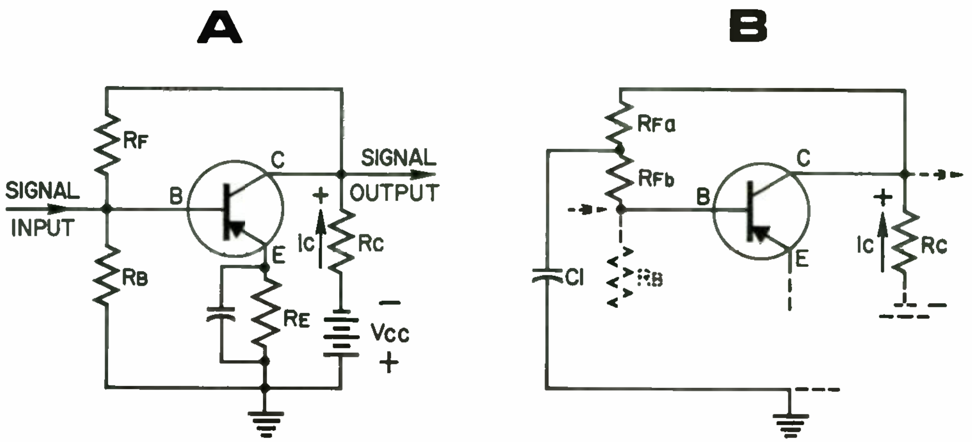
$V_{BE} = V_{Rin} - V_{RE}$

change with temperature by feeding back an opposing voltage proportionate to the temperature change.

In Figure 32A, the circuit represents both AC and DC feedback. When resistor RF is divided into two parts and bypassed by capacitor C1, as shown in Figure 32B, the feedback loop is shunted. When this happens only the DC bias variations affect operation. Compensation is achieved in the following manner. When the collector current IC increases, the collector becomes less negative because of the larger positive voltage drop across resistor RC. As the drop across RC opposes the initial bias, less forward bias is applied to the base through feedback resistor RF. 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 32, voltage-divider stabilization through RB and emitter current feedback through RE.

Additional Methods

There are additional methods that have been developed for stabilizing the operation of transistors. These other methods use diodes or thermistors in the circuit, but the end result is the same. The transistor is made to operate with the least amount of variation even though its temperature varies considerably. Circuit designers apply the method that is best suited to produce the result they want and still remain within their budget limitations and restrictions.



Both AC and DC feedback is present in this circuit.

The AC feedback is shunted to ground through C1 and only the DC change remains for control of the base bias.

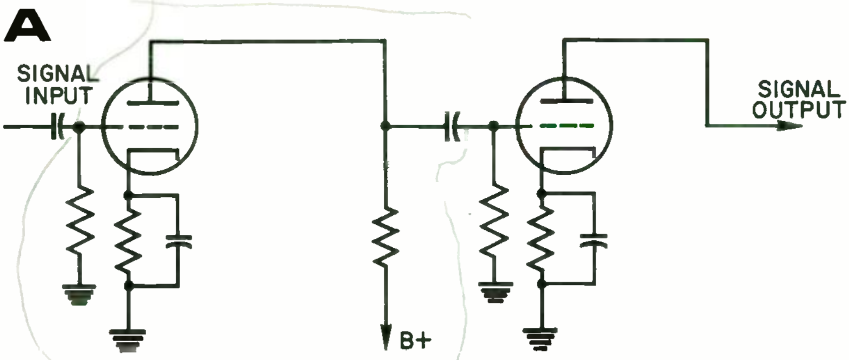
Figure 32 - Stabilization of the forward bias on the base is obtained from the feedback voltage derived from the variation in the collector circuit.

VOLUME AND TONE CONTROLS

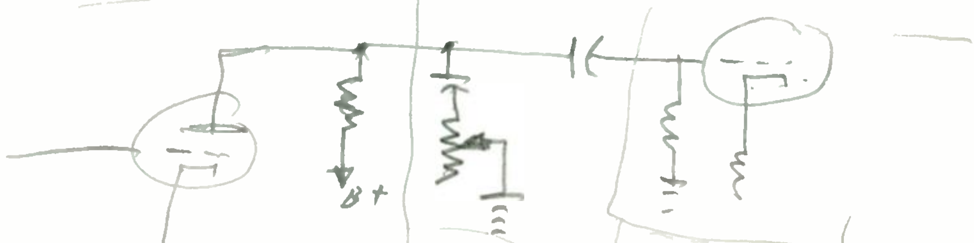
A method of controlling the volume of sound from a speaker always is included in audio amplifiers. The volume control determines the amplitude of the signal applied to the input of the first stage of a multi-stage amplifier (Fig. 33B). The volume control is the input signal applied to one end of the potentiometer. The other end of the input signal is grounded. The movable contact of the potentiometer is connected to the grid of the first tube. Any portion of the voltage developed across the pot may be selected by positioning the wiper arm of the pot.

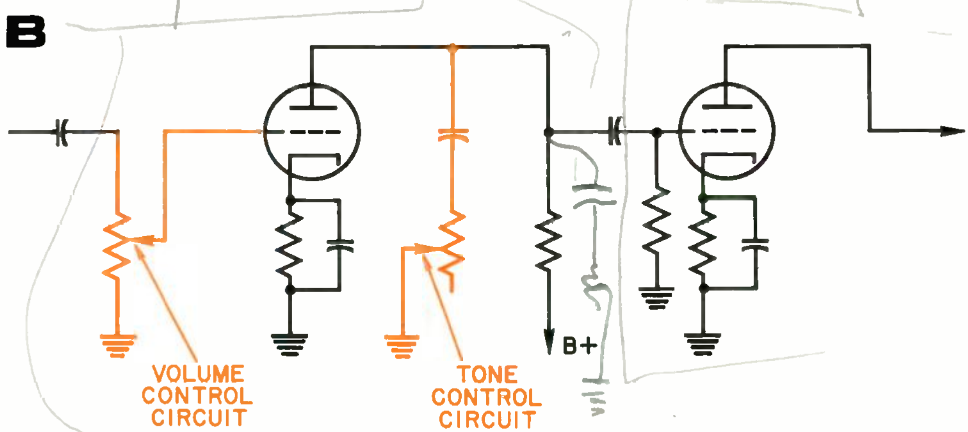
The tone control is a filter circuit that may be adjusted to vary the output frequency response of an amplifier. A high frequency tone control, known as a *treble* control, consists of a capacitor and a variable resistor in series (Fig. 33B). Because it has a minimum impedance to high frequencies, the capacitor allows the high frequencies to pass. The position of the wiper arm selects the amount of high frequency energy which is shorted to ground.

The volume and tone controls for a transistor amplifier are similar, but precautions must be taken to stabilize the bias at the input of the first transistor (Fig. 34B). If the input from the wiper arm of the pot does not have a capacitor in series with it, the bias voltage of the base-emitter circuit is changed every time the volume control is adjusted. This coupling capacitor passes the AC signal and prevents the DC bias from



A basic two stage vacuum tube amplifier

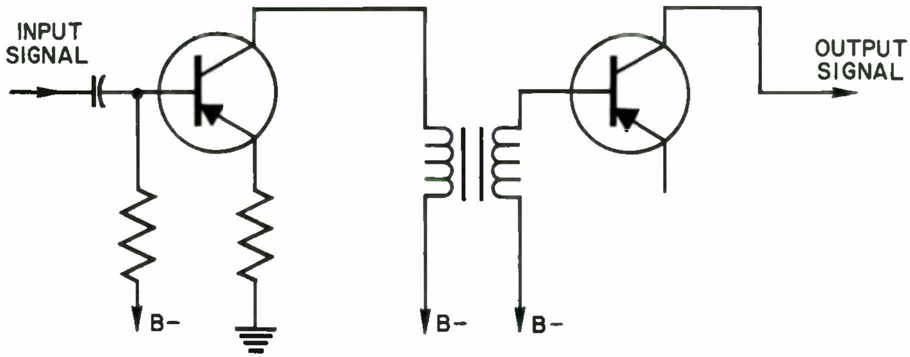




The same two stage vacuum tube amplifier with the addition of a volume control and a tone control.

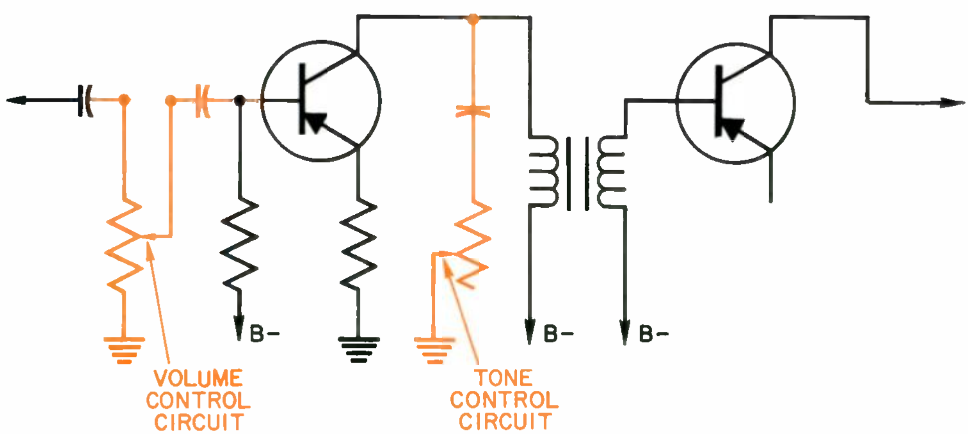
Figure 33 - Volume and tone controls allow the loudness and the frequency response in a vacuum tube circuit to be adjusted.

A



A basic two stage transistor amplifier.

B



The same two stage transistor amplifier with the addition of a volume control and a tone control.

Figure 34 - Volume and tone controls allow the loudness and the frequency response to be adjusted in a transistor circuit.

varying each time the resistance value of the pot is varied.

Tone controls have many forms. Audio amplifiers of high quality have both treble and bass controls. The basic forms of these controls are illustrated in Figure 35. The treble control acts on the high frequencies. The bass control acts on the low frequencies through the capacitor C which has a large value of reactance at low frequencies. Capacitor C has a low reactance value to the higher frequencies. Therefore, there is not much voltage appearing across it.

Because capacitor C offers a large reactance at low frequencies, the resultant high voltage may be controlled by the position of the contact arm on RB. When the wiper is at the top of its range, it effectively shorts the voltage across capacitor C. This lowers the amplitude of the bass or low frequencies.

AMPLIFIER NAMES

Amplifiers are classified by a wide variety of names. Most names serve as descriptions of the amplifier's action.

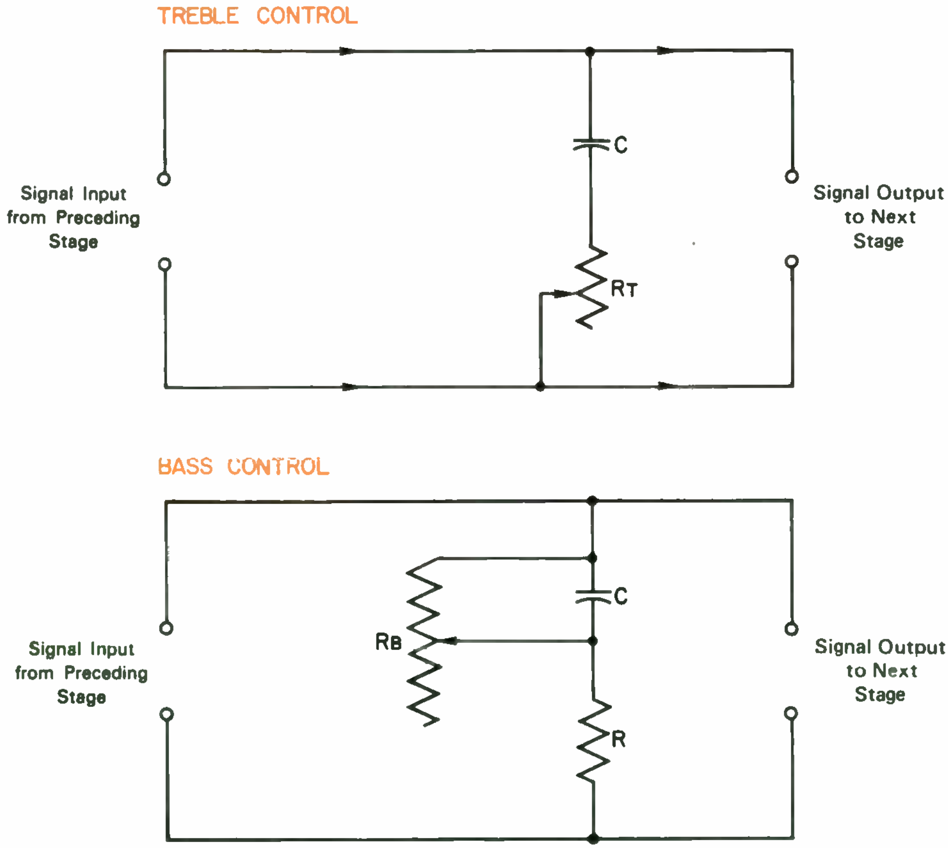


Figure 35 - Tone controls, acting as variable frequency filters, vary the impedance to high frequencies (treble) and low frequencies (bass).

For example, voltage amplifiers increase the value of the input voltage in a number of steps or stages. Thus, amplifiers used for audio work are called *sound amplifiers* or *interstage amplifiers.* Amplifiers used for weak signals (such as the signal from a microphone or the weak, but undistorted output signal from a TV tuner) are termed pre-amplifiers. Finally, the amplifying stage immediately preceding the final power amplifying stage(s) is termed the *driver stage.* The function of the driver stage is to do what it's name implies. It has sufficient voltage and current to *drive* the last, or power, stages so that they can supply adequate power to the speaker(s).

SUMMARY

Audio frequency amplifiers are used to develop sufficient power to operate speakers. The weak audio signals are strengthened in voltage amplifiers.

The vacuum tubes used in amplifiers must be operated so that they increase the voltage output without distorting the signal. Proper operating conditions for a vacuum tube must be selected. This includes selecting the proper bias, which might be either grid leak bias or cathode bias.

The voltage gain provided by a single stage is usually not sufficient, thus, it requires the cascading of additional stages in the amplifier. The coupling between stages may be provided by one of the following methods: RC, transformer, impedance, or direct coupling. Circuit design usually includes provisions for maintaining uniform frequency response, and a method of adjusting the volume and tone of the audio signal.

Feedback in amplifiers is used to maintain a given output level. This provides a measure of control over voltage and temperature changes.

....

TEST
Lesson Number 40

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 52-040-1.

1. The phase relationship between the grid input voltage signal and the plate output voltage signal in a triode amplifier is
   4 A. the same.
   B. 90 degrees out of phase.
   —C. 180 degrees out of phase.
   D. increased in value.

2. As the voltage at the plate of the amplifying tube increases, the
   A. voltage across the load increases.
   B. voltage across the load remains constant.
   —C. voltage across the load decreases.
   D. current in the plate circuit increases.

3. The voltage drop across resistor R_L in Figure 7 is obtained by
   —A. multiplying 6 ma times 30k ohms.
   B. dividing 180 by 30.
   10 C. multiplying 6 ma times 500 ohms.
   D. subtracting 117 volts from 300 volts.

4. The names of the two most common methods used to provide bias voltages for a vacuum tube are
   3 A. cathode resistor bias and plate bias.
   4 B. cathode bias and grid leak bias.
   5 —C. grid leak and plate bias.
   D. DC bias and AC bias.

Load V

plate volt.

5. The basic methods of coupling between amplifier stages are
   A. RC and impedance coupling.
   B. transformer and direct coupling.
   C. RC, transformer, and direct coupling.
   D. all of the above.

6. The voltage across a cathode resistor is kept relatively constant by
   A. a large capacitor across it.
   B. a small capacitor across it.
   C. the miller effect.
   D. varying the bias.

7. Feedback is commonly used in audio amplifiers to
   A. always feed the signal back 45° out of phase.
   B. feed the signal back to add to the input signal.
   C. increase distortion.
   D. reduce distortion.

8. Bias stabilization of a transistor may be accomplished by
   A. connecting the base to the collector.
   B. placing a swamping resistor in series with the emitter.
   C. connecting the base directly to the cathode.
   D. connecting a capacitor from the base to the ground.

9. A transistor uses a resistor between the emitter and the ground to
   A. decrease the frequency response.
   B. increase the frequency response.
   C. act as a swamping resistor.
   D. none of the above.

10. A volume control and a tone control are generally located in which parts of the audio amplifier?
   A. volume control at the input and the tone control between stages.
   B. neither control is located between stages.
   C. the treble control at the input stage and the bass control between stages.
   D. both are located in the voice coil circuit.

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TACT

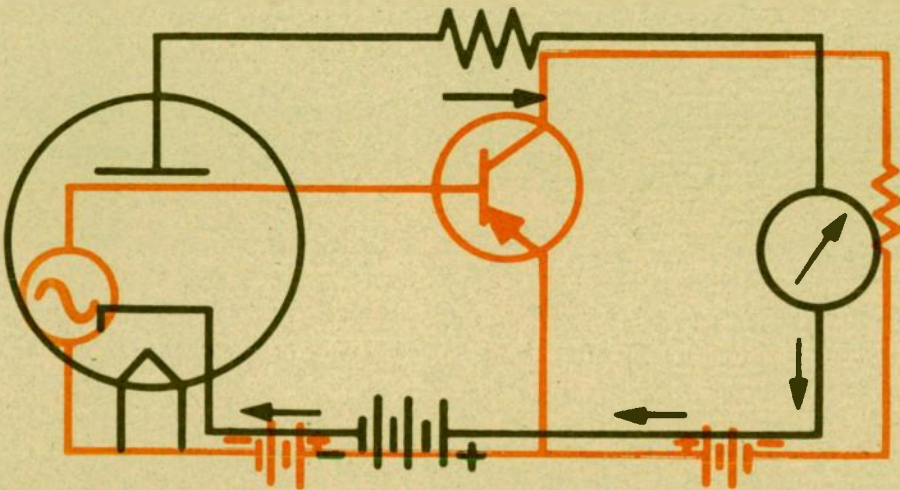
Tact is that quality in a man which enables him to adapt his words, actions and manners so as to be agreeable to others. It implies patience, gracious acceptance of an inevitable situation, cheerfulness, the ability to understand others and to be broadminded and generous in considering them and their faults, and the power of quick decision as to the best thing to do or say.

Your ability to apply and use tact can be an important talent in your career as an Electronic Service Technician. Study every article and book you can find about tact (there are many in your local public libraries). Apply these principles to your everyday life and your entire future can change for the better.

S. T. Christensen

LESSON NO. 41

RADIO FREQUENCY AMPLIFIERS



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
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CONTENTS

RADIO FREQUENCY AMPLIFIERS

INTRODUCTION

The signal that arrives at a receiver's antenna contains only a minute fraction of its original broadcast power. The power at the receiver's antenna may be in the order of a few hundred microwatts. Remember! One watt equals one million microwatts, or:

$$1 \text{ microwatt} = \frac{1}{1{,}000{,}000} \text{ watts}$$

The input signal must be amplified many times before sufficient power is developed to drive a speaker or produce a TV picture.

TRF RECEIVER

In early radios a series of tuned radio frequency stages provided signal amplification. These radios, called TRF receivers, had several detracting features. First, they barely provided adequate signal gain. Second, they did not provide uniform gain at all frequencies. Third, when a large number of stages were *cascaded* (one following another), they were subject to oscillation. These oscillations produced the chirps and squeals that were present until the signal was properly tuned in.

In order to prevent oscillation, either the overall amplification was limited or some form of degenerative feedback was used. Degenerative (negative) feedback reduced the possibility of oscillation, but it also reduced the signal gain of the receiver.

A block diagram of a TRF radio is shown in Figure 1. It incorporates three stages of tuned RF to provide amplification, a detector, and an audio amplifier (AF) section.

TRIODE RF STAGE

In Figure 2, the schematic diagram represents a tuned radio frequency amplifier stage. Transformer T1 is the antenna transformer. The primary of T1 couples signal currents from the antenna into the secondary. A section of the tuning capacitor C_{1A} resonates the secondary of T1 to the desired station frequency. The trimmer capacitor C_{1B} is added to compensate for small variations in component values.

A triode vacuum tube is used as the amplifying element and a tuned RF signal is applied to its grid. An

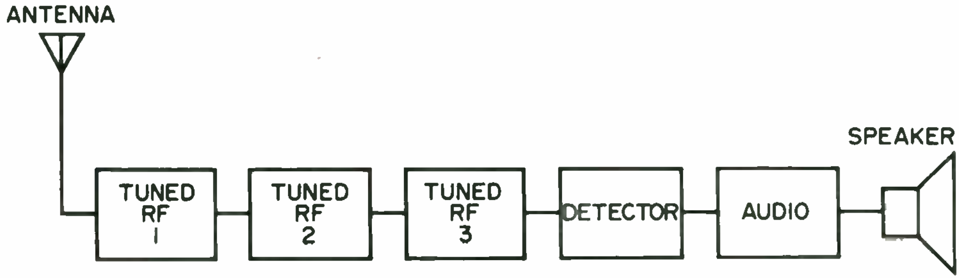

Figure 1 - Block of TRF receiver.

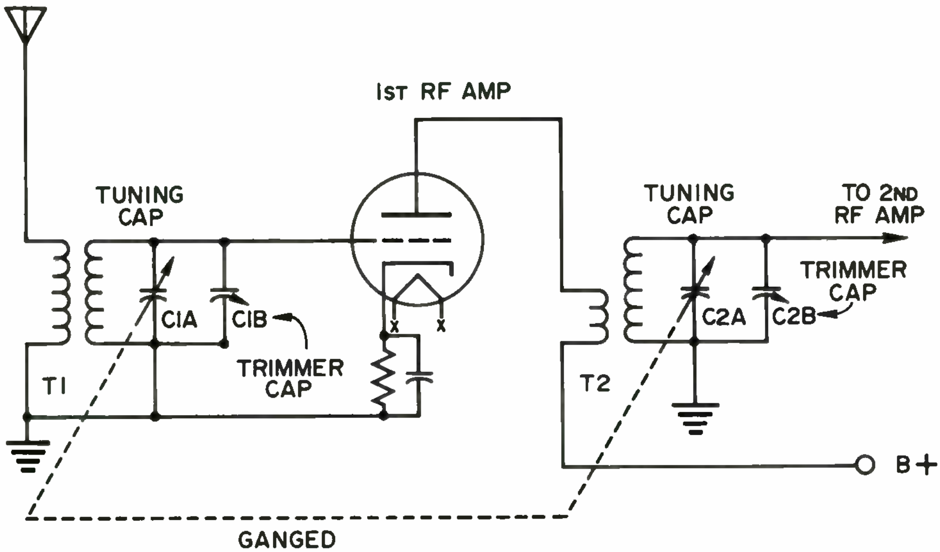

Figure 2 - Triode RF amplifier.

amplified signal voltage is developed across the primary of T2. Due to the primary reactance of T2 to fluctuations in plate current, signal current is developed in the secondary of T2. Tuning capacitor C2A is ganged with C1A by a common shaft. Rotating the shaft causes the secondaries of both T1 and T2 to resonate to the same frequency. T2 is the RF interstage transformer; it couples signals from the output of the first RF amplifier into the second.

Triode amplifiers have one characteristic that limits their use as RF amplifiers . . . that is, their large value of plate-to-grid capacitance. This capacitance can cause the tube circuit to oscillate at some unwanted frequency. Severe oscillation causes distortion, chirps, or squeals in the output of the receiver.

DEGENERATIVE FEEDBACK (NEUTRALIZATION)

Several innovations have been used to prevent oscillation in triode stages. Most of these involve the use of degenerative feedback. Degenerative feedback is negative in the sense that it opposes the signal at the grid by 180°. Thus, if the output signal is coupled back into the grid circuit in a positive direction by distributed capacitance, degenerative feedback can be applied to oppose the change and prevent unwanted oscillation.

Several methods of degenerative feedback have been used. The two most common forms employ feedback through either a capacitor or an inductor. We will illustrate both methods in the following paragraph.

Figure 3 is the schematic diagram of a triode amplifier with the plate and grid windings shown. Note that an additional winding is included in the plate circuit. It is inductively coupled to T1 and feeds an out-of-phase signal into the grid circuit. Incidentally, the direction of the current flow through the feedback winding of a degenerative circuit is opposite to the current flow when the circuit is designed as a regenerative one, such as is used in an oscillator.

Figure 4 shows the use of a capacitor (Cn) to prevent oscillation. The voltage between point A and ground is 180° out of phase with the voltage from point B to ground. The neutralizing capacitor, Cn, couples a portion of the voltage between point B and ground to the grid input circuit. This action is degenerative and tends to block oscillations. This type of feedback is frequently called capacitive neutralization.

Neutralization through degeneration effectively prevents oscillation but it also opposes or neutralizes some of the desired signal. This causes a considerable reduction in stage gain.

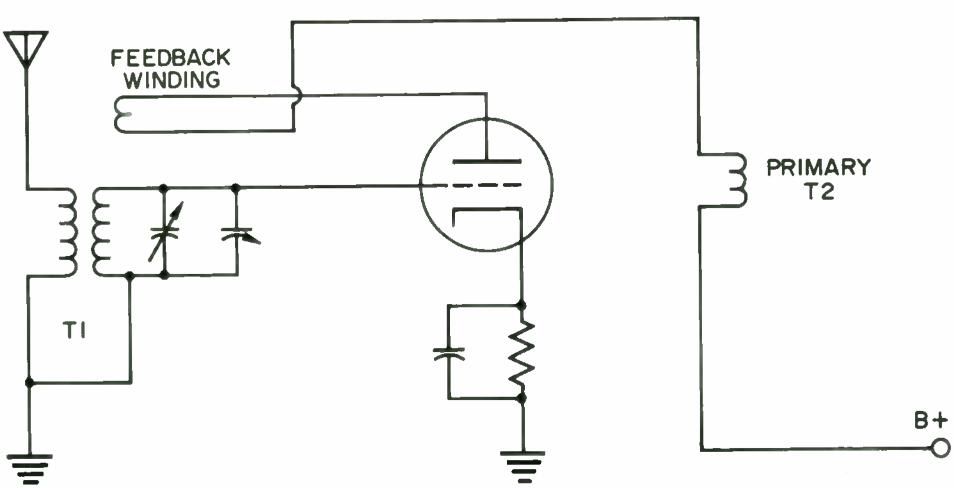

Figure 3 - Triode RF amplifier with inductive degeneration.

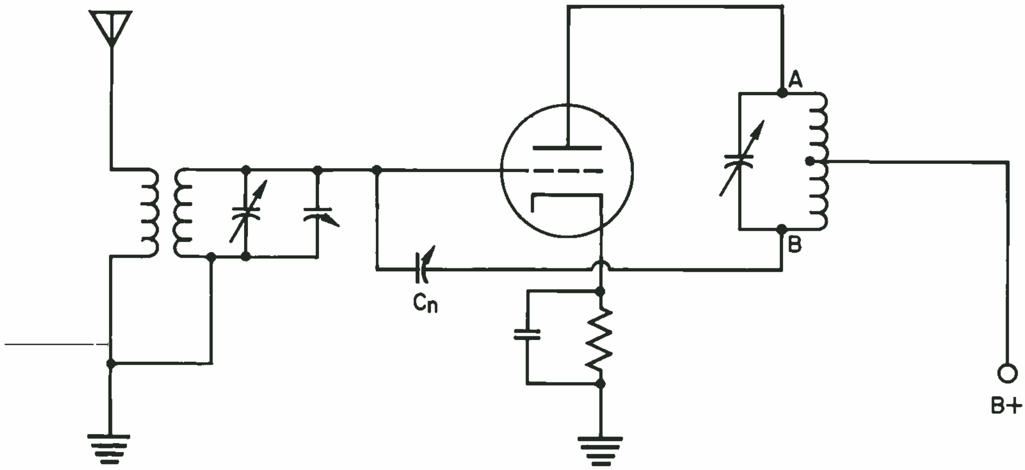

Figure 4 - Triode RF amplifier with capacitive neutralization.

TETRODE STAGE

Tetrodes and pentodes were developed to overcome neutralization problems encountered with triodes. To do so, both tube types incorporate a screen grid. Their screen grids isolate the control grid from the plate and reduce the effects of plate-to-grid capacitance. As a result, screen grid tubes seldom require neutralization.

Figure 5A shows a tetrode RF tube with its associated components. Resistor R1 is included to provide bias voltage. Bias voltage establishes the operating point for the tube and prevents it from drawing maximum plate current. Capacitor C3 bypasses unwanted AC variations that appear at the cathode. If these were allowed to exist they would act as negative feedback and reduce the stage's gain.

The screen grid is frequently, though not always, operated at a reduced voltage from that of the plate voltage. Early battery powered radios usually received their screen voltage from a voltage tap on the battery pack. In early AC powered sets, the screen voltage was supplied from a tap on the bleeder resistor across the power supply. In later vacuum tube radios, resistors were included in series with each screen grid. For example, R2 in Figure 5A is included to reduce the B+ potential to a correct voltage for the screen.

Eventually, tubes were developed that were operated with a hundred volts or more on both the plate and screen. A reduction of the screen voltage was no longer necessary.

Capacitor C4 in Figure 5A is vital to the operation of the circuit. This capacitor bypasses the screen grid and removes AC fluctuations. If these AC fluctuations are not removed they will periodically block the plate current in a low frequency oscillatory fashion. The sound heard in the speaker when this condition occurs resembles that of an idling boat engine and is called

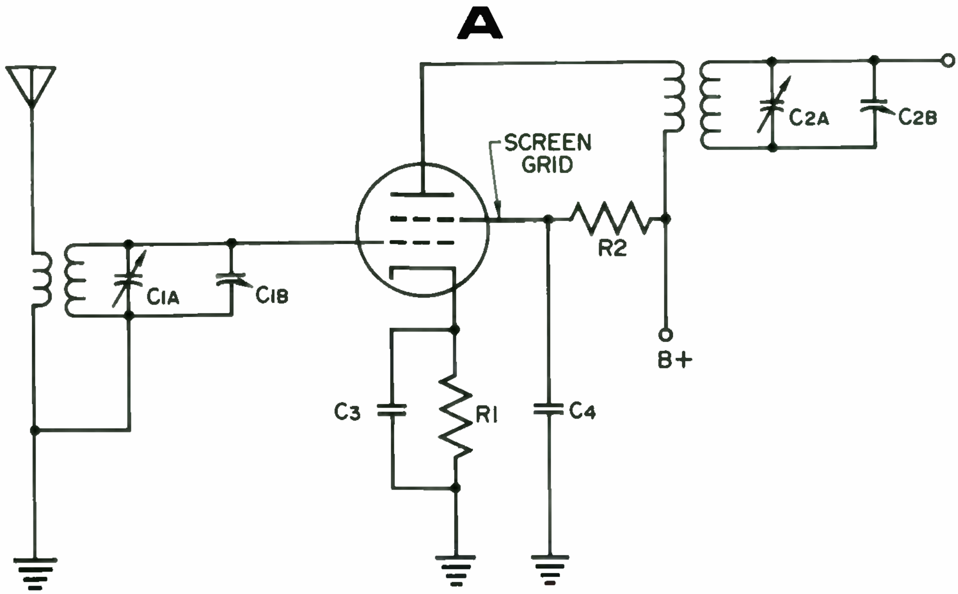

Figure 5A - Tetrode RF stage.

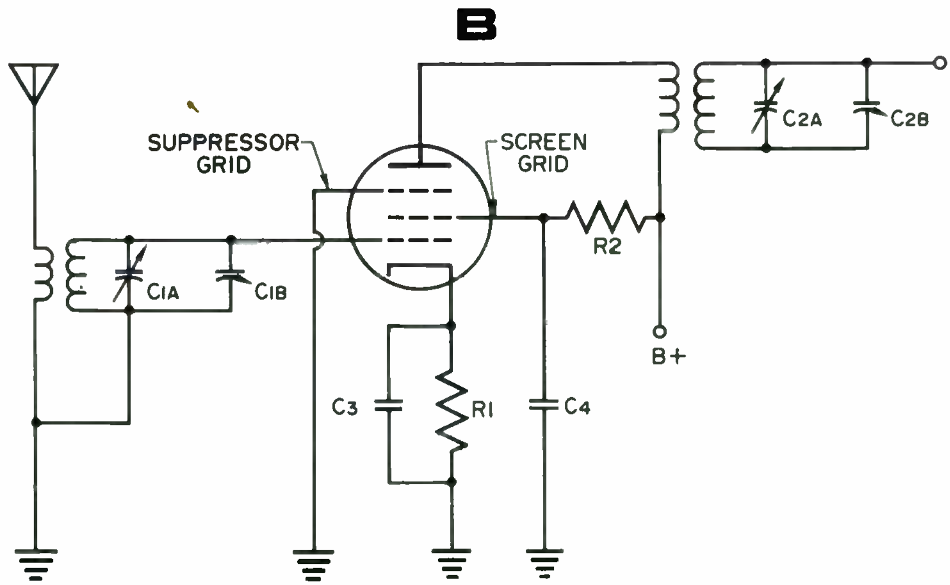

Figure 5B - Pentode RF stage

motorboating. If you encounter this condition check both the screen bypass capacitors and the filter capacitors in the power supply as they may be open.

PENTODE RF STAGE

The pentode RF stage of Figure 5B is similar to the tetrode RF stage of Figure 5A. However, the pentode has an additional element, a suppressor grid. The suppressor grid of the pentode is returned to the *supply negative* or ground. Due to its negative potential this grid reduces secondary emission from the plate; that is, electrons which strike the plate and attempt to bounce back toward the screen are forced to return to the plate due to the negative potential on the suppressor grid. These secondary electrons, if not controlled, reduce the gain of the stage by interfering with electrons arriving from the cathode. Pentodes produce greater amplification than tetrodes because of the higher operating potentials. These greater potentials are permissible in pentodes because of the low secondary emission.

MANUAL RF GAIN CONTROL

In early radios some means of manually controlling the RF gain was employed. This control was necessary to prevent strong signals from overdriving some of the RF stages. This provision is still incorporated into high quality communication sets. These potentiometers (pots) are generally used to provide manual control over the RF gain.

Gain pots may be inserted into RF circuits in a number of different ways. In an early arrangement a pot was placed in series with the filaments of all or some of the RF tubes (Fig. 6). In this application the resistance of the pots could be varied by rotating the shaft which results in control over

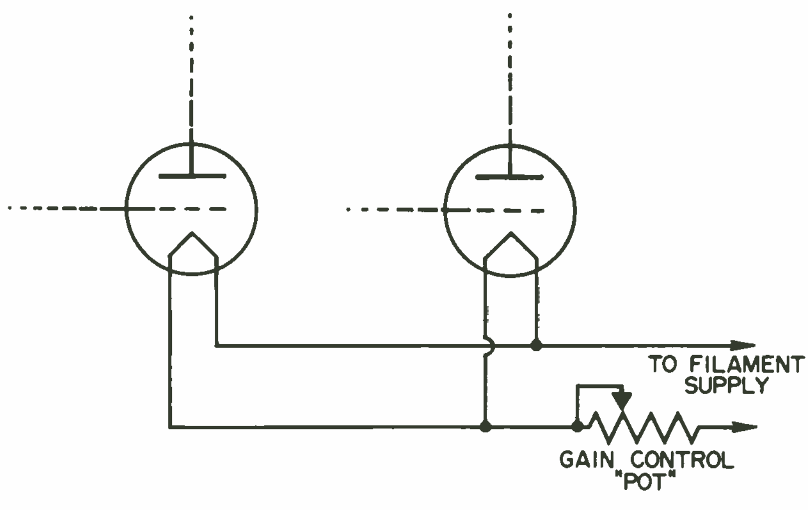

Figure 6 - RF gain control in series with tube heaters.

the current through the tube's filaments. A reduction in filament current reduced electron emission of the cathodes and thereby reduced the overall gain.

Another method to manually control the RF gain was to connect a pot across a bias source (Fig. 7A). The arm of the pot supplied a variable voltage to the grids of all controlled tubes. This was a very effective means of providing variable gain control and is still quite popular.

A variation of the controlled bias method is to place a pot in series with a tube's cathode (Fig. 7B). Generally it is placed in the cathode circuit of the first RF stage. The cathode voltage can be raised or lowered with respect to the grid potential and results in control over gain of the tube.

The screen voltage can be varied to control RF gain, but this method is seldom used. Other methods employed the use of a pot in series with a winding of the antenna transformer. This provides control over the amount of signal current through the winding. Many other systems have been used in the past, including a coil whose position could be varied in relation to another coil (to which it was inductively coupled).

The development of remote cutoff pentodes and automatic volume (gain) control virtually eliminated the need for manual controls. Manual RF gain control now appears only in communications gear and some multiband short wave sets.

REMOTE CUT OFF TUBES

Remote cutoff tubes use a special grid structure that does not allow strong signals to cause either plate current saturation or plate current cut off. They permit the use of large control voltages which are derived automatically from the detected signal. These automatic volume control voltages are directly proportional to the strength of the received signal. They automatically control the gain of RF stages to reduce the effects of signal variations on output volume.

RF STAGE TUNING

As previously stated, early radios were of the TRF type with many stages of RF gain. It was necessary for all these stages to resonate to the same frequency. Station selection was accomplished by rotating the shaft of a multisection variable capacitor. Several tuning sections were rotated by this common shaft and several RF stages were thereby resonated to the station's frequency.

The development of the *superheterodyne* type radio eliminated the necessity for numerous variable tuned RF stages. In the superheterodyne receiver, the incoming signal is beat against an oscillator signal to produce a *heterodyne* frequency. This heterodyne frequency is constant and can be amplified by one or two fixed tuned stages called intermediate frequency (IF) amplifiers.

The IF amplifiers are superior to the RF amplifiers in several ways. They are designed to amplify a

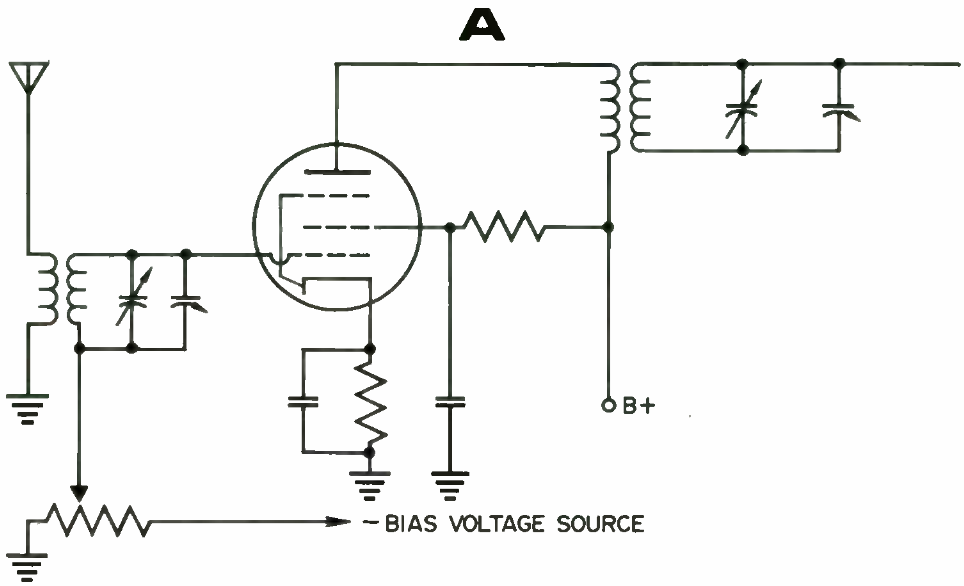

Figure 7A - Variable bias RF gain control.

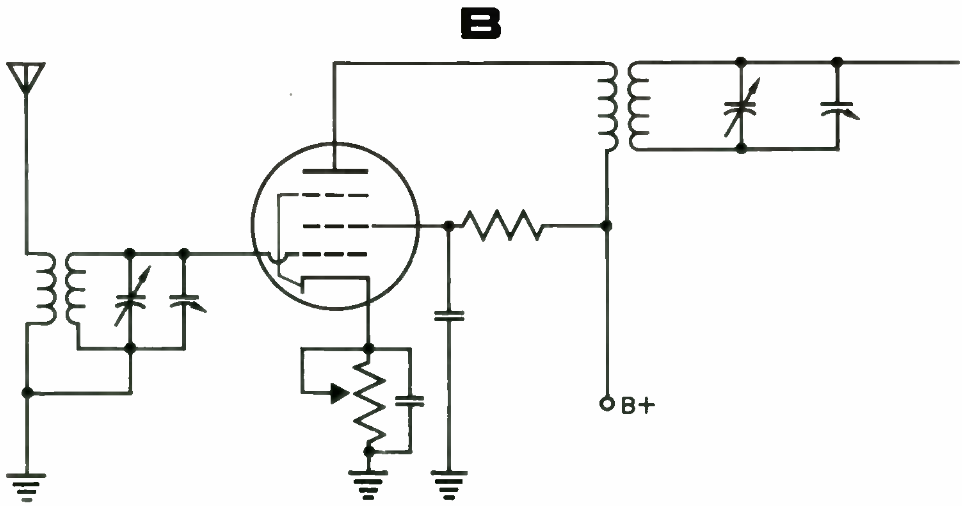

Figure 7B - Variable cathode bias used for RF gain control.

constant frequency and can be made to provide constant gain regardless of the frequency of the incoming signal. They can be designed to provide much greater amplification, because they amplify a signal that is constant in frequency. In addition, since only a single frequency is amplified, their passband can be rigidly controlled to include only the required signal and its sidebands.

Millions of superheterodyne receivers have been manufactured and sold without incorporating an RF amplifier stage. These sets perform satisfactorily for most uses, but they do lack selectivity and sensitivity as required by serious hi-fi listeners, amateur operators, and others who desire superior performance. For those who need or want superior performance, high quality AM, FM, or multiband radios are available with one or more stages of RF amplification prior to the frequency converter. These stages may be either untuned, broadly tuned, or sharply tuned circuits.

SHARP TUNED RF STAGE

In sharply tuned systems, sections of the variable tuning capacitor resonate the RF to the station signal. Figure 8 illustrates a commonly used, tuned RF stage. It includes both a tuned antenna transformer and a tuned RF interstage transformer to improve station sensitivity and selectivity.

Untuned RF Stage

The untuned RF amplifier does not improve selectivity. It does, however, improve the sensitivity of a radio and allow it to receive weaker signals. Examples of untuned RF stages are shown in Figures 9A and 9B. In both cases, signal currents appearing in the

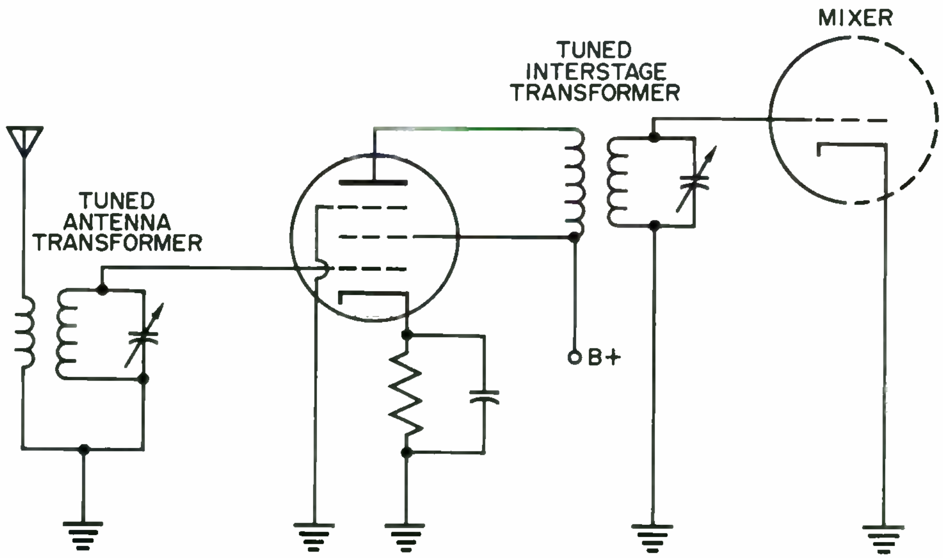

Figure 8 - Tuned RF amplifier.

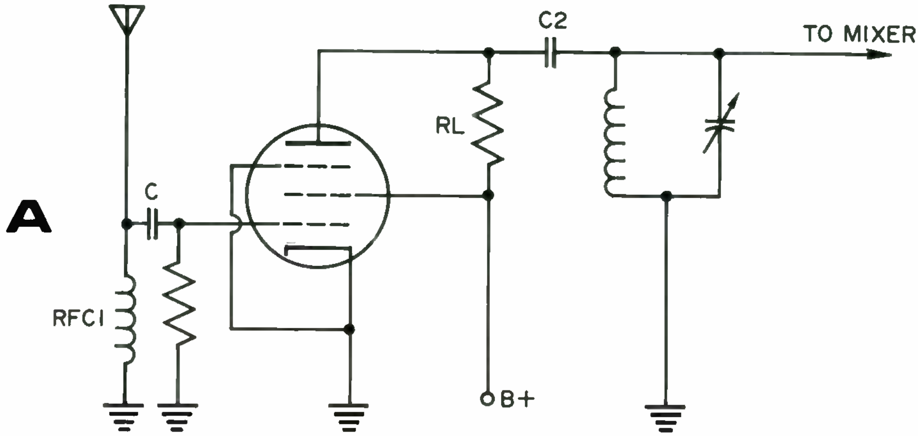

Figure 9A - Untuned RF amplifier with a resistive load.

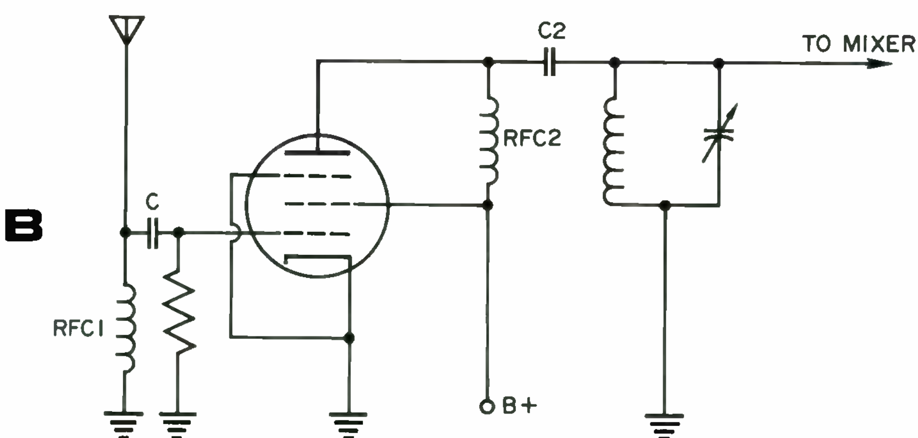

Figure 9B - Untuned RF amplifier with an inductive load.

antenna develop signal voltages across an RF choke (RFC1). These signals are then coupled to the grid of the RF amplifier through the capacitor (C).

In Figure 9A, amplified signal voltage appears across RL and is applied to the tuned RF coil at the input of the mixer, through C2. The circuit in Figure 9B is similar in operation but it uses a second RF choke (RFC2) as a plate load. RFC2 has much less DC resistance than RL (Fig. 9A) and therefore drops less of the DC voltage applied to the plate. The plate of the tube operates at a greater potential and it can provide more gain. The circuit of Figure 9A is a resistance-capacitance (RC) coupled circuit. Figure 9B illustrates an inductance-capacitance (LC) coupled circuit.

As shown in Figure 10, when an untuned RF amplifier is used, the resonant RF circuit appears at the input to the RF stage.

Broad Band Tuning

Broad tuned RF stages use a broad band filter with a high and low cutoff frequency. These cutoff frequencies fall inside the band of frequencies being received. Broad band stages do not have the sharp tuning characteristics of variable tuning, but do provide gain and some selectivity.

An example of broad tuned RF selection is shown in Figure 11. This tuning is also called band pass tuning. Networks L1/C1 and L2/C2 are series and parallel resonant circuits respectively. Series tuned circuit L1/C1 acts as a low impedence to its resonant frequency. It is usually broadly tuned to the center frequency of the band of frequencies being received.

Parallel resonant circuit L2/C2 presents a high impedance to frequencies to which it resonates. It is broadly resonated to a frequency within the

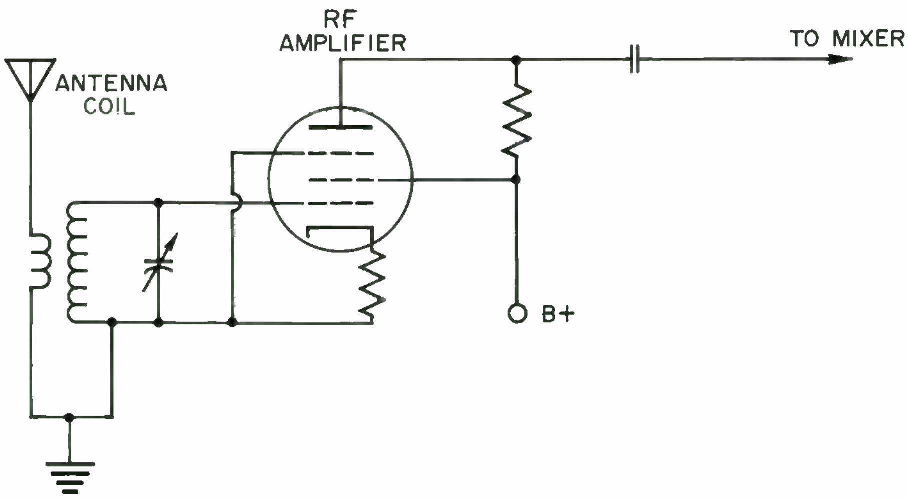

Figure 10 - RF amplifier with tuning in the input.

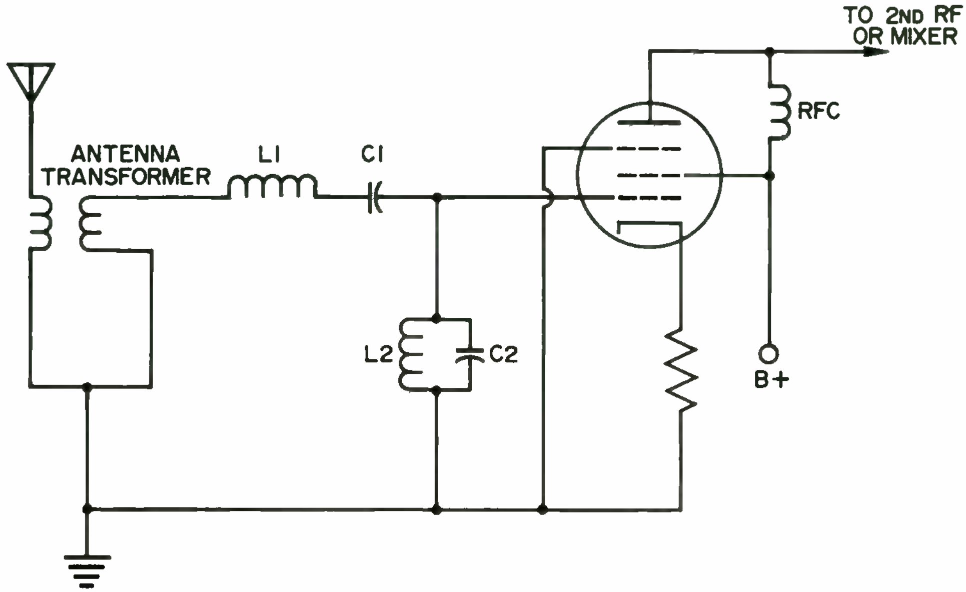

Figure 11 - Bandpass RF amplifier.

band selected. Both circuits attenuate signal frequencies beyond the desired band pass. The series resonant circuit rejects unwanted frequencies outside the band, while the parallel resonant circuit passes them to ground.

Traps

Traps are added to an RF circuit to suppress or bypass certain unwanted frequencies. Figure 12 shows a parallel resonant trap inserted in series with
8 the primary of an antenna coil. It is resonated to an unwanted frequency and offers a high impedance to that frequency.

A series resonant trap is sometimes used to shunt unwanted frequencies around the primary of the antenna coil (Fig. 13). This series resonant circuit offers a low impedance path to ground for the unwanted signal.

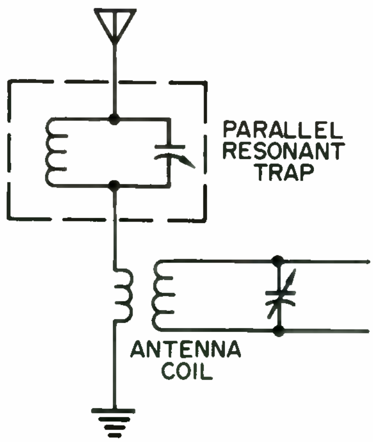

Figure 12 - Series trap.

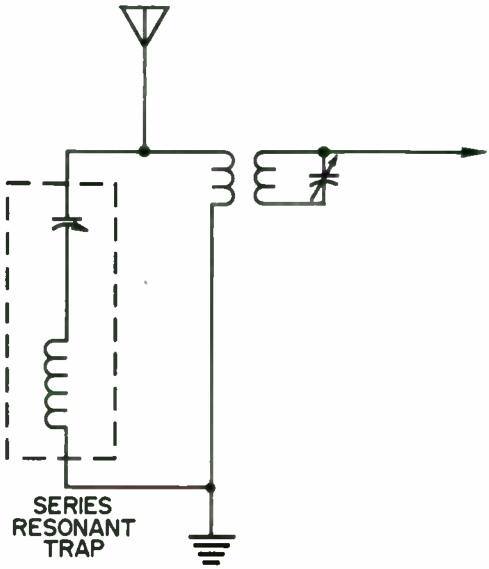

Figure 13 - Parallel trap.

A combination of series and parallel resonant traps are occasionally used to prevent interference from unwanted signals. When used together, they act as a band rejection filter which can be effectively used to suppress a series or band of frequencies (Fig. 14).

GROUNDED-GRID RF AMPLIFIER

The grounded-grid triode amplifier (Fig. 15) is very effective for very high frequencies. It removes the feedback coupling between grid and plate which could cause oscillation. Grounded-grid amplifiers are used as RF amplifiers at lower radar frequencies and in UHF-VHF television sets.

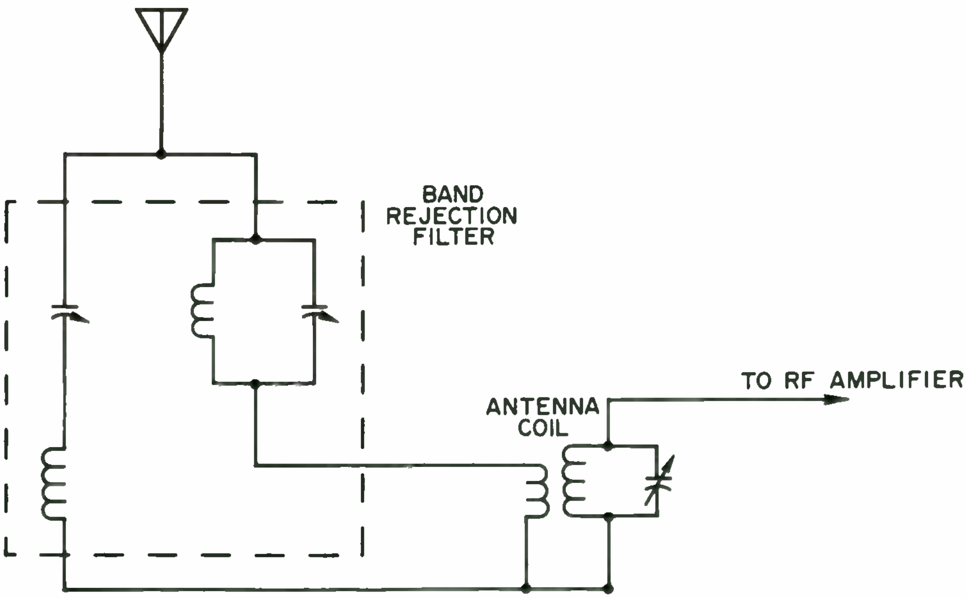

Figure 14 - Series-parallel band rejection filter.

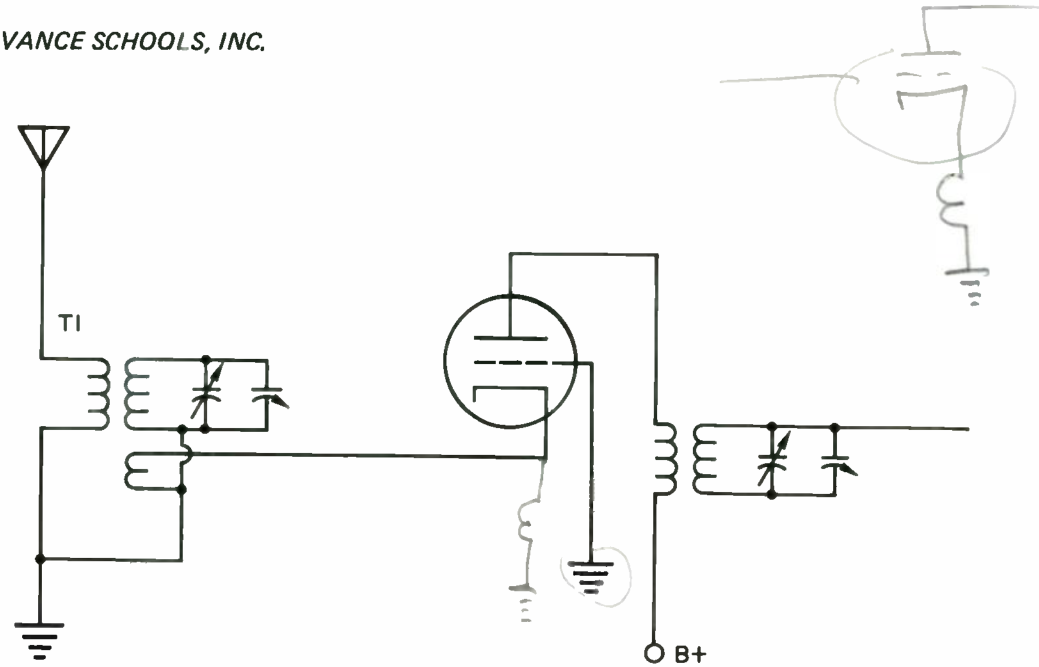

Figure 15 - Grounded grid RF amplifier.

The input signal to a grounded-grid amplifier is introduced into the cathode in series with the grid bias and varies the grid-to-cathode voltage. The output signal is taken from the plate. Plate current (including the AC component) flows through the signal source in series with the cathode circuit. The source has appreciable impedance and the signal voltage drop across it acts as degeneration. This lowers the stage's gain considerably compared to a grounded cathode amplifier.

CASCODE RF AMPLIFIER

The cascode RF amplifier combines the good features of both the pentode and the triode. A simplified circuit of a cascode amplifier is shown in Figure 16. The plate voltage of V1 is held at a fixed value while its plate current is allowed to vary. This action is like a pentode except that no screen current is required and the noise signal generated by the screen is absent.

The signal is fed into the grid of V1 and causes its plate current to vary. This, in turn, causes a varying voltage to appear at the cathode of V2. Since the grid of V2 is grounded for AC signals through capacitor C3, the signal at the cathode appears between the grid and cathode. This causes the plate current of V2 to vary and develop signal voltage across L4. From the plate end of L4 amplified signal voltage is fed to the mixer. Cascode amplifiers are superior to other types of amplifiers at high frequencies, because they add much less noise to the amplified signal.

IF AMPLIFIER

The IF amplifier used in a superheterodyne receiver is a high-gain circuit commonly using pentode tubes. The transformer windings in these amplifier sections are permanently tuned to the frequency difference between the local oscillator and the incoming RF signal. One, two, or

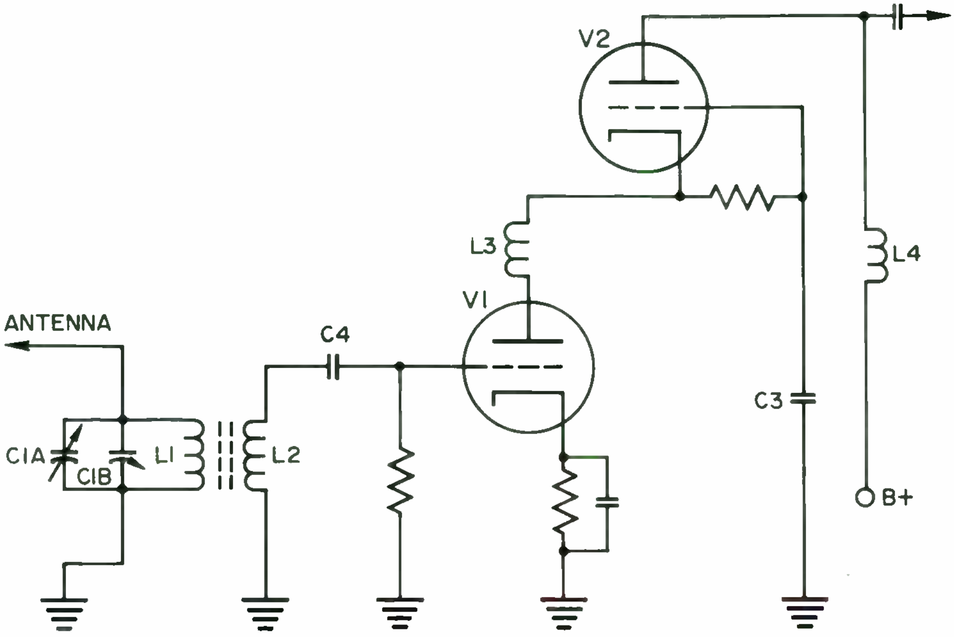

Figure 16 - Cascode RF amplifier.

three IF stages may be used depending upon the gain required.

As previously stated all incoming signals are converted to the same frequency by the frequency converter in a superheterodyne receiver. The IF amplifier, therefore, can be fixed-tuned to this frequency and permanently adjusted for maximum gain at the required pass band. Practically all of the selectivity of a superheterodyne receiver is developed by the IF stages.

Figure 17 shows the first IF amplifier stage immediately after the converter. Bias is established by means of R1/C1 and automatic volume control voltage is applied to the grid through the secondary of the first IF transformer.

Both IF transformers are tuned to resonance by means of moveable, powdered iron cores. This method is called *permeability tuning.* The capacitive component is a fixed capacitor across each winding. In another frequently used system, trimmer capacitors are used to adjust the windings to the IF frequency.

IF amplifiers must perform two important functions. They must provide sufficient signal amplification and they must pass the required side bands associated with the carrier. In AM broadcast receivers the passband required is only ± 5 k hertz for a total of 10 k hertz. Better quality receivers pass frequencies of ± 7.5 k hertz from the carrier.

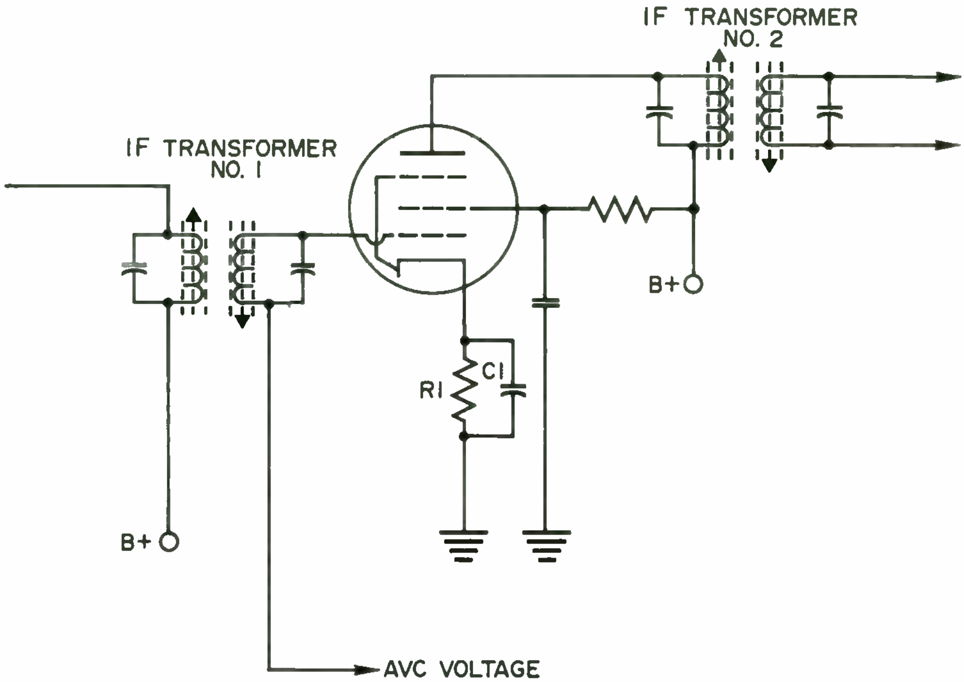

Figure 17 - A common IF amplifier stage.

FM broadcast receivers have a much broader bandpass than the AM. This is because FM signals have considerable deviation from the center frequency. In order to amplify all these frequencies the passband must be in the order of ± 100 k hertz.

A TV IF section is designed to be extremely broad, relative to other receiver IF sections. Televised information is spread through a band of frequencies 4.5 MHz wide. These frequencies must be amplified and passed to the video detector if all the information is to be present to reproduce pictures and sound.

Q Factor

The bandpass of an IF section is dependent upon a number of factors. Sharpness of resonance is determined by the "Q" of the resonating circuit. The Q factor is a ratio of circuit reactance to circuit resistance:

$$Q = \frac{X}{R}$$

Since nearly all of the resistance in an LC circuit appears in the windings of the coil or transformer, we can generally ignore the small amount appearing in the capacitor. Thus, if the winding in Figure 18A has a reactance of 10,000 ohms and DC resistance totalling 33-1/3 ohms, its Q factor will be:

$$Q = \frac{X}{R} = \frac{10{,}000\Omega}{33\text{-}1/3\Omega} = 300$$

This is a relatively high value for Q and this particular circuit will resonate sharply to its tuned frequency. It will have a very narrow passband.

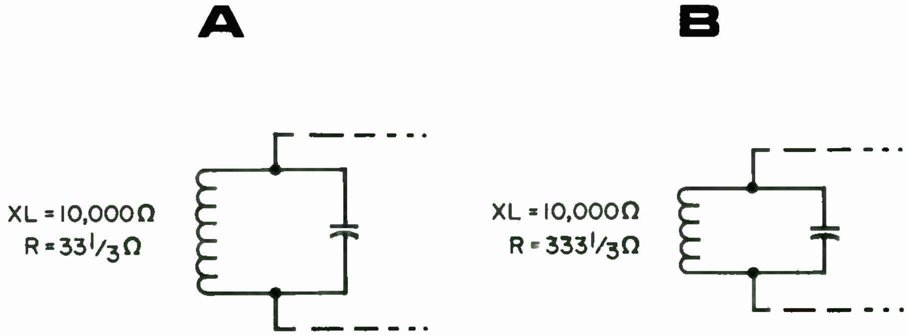

Figure 18 - Most of the resistance in a tuned circuit appears in the transformer or coil.

The winding in Figure 18B has a reactance of 10,000 ohms but the DC resistance of its winding is 333-1/3 ohms. Its Q factor will be:

$$Q = \frac{X}{R} = \frac{10{,}000\Omega}{333\text{-}1/3\Omega} = 30$$

A Q factor of 30 is relatively low, therefore, the circuit in Figure 18B will be broadly resonant and it will pass a wide band of frequencies. It will, however, be low in efficiency and will present less signal to the amplifier than a tuned circuit with greater Q.

Coupling

Low Q IF circuits are frequently used to pass the required band of frequencies, but other methods can be employed. One of these other methods involves the amount of coupling between windings. When a greater coefficient of coupling is used, more signal energy is transferred. When greater amounts of signal are transferred, a greater range of frequencies are transferred.

Figure 19 shows different amounts of coupling by means of three different IF transformers and their associated bandwidth curves.

Suppose in Figure 19 we want to select a circuit that will pass fo (the center frequency) and all frequencies between f1 and f2. Which transformer would we choose? The circuit illustrated in A passes the center frequency (fo) but severely attenuates frequencies f1 and f2 . . . So we can eliminate A as a choice. Notice that there is considerable space between its primary and secondary. In B we see a transformer with closer spaced windings. Its passband includes fo, f1 and f2. Frequencies f3 and f4 are far down on the curve and will present very little energy to the amplifier. Is this the circuit we want? Before deciding let us examine C.

The example in C has its windings very close together and will couple more energy to the secondary than transformers A and B. Notice, however, that frequency fo is severely attenuated. Also, f3 and f4 are nearly as high on the curve as fo. This is obviously not the circuit we want. The example in B must be our choice.

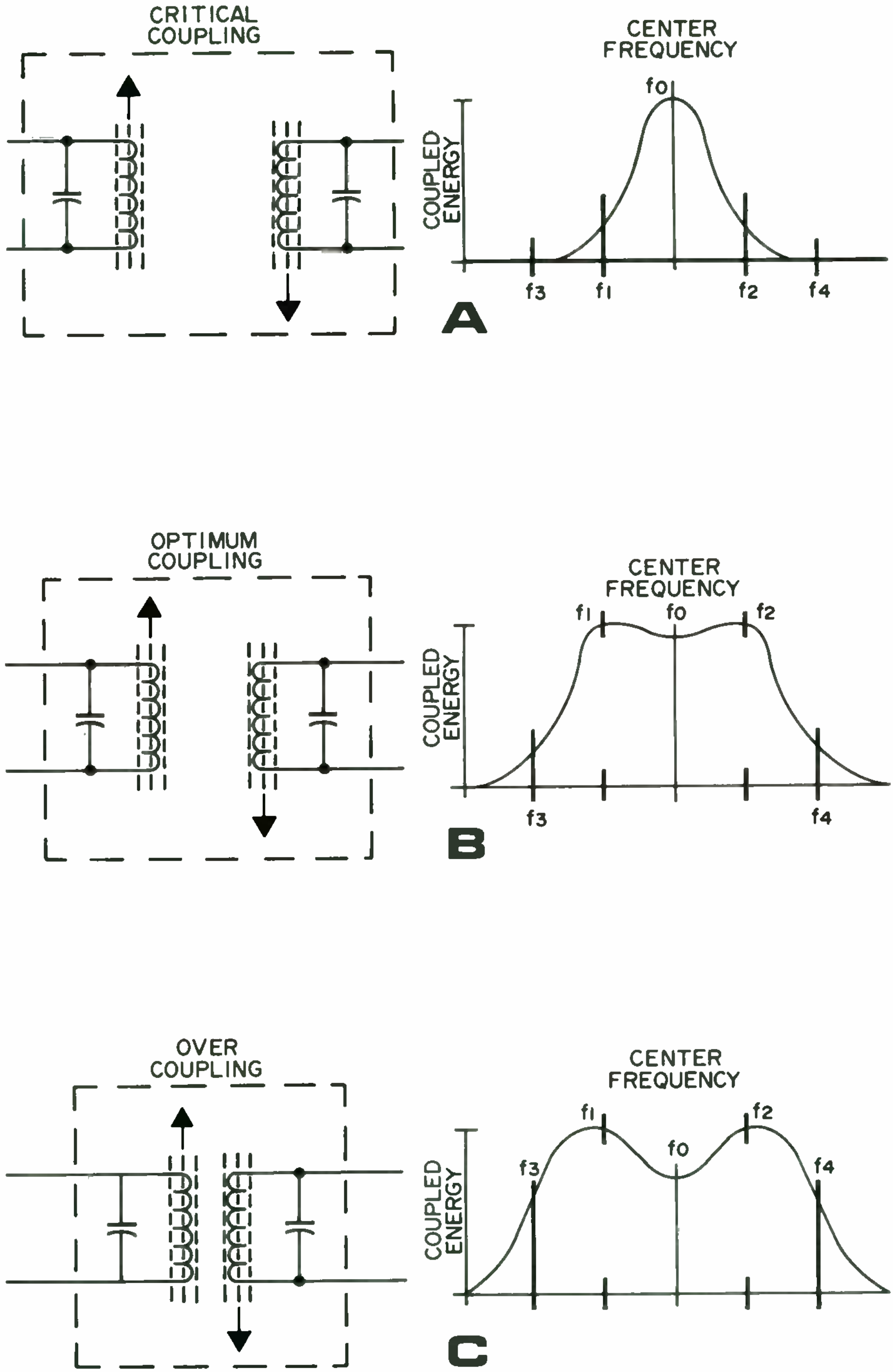

Figure 19 - Degrees of coupling.

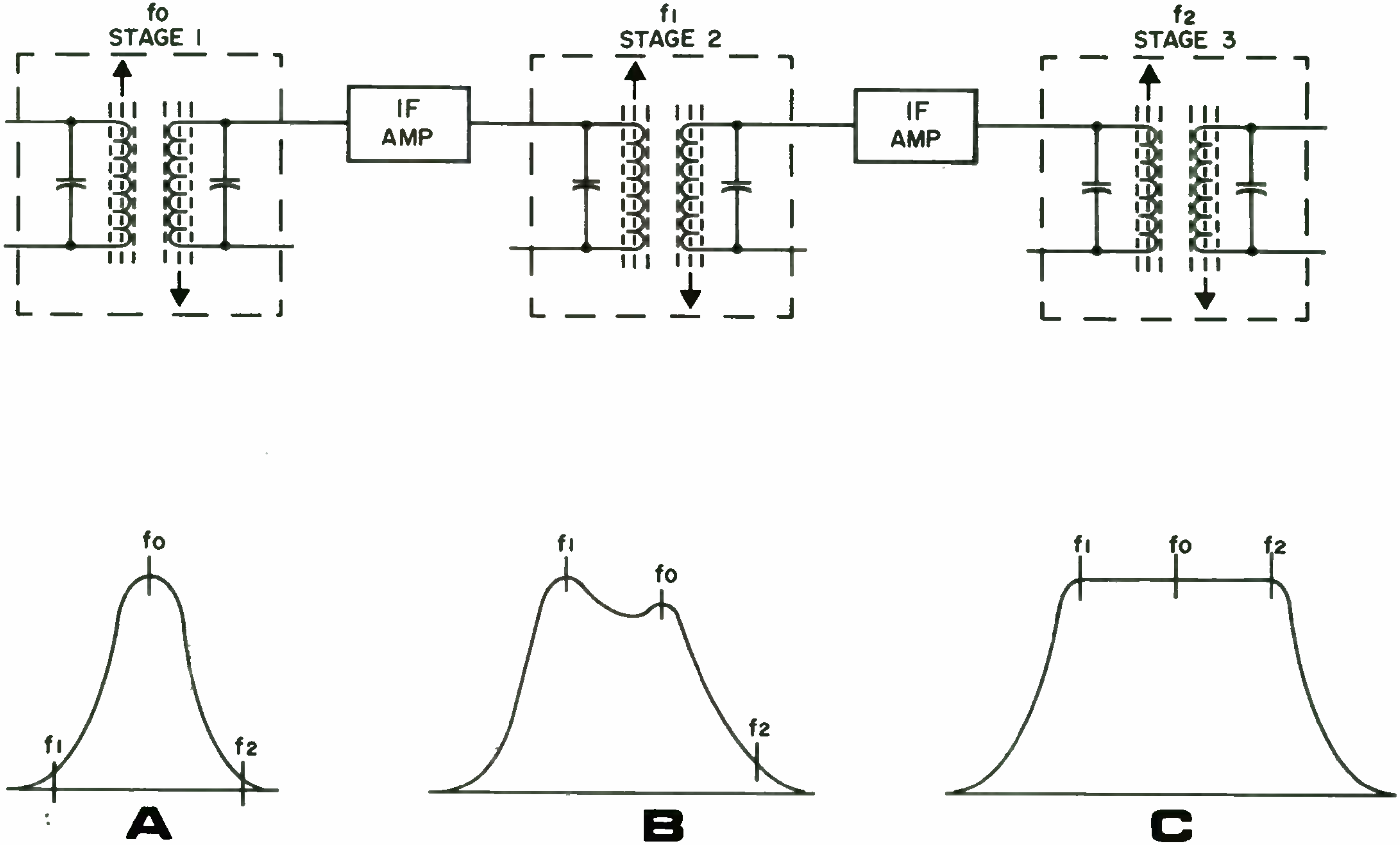

Figure 20 - Stagger tuning to achieve bandpass.

Stagger Tuning

Another method of obtaining a required IF bandpass is by means of staggering the tuning of the IF stages. This method is illustrated in Figure 20 with curves below each stage showing how the required bandpass is obtained.

Stage 1 is resonated to fo, the center frequency, and produces the curve shown at A. Frequencies f1 and f2 are attenuated and appear far down the curve.

Stage 2 is resonated to f1 and contributes much of its gain to this frequency. Frequency fo is slightly attenuated and f2 is far down in amplitude.

Stage 3 is tuned to f2 and causes its amplitude to be boosted to the level of fo and f1. The curve at C shows the three frequencies equal in amplitude and all the information they contain will be available to the next stage.

Television receivers generally use a stagger tuned method to obtain the required bandpass. In addition, they incorporate series or parallel tuned traps to steepen the sides of the curve and reject unwanted signal frequencies that could interfere with the sound or picture.

TRANSISTOR RF AMPLIFIER

The RF and IF amplifiers discussed so far have used vacuum tubes. Transistors are replacing vacuum tubes in RF circuitry at an increasing rate. Circuit operation of transistorized RF and IF stages are similar to those using vacuum tubes except for coupling.

Figure 21 shows a transistorized RF amplifier with its associated components. The antenna is a ferrite loop; which is a coil of wire on a powdered iron core. The loop antenna is connected to a tap on the RF coil winding. The base of transistor Q1 receives its signal from a lower tap on the same winding.

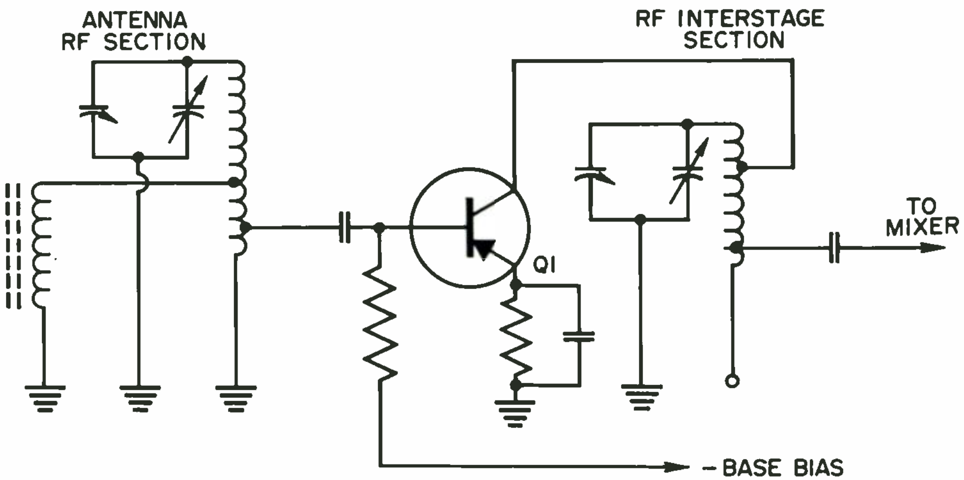

Figure 21 - Transistor RF amplifier.

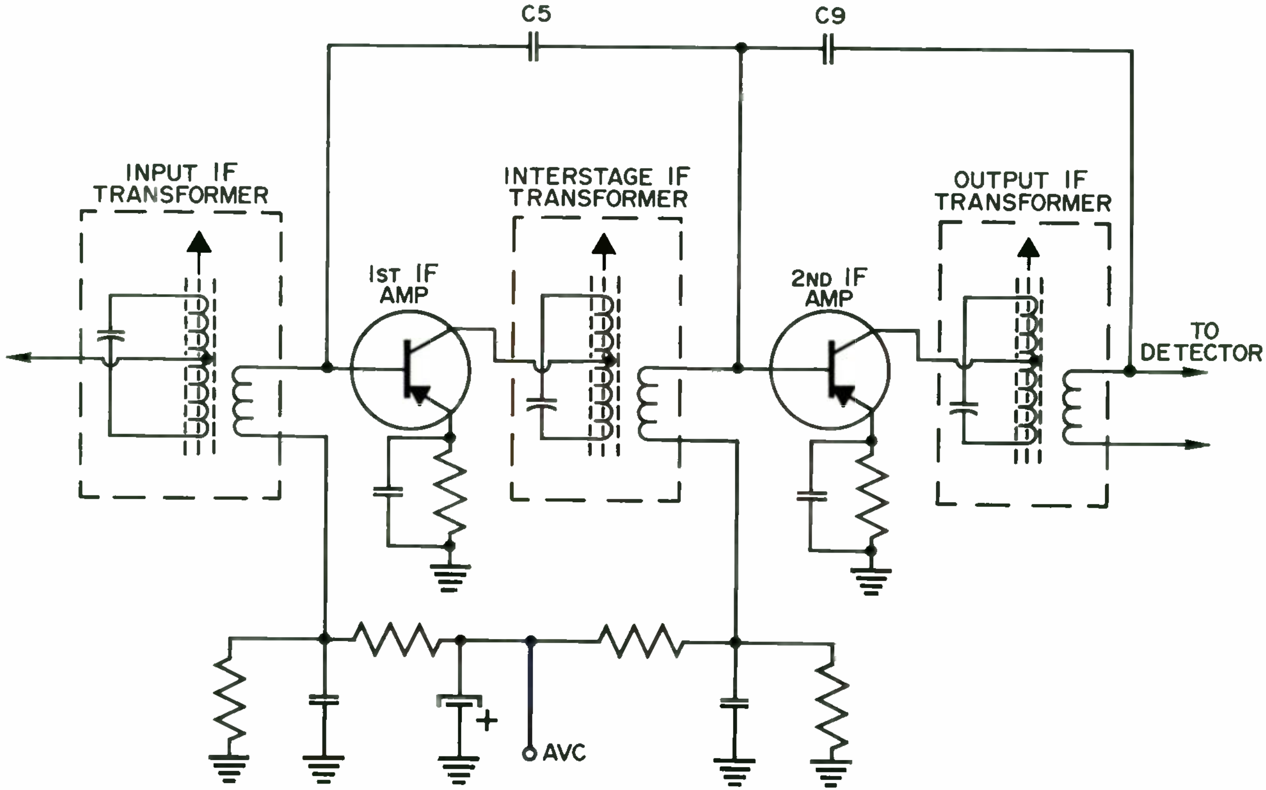

Figure 22 - Transistor IF amplifier.

You will notice in Figure 21 that the collector of Q1 is connected to a tap on the RF interstage coil. The mixers input signal is taken from a lower tap.

The reason that signals are tapped in and out of coils in transistorized equipment is because of a transistor's low impedance characteristics. Also, transistors require considerable signal current to drive their base. The taps are positioned on the coils to provide required signal current at the correct impedance.

TRANSISTOR IF AMPLIFIER

The IF windings of transistorized receivers are usually tapped. Notice from the schematic in Figure 22 that only the primary windings of the IF are tuned. To obtain the required IF selectivity, two stages of IF amplification are used instead of just one stage common in most tube type broadcast receivers.

The capacitive network C5 and C9 provides negative feedback for the two IF stages. This negative feedback prevents unwanted oscillation from occurring at interfering frequencies.

The information presented in this lesson is general in nature, but it is representative of many IF and RF systems. Variations and special cases occur in some manufacturers' equipment. Some of these will be discussed in later lessons on servicing.

SUMMARY

RF amplifiers must amplify signals at extremely high frequencies. When used as an RF amplifier, a triode has one limiting characteristic, the plate-to-grid capacitance. At high frequencies this interelectrode capacitance will produce a positive feedback and cause the amplifier to break into oscillation. To neutralize this oscillation, a signal that opposes this positive feedback must be supplied to the amplifier. This is called degenerative feedback and may be accomplished with a feedback winding or feedback capacitor. Tetrode and pentode vacuum tubes incorporate a screen grid to reduce the plate-to-grid capacitance and, therefore, they seldom require neutralization.

An IF amplifier stage is utilized in superheterodyne receivers to amplify the intermediate frequencies. The IF amplifiers also determine the selectivity of the receiver. Inductive coupling is used extensively in IF amplifiers. An IF transformer may be broadly tuned to a frequency at which optimum coupling will occur. The IF transformer will respond to the desired frequencies and attenuate undesired frequencies. This produces the selectivity of the IF stage. Some IF stages incorporate a method of tuning called stagger tuning. In stagger tuned receivers each stage responds to a different frequency producing the desired bandpass at the final stage.

Transistors are replacing vacuum tubes in RF and IF amplifiers. One characteristic of the transistor RF and IF amplifier is the tapped transformers used for interstage coupling. This allows for impedance matching between stages.

TEST

Lesson Number 41

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 52-041-1.

1. Triode RF amplifiers are limited in gain because
   A. they are hotter than other types.
   B. they have lower plate to grid capacitance than other types.
   C. they are subject to oscillation.
   D. none of the above.

2. A receiver that amplifies a station's signal through a series of variable tuned RF amplifiers prior to detection is called a__________receiver.
   A. TRF
   B. superheterodyne
   C. broad band
   D. band rejection

3. Degenerative feedback is used to neutralize
   A. pentode RF stages.
   B. triode RF stages.
   C. tetrode RF stages.
   D. pentode IF stages.

4. One commonly used form of manual RF gain control is
   - A. varactor tuning.
   - B. variable suppressor control.
   - C. variable cathode control.
   - D. variable screen control.

5. Pentode and tetrode RF stages are not subject to oscillation because of their
   - A. cathode construction.
   - B. suppressor grids.
   - C. screen grids.
   - D. heater construction.

6. TRF receivers are inferior to superheterodyne receivers because
   - A. they barely provide adequate signal gain.
   - B. they did not provide uniform gain at all frequencies.
   - C. they are subject to oscillation.
   - D. all of the above.

7. A broad band RF stage
   - A. resonates sharply to only one frequency.
   - B. is variable over a wide range.
   - C. is broadly tuned to the center of a band of frequencies.
   - D. resonates sharply to an unwanted frequency.

8. Traps are used
   - A. to reject certain frequencies.
   - B. to boost certain frequencies.
   - C. to receive a band of frequencies.
   - D. none of the above.

9. Grounded-grid amplifiers operate with their ____________ at ground potential.
   - A. screen
   - B. plate
   - C. cathode
   - D. grid

10. Transistors unlike vacuum tubes are usually connected to a tap on a coil or transformer because of their
   - A. high capacitances.
   - B. low capacitances.
   - C. low impedances.
   - D. high impedances.

Notes

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PRESS ON

No man escapes days when setbacks make him wonder whether his choice of profession was a wise one. Next time you are troubled by no job, tiredness, missed appointments, or any of the "little things" that get you down, and you are tempted to quit for the day – remember these words by Calvin Coolidge:

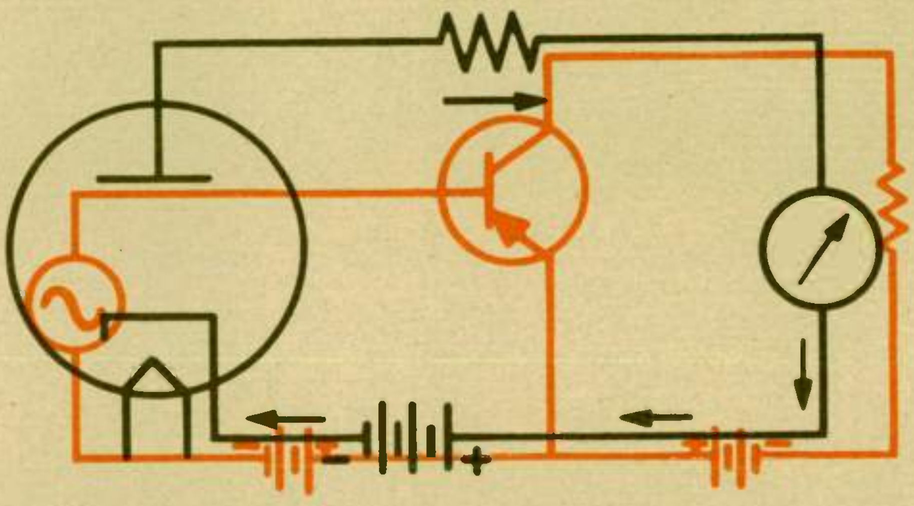
"Nothing in the world can take the place of "persistence". Talent will not; nothing is more common than unsuccessful men full of talent. Genius will not; the world is full of unrewarded "geniuses". Education will not; the world is full of educated derelicts. PERSISTENCE AND DETERMINATION – ALONE – are omnipotent. The watchword "PRESS ON" has solved and always will solve the problems of man!

You can solve your problems by following the same advice. Study regularly and by all means put what you learn from studying – to work!

S. T. Christensen

LESSON NO. 42

POWER AMPLIFIERS



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CONTENTS

POWER AMPLIFIERS

INTRODUCTION

An audio amplifier is used to amplify signals whose frequency limits fall within the audio frequency range (usually considered to extend from 20 to 20,000 hertz). Only one amplifier, the so-called "high fidelity" audio amplifier is *designed* to amplify all frequencies within this audio range. Audio amplifiers in many other applications are designed to amplify only portions of the audio range. Any amplifier that amplifies an input signal whose frequency lies between 20 and 20,000 hertz however, may be classified as an audio amplifier. Audio amplifiers are further classified into two general groups: *voltage* amplifiers and *power* amplifiers.

It has been previously explained that the primary function of a voltage amplifier is to increase the voltage of an audio signal to a higher value without distorting the waveform. Under ideal conditions no appreciable power is consumed from the preceding stage, and no appreciable power is supplied to the succeeding stage. In general, the output voltage is proportional to the product of the input voltage and the mu of the tube.

POWER AMPLIFIERS

The primary function of a power amplifier is to deliver power to a load, and any increase in voltage is of secondary importance. Because the power amplifier requires a relatively high signal-voltage input, the power amplifier must usually be preceded by one or more voltage amplifiers to raise the voltage to the proper level to operate the power stage.

Various types of tubes may be used as audio amplifiers, including triodes (or tubes operated as triodes) and pentodes. The tubes may be operated singly or in pairs as in push-pull stages.

In general, power amplifiers have low amplification factors, low plate resistance, and high plate current. In order to obtain low plate resistance, the space between the plate and cathode is made smaller in a power tube than it is in a voltage amplifier tube. Also, in a power tube the area of the plate is made larger and the cathode is designed to supply a larger number of electrons. The grid must not block too many of the electrons flowing to the plate; accordingly the grid meshes are widely separated, and the amplification factor is thereby reduced.

Power amplifiers have numerous applications. The most familiar use is as the output stage of a radio receiver. Power is needed to operate the loudspeaker; therefore, the last audio stage is operated as a power amplifier.

Amplifier Names

Amplifiers have been given many names that describe their function, such as stereo amplifiers, hi-fi amplifiers, audio frequency (AF) or radio frequency (RF) amplifiers, etc. But these names only describe the use to which the stage of amplification is applied, while a true and correct classification of amplifiers would list them according to their electrical action.

Even though vacuum tubes have been designed to accentuate a specific electrical characteristic when amplifying, they can, in general, also be operated over a wide range of input and output voltages. The wide range of bias voltage that can be applied to the control grid of a tube has provided a simple method of classifying the amplification action of vacuum tubes.

Classification by Bias

Amplifiers are classified according to the bias conditions under which they operate. As the lesson on Vacuum Tubes explained, the negative DC bias that is selected determines at what point on the characteristic curve the tube will be operated. In other words, the choice of bias voltage in an AF amplifier determines the wave shape in the output circuit.

The effect of shifting the value of grid bias is illustrated in Figure 1. One value of bias allows the tube to operate on the linear portion of the ip – eg characteristic curve. A different value of bias forces the tube to operate on the nonlinear portion of the curve. When the operating bias is at point A (-3 volts) the grid-voltage variation is within the limits of the linear portion of the characteristic curve. This allows the plate current to faithfully reproduce the grid-voltage waveform. When the fixed bias is increased to point B (-7 volts) the amplitude of the output waveform is considerably distorted. The extent of this distortion of the plate current curve depends upon the actual biasing point of the tube and the amplitude of the grid signal voltage.

The point on the zero axis intersected by the characteristic curve (point C in Fig. 1) is commonly known as the cutoff point. An amplifier biased to cutoff functions as a diode rectifier because only alternate half cycles are reproduced in the output circuit. When an amplifier is biased well beyond cutoff and is driven with an excessively large input grid voltage, only that part of the grid-voltage waveform extending into the operating region of the characteristic curve is reproduced in the output. The input signal is thus distorted in the output because only a small portion is amplified.

Even though vacuum tubes can be operated under many different values of plate voltage and grid bias, it was found that many different operating conditions could be grouped into four major classifications. These four classifications are determined by the value

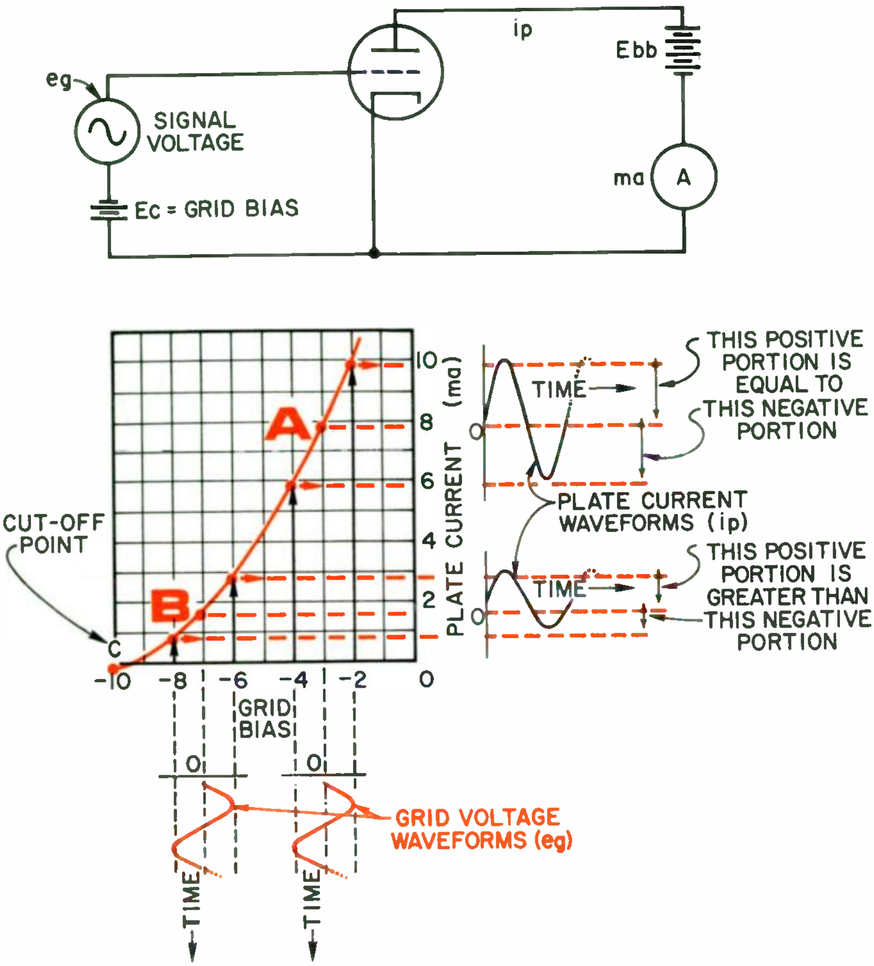


Figure 1 - The negative value of the grid bias on a particular characteristic curve determines the shape of the plate current waveform.

of the grid bias, which in turn determines when current flows in the plate circuit.

The four major classifications of amplifiers are known as class A, B, AB, and C. There are additional subclasses such as AB1 and AB2, with the subscript numbers giving additional information about the action of the circuit.

Class A Amplifiers

Class A amplifiers operate in a manner that allows plate current to flow throughout the entire cycle of a normal input signal, with the amplification being essentially linear (Fig. 2). Grid current does not flow in a class A amplifier because the grid is *not driven* into the positive region.

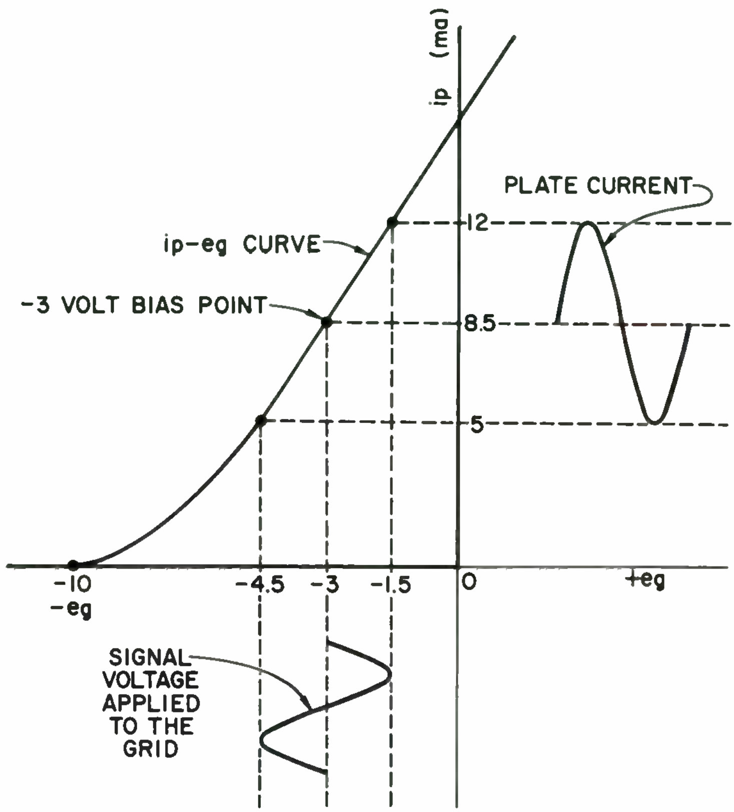


Figure 2 - Operation of a Class A amplifier, showing that the output current wave is an exact amplification of the weaker input signal applied to the grid. The input signal shown here never drives the grid into the positive, or +eg, region.

Class A_1 and A_2 Amplifiers

To show that grid current does not flow during any part of the input cycle, the subscript number "1" is added to the letter or letters of the class identification. The subscript "2" is used to indicate that grid current does flow during some part of the input cycle. Thus, if the grid is not driven positive at any time that the AC input signal is applied, no grid current will flow and the amplifier is designated class A1.

The principal characteristics of class A amplifiers are minimum distortion, low power output for a given tube (compared to class B and class C amplifiers), high power amplification, and relatively low plate efficiency (20 to 35 percent). This type of amplifier finds wide use in various audio systems where low distortion is important.

Class B Amplifiers

Class B amplifiers are biased so that no plate current flows when no signal is applied to the grid. But plate current will flow for approximately one-half of each cycle of grid signal voltage (Fig. 3). Such amplifiers are characterized by medium power output, medium plate efficiency (50 to 60 percent), and moderate power amplification.

Class AB Amplifiers

Class AB amplifiers have grid bias and input-signal voltages of such values that plate current flows for appreciably more than half the input cycle but for less than the entire cycle (Fig. 4). Class AB operation is essentially a compromise between the low distortion of the class A amplifier and the higher efficiency of the class B amplifier.

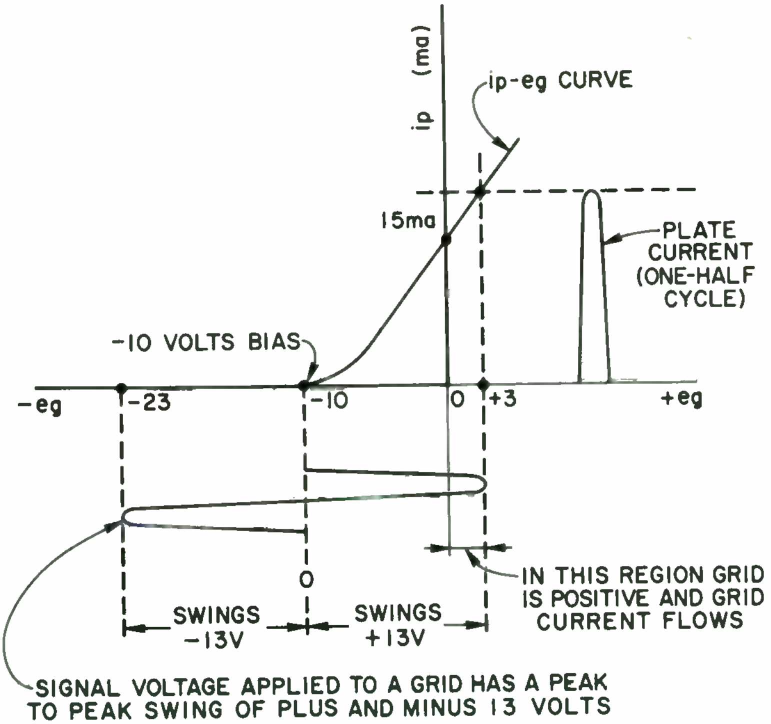


Figure 3 - Operation of a Class B amplifier, showing that the grid voltage is biased at the cut off point (a–10 volts in this example). Plate current flows only during one-half of the input cycle.

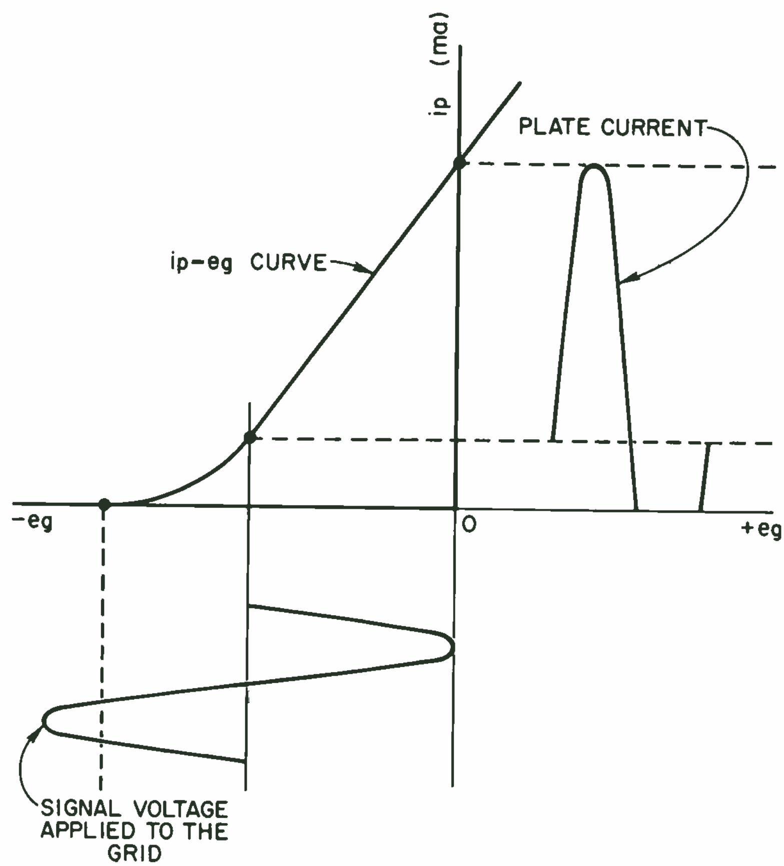


Figure 4 - Operation of a Class AB1 amplifier showing that the plate current flows during more than one-half of the input cycle. The grid voltage never goes positive with this particular input signal as shown, but if it did go positive, the grid would draw current and the amplifier would be termed a Class AB2.

If the input signal drives the grid positive with respect to the cathode, grid current will flow during the positive peaks and the amplifier is designated as a class AB2 amplifier. Although a class AB2 amplifier delivers slightly more power to its load, the class AB1 amplifier has the advantage of presenting a constant impedance to its driver. In contrast with this effect the amplifier that draws grid current over a portion of its input cycle presents a changing impedance to its driver at the point where grid current starts to flow. Thus, before grid current flows, the impedance is relatively high, and during the part of the input cycle when grid current flows the impedance falls to a relatively low value. The driver that supplies this kind of load must be designed to supply undistorted power to the load during these periodic intervals of low impedance.

Class C Amplifiers

Class C amplifiers have a negative bias that is appreciably greater than cutoff; consequently, plate current flows for less than half of each cycle of the applied grid signal voltage (Fig. 5). This class of amplifier has a relatively high plate efficiency (70 to 75 percent), high power output, and low power amplification.

Class C amplifiers cannot be used as audio amplifiers, but they are used as RF power amplifiers in transmitters. If power is delivered to a tuned load, this load will present a high impedance at the resonant frequency and low impedance at other frequencies. If the load is tuned to the same frequency as that which is applied to the grid it will offer optimum loading at this frequency. A low impedance will be offered to the harmonics (multiples) of the frequency applied to the grid, and hence these undesirable components will be eliminated.

Various types of tubes may be used as audio amplifiers, including power triodes, power pentodes, and beam power tubes. These tubes may be

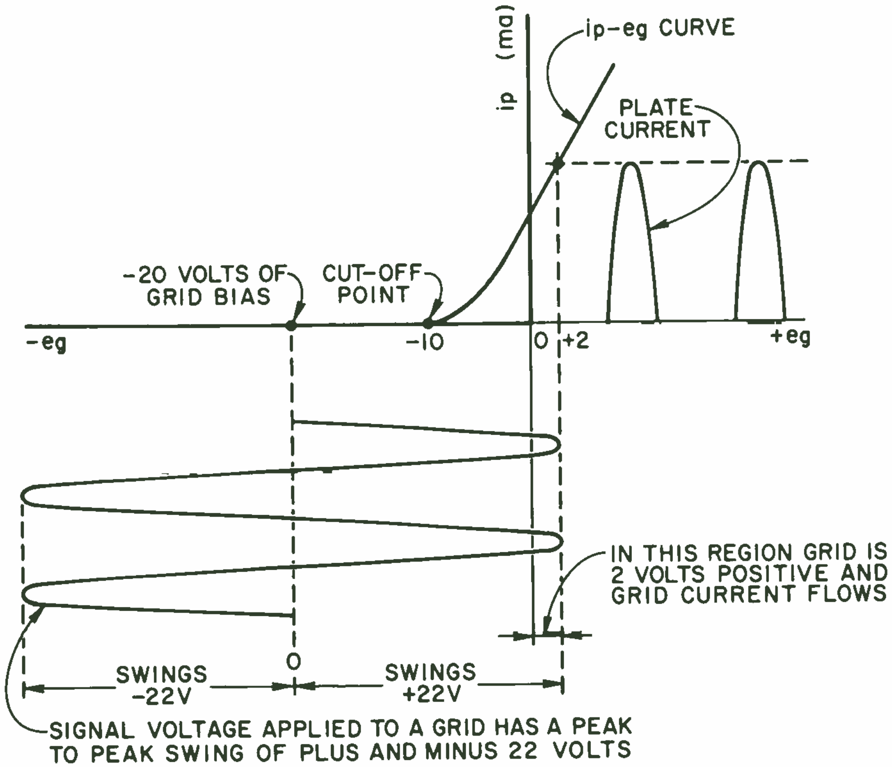


Figure 5 - Operation of a Class C amplifier showing that the grid is biased at a much greater negative value than the cut off value of—10 volts in this example. The plate current flows for appreciably less than one-half of each cycle of the signal applied to the grid.

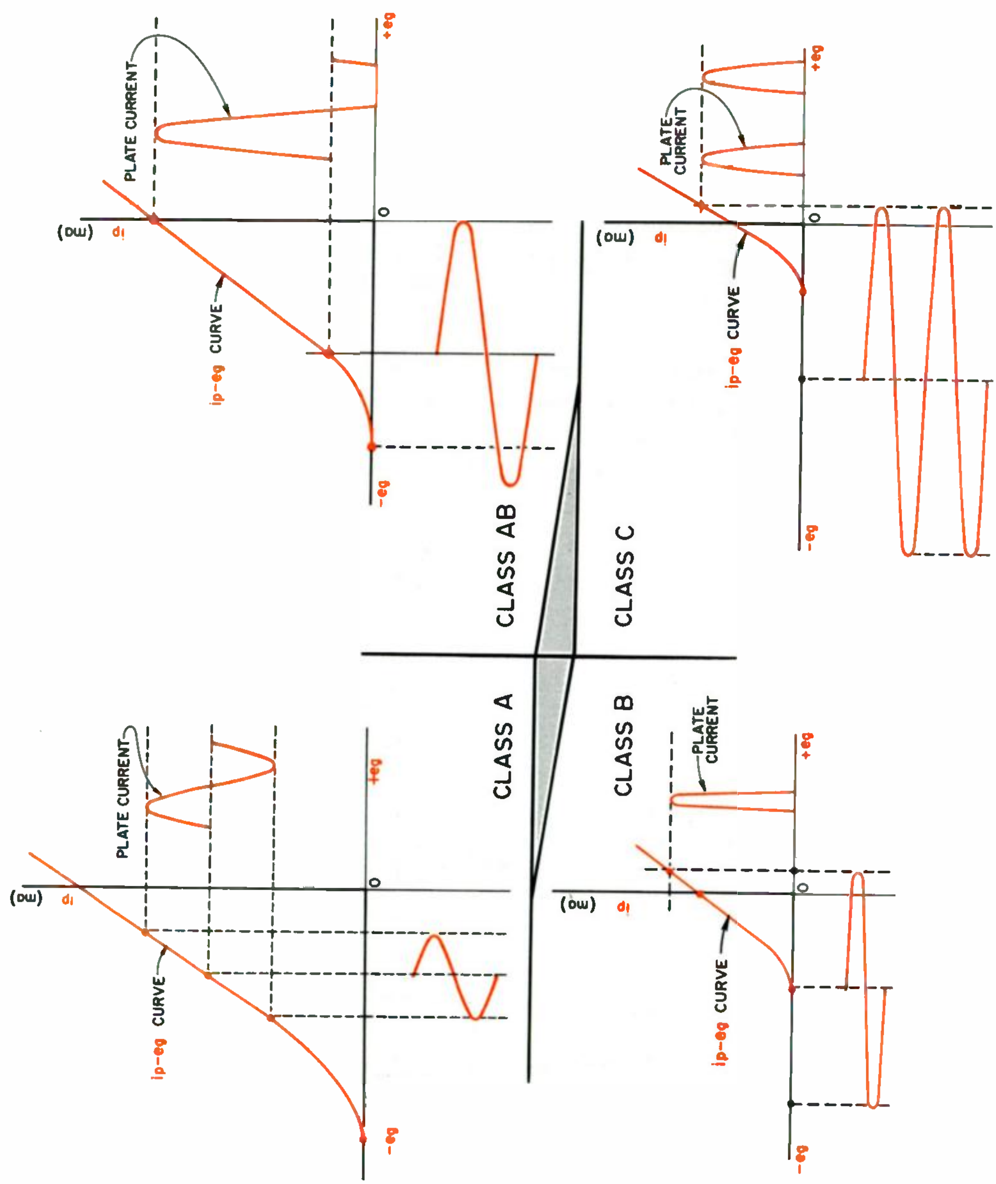


Figure 6 - A comparison of the operation curves of the four classes of vacuum tube amplifiers.

operated as *single-ended* or as *push-pull* stages. Single-ended audio power stages may consist of single-tube amplifiers or two or more tubes connected in parallel. Such parallel-connected tubes provide a greater power output for a given input than do single tubes. Regardless of the particular circuit used, single-ended audio power amplifiers are operated as class A only. On the other hand, push-pull audio power amplifiers may be operated class A, AB, or B and provide greater output power than the same two tubes connected in parallel. Due to the excessive distortion involved, audio power amplifiers are never operated class C.

Representative curves for each of the four classes of tube amplifiers have been grouped in Figure 6 for comparison.

The information about power amplifiers is subdivided into two major subjects — single-ended and push-pull audio power amplifiers. The power, distortion, frequency response and efficiency of single-ended amplifiers are reviewed, and the discussion of push-pull amplifiers includes circuit requirements, DC and AC flow, balancing networks and circuit characteristics under various classes of operation.

SINGLE ENDED POWER AMPLIFIER

A single-ended power amplifier using a power triode driving a speaker always contains certain basic components (Fig. 7). In this circuit, C1 and R1 form the input coupling network.

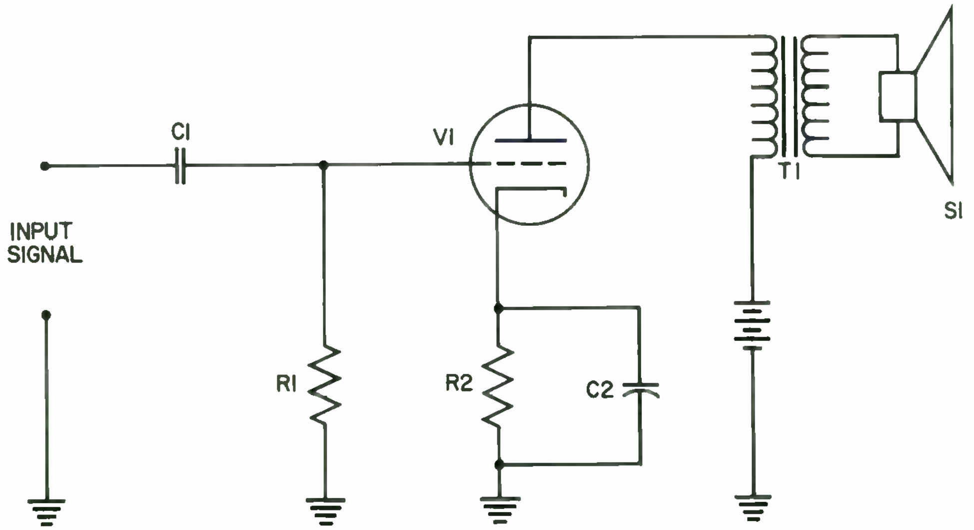


Figure 7 - Single-ended power amplifier.

C1 blocks the DC component of the plate voltage of the previous stage from being applied to the grid. The AC component is developed across R1. R2 is used to develop cathode self-bias. C2 keeps the bias voltage across R2 relatively constant when a varying input signal is applied. T1 is the output transformer that acts as the plate load impedance and provides power transfer from the plate circuit to the speaker.

Impedance Matching Transformer

To transfer maximum power to a load, the load impedance must equal the source impedance. In the audio power stages used to drive the speaker, the plate resistance of the tube V1, (several thousand ohms) is the source impedance. The load impedance is speaker S1, which is 4 to 16 ohms. If this load were connected directly to the plate of a power amplifier, the transfer of power to the speaker would be small. Therefore, a means to improve the power transfer to the load must be developed. This is the purpose of the *impedance matching transformer*. The transformer will match the impedance of the load to the impedance of the source.

When the secondary of a transformer is open (there is no load connected to it), the current flow through the primary is very small. Under such a condition, the primary impedance is very large. However, when a load resistance is connected to the secondary, the current that flows in the secondary produces a flux field which cancels some of the primary flux. This results in an increase in current drawn from the source trying to reestablish the original number of total flux lines. This effect of reflected impedance on primary current is the same as placing a physical resistor in shunt with the primary winding. In practical applications, the inductive reactance of the primary winding will be at least 10 times greater than the reflected impedance of any resistive load connected to the secondary.

The transformer used in matching a high value of impedance in the plate circuit to the low value of impedance of the speaker is commonly called the *audio transformer*, *speaker transformer*, or *output transformer*. A circuit designer would specify the number of turns in the primary and in the secondary by applying this simple formula:

$$\sqrt{\frac{Zp}{Zs}} = \frac{Np}{Ns}$$

which states that the

$$\sqrt{\frac{\text{Impedance in the primary}}{\text{Impedance in the secondary}}} = \frac{\text{Number of turns in the primary}}{\text{Number of turns in the secondary}}$$

A practical example of the application of this formula will show how it is used. If the plate resistance had an impedance of 40,000 ohms and it was to deliver maximum power to a 4 ohm speaker, the *turns ratio* of the transformer required to do this would be determined by substituting:

$$\sqrt{\frac{40{,}000}{4}} = \frac{Np}{Ns}$$

$$\frac{\sqrt{40{,}000}}{\sqrt{4}} = \frac{Np}{Ns}$$

$$\frac{200}{2} = \frac{Np}{Ns}$$

$$\frac{100}{1} = \frac{Np}{Ns}$$

Therefore, the primary winding should have 100 turns for every turn in the secondary winding for maximum power transfer. It should be noted that even though power is being supplied to a 4-ohm load, this load appears as 40,000 ohms of impedance in the plate circuit of the amplifier.

Beam Power Tubes

Power sensitivity is another term used when discussing power amplifiers. It is the ratio of the power output in watts to the grid signal voltage causing it (when no grid current flows). If grid current flows, the term usually means the ratio of plate power output to grid power input. Pentodes and beam power tubes require less driving power than triodes for the same power output and thus have a greater power sensitivity.

Power amplifier circuits normally use vacuum tubes which are specifically designed for purposes of power amplification. One such tube is the beam power tube. Its special design gives it the ability to handle very high values of current. The plate characteristics of the beam power tube are similar to the characteristics of a pentode tube. The primary difference between these two tubes is that in the beam power tube the electrons are concentrated into sheets as they are attracted to the plate. The sheets or beams of electrons are formed by a set of beam-forming plates located inside the tube.

The location and configuration of all the elements of a beam power tube are shown in Figure 8. The cathode is large and flat on two sides to provide a large emitting surface. The plate is usually corrugated to increase the effective plate area, thereby increasing its power dissipation capability.

Another basic difference in the construction of the beam power tube is the way in which the grids are wound. In the beam power tube, the screen grid is wound directly in line with the control grid, which reduces the likelihood of electrons striking the screen grid on their way to the plate. Figure 9A shows how the control grid and screen grid wires in an ordinary tetrode determine the electron paths. The wires are out of alignment, so that many of the electrons which pass through the control grid wires are deflected from their paths, striking the screen grid. This produces a screen current which reduces the value of the plate current. The need for a very large plate current in power tubes makes this characteristic undesirable.

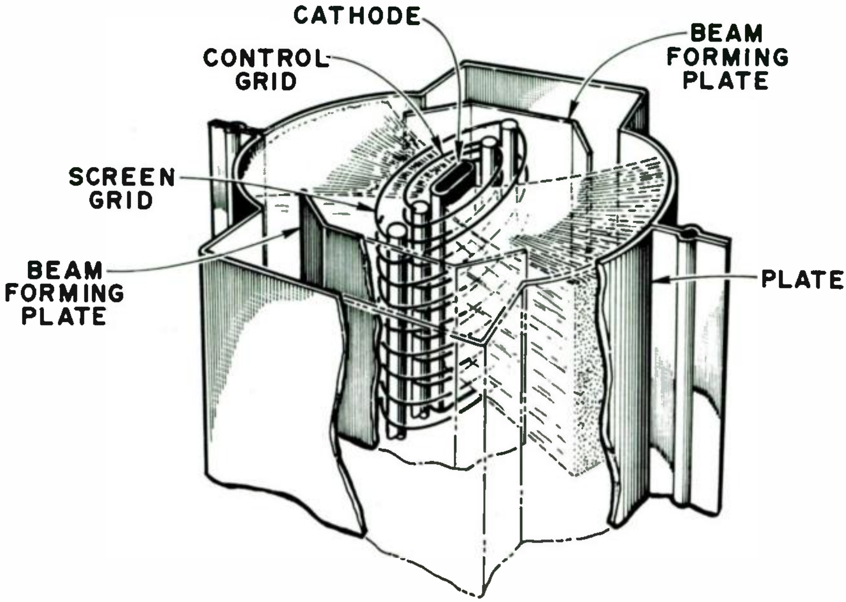


Figure 8 - Internal construction of a beam power vacuum tube.

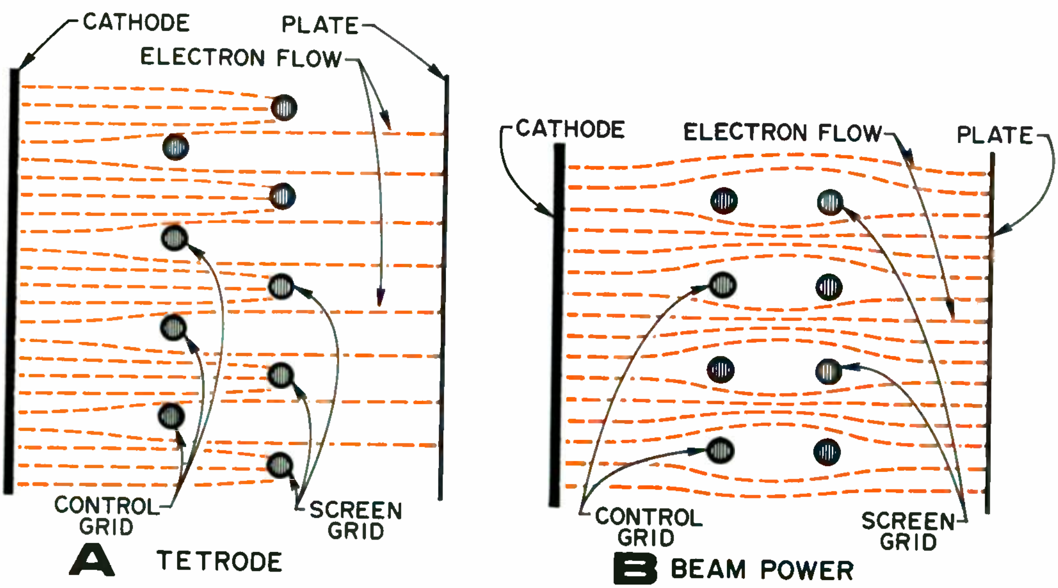


Figure 9 - A comparison of the basic internal construction of a tetrode and a beam power tube.

In Figure 9B the screen grid wires are wound directly in line with the control grid wires so that the screen grid is shaded from the electron stream. As a result, the screen grid intercepts fewer electrons.

The overall result of the addition of the beam-forming plates, the shading of the grids, and the use of a corrugated plate is a tube which can handle a substantial amount of electrical power without a great deal of distortion. The plate and control grid of the beam power tube are electrically isolated, the plate current is high, and the plate resistance is relatively low.

Another important function of the beam-forming plates is the suppression of secondary electrons from the plate. Figure 10 shows how the electrons pass through the control grid and screen grids, past the ends of the beam-forming plates, and finally to the plate. Since the beam-forming plates are connected to the cathode, the plates are at the same potential as the cathode; that is, highly negative with respect

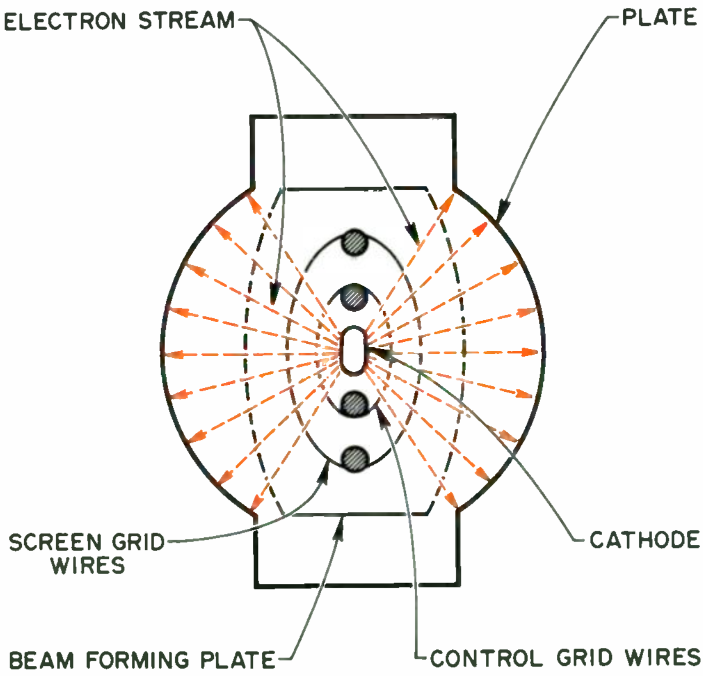


Figure 10 - This top view of a beam power tube along with Figs. 8 and 9 illustrate how the beams of electrons are formed and directed.

to the plate. Because of this, the beam-forming plates produce an effect equivalent to a space charge in the area between the screen and the plate.

Figure 11A illustrates the beam power tube with the beam-forming plates, whereas, Figure 11B shows the version in which a grid replaces the beam-forming plates. As can be seen, there is no difference between the schematic representation of the power pentode and the schematic symbol used to represent the ordinary pentode.

BEAM POWER AUDIO AMPLIFIER

The circuit configuration of the audio amplifier using a beam power tube is much the same as the triode power amplifier circuit. The difference is the addition of a screen bypass capacitor, a screen voltage, and a screen dropping resistor. This circuit using a type 6V6 beam power tube is shown in Figure 12 with representative voltage values. The beam power tube will deliver more power output with less input voltage than a triode or a pentode. When operated as a single-ended tube, the beam power tube does produce slightly more distortion of the audio signal, but this disadvantage is eliminated when two beam power tubes are operated in a push-pull configuration.

Push-Pull Power Amplifier

It was previously pointed out that the beam power tube was capable of providing a power output greater in magnitude than its triode tube counterpart under the same operating conditions. The push-pull power amplifier

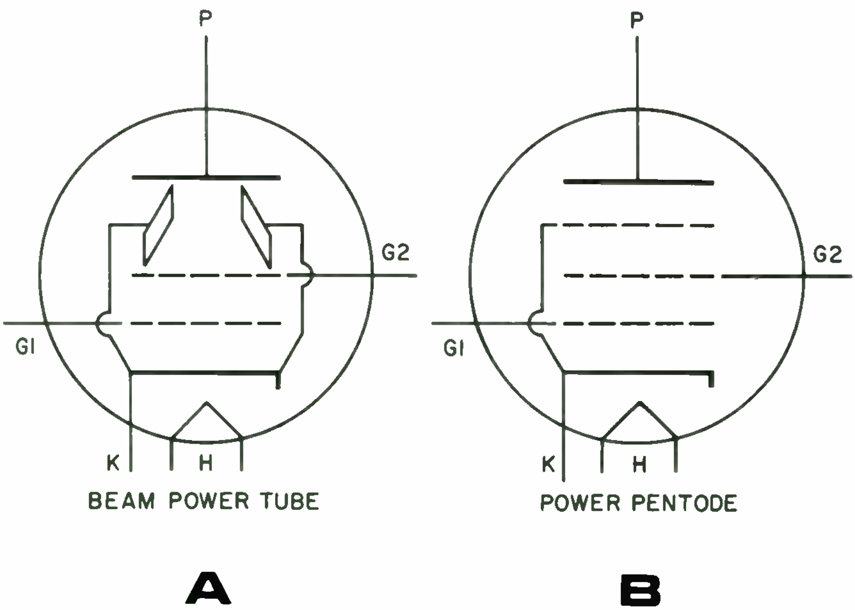


Figure 11 - Schematic representation of the beam-power tube and the power pentode.

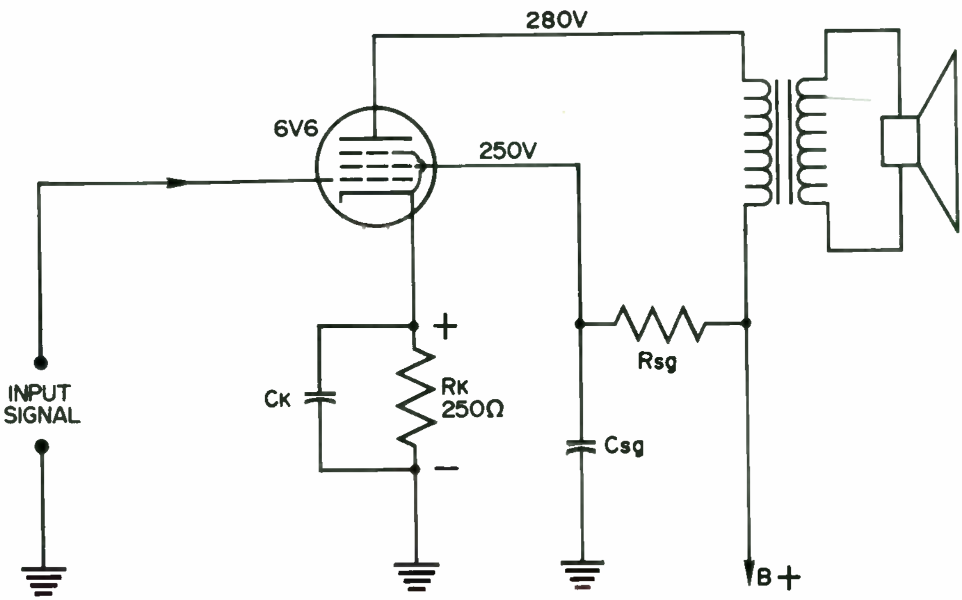


Figure 12 - A single-ended amplifier using a type 6V6 beam power tube.

will also provide a greater power output with *less* distortion than a single-ended power amplifier under the same operating conditions. The schematic diagram of a basic push-pull amplifier is shown in Figure 13.

A push-pull power amplifier must have two input signals of equal amplitude, but of *opposite* polarity. These two signals are generally provided by the center-tapped secondary of the input transformer T1. The output trans-

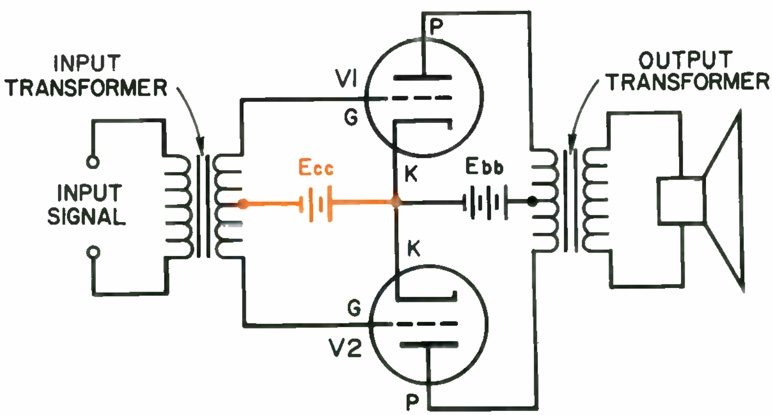


Figure 13 - Push-pull power amplifier. This circuit also illustrates the use of a battery for grid bias.

former is also center-tapped, permitting it to provide output power on alternate half cycles. To obtain equal amplification, each half of the circuit must be balanced to insure that the signals will be amplified equally. As in all amplifier circuits there is a DC path and an AC path, and a description of the DC path will show a number of unique features.

DC Path

The path of the plate current flow through V1 in Figure 13 will be analyzed, beginning at the cathode connection. It is assumed that there is no signal applied to the input grids. Current flows from the cathode to the plate of V1, down through the top half of the primary of the output transformer, through the power supply and back to the cathode. The current path of V2, starting at the cathode connection, flows from the cathode to the plate of V2, up through the bottom half of the output transformer primary, through the power supply and back to the cathode.

The two tubes used in Figure 13 are the same type. They have been tested to insure that their conduction characteristics are nearly the same. Two tubes of the same type are said to be *matched* if they have the same operating characteristics. When two tubes are matched, they have equal plate loads, and a single bias voltage. The plate currents through V1 and V2 will be equal.

Since the equal plate current flow through each half of the transformer primary is in opposite directions, the resulting magnetic fields are equal in intensity but are *opposing* each other. Thus, the magnetizing effect of the direct currents on the iron core is cancelled and there can be no DC core saturation of the output transformer.

Bias for the push-pull amplifier may be provided by a battery Ecc (fixed bias) or, as shown in Figure 14, by a common cathode resistor R_K (cathode bias). By using either arrangement equal bias is obtained for each tube. Note that the negative terminal of the

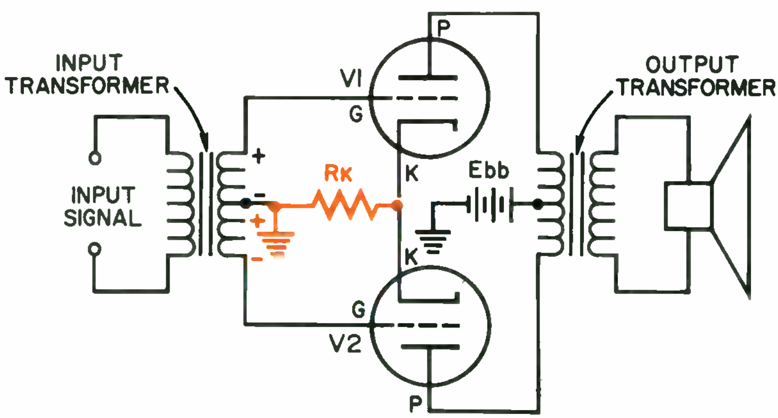


Figure 14 - A push-pull amplifier with a cathode resistor to provide grid bias.

battery is no longer connected directly to the cathode but is connected to the grounded end of the cathode resistor R_k.

AC Path

The circuit shown in Figure 15 is a push-pull amplifier biased to operate class A. This means that plate current will flow through each tube for 360 degrees of the input signal. The signals applied to the tubes will have the instantaneous polarities shown; that is, the grid of V1 is positive with respect to the center tap at the instant the grid of V2 is negative with respect to the center tap. Plate current ib1 increases through V1 and the plate current ib2 decreases through V2. The proportion of increase and decrease through each tube is equal.

The action produced by the increase of current in the other tube can be understood by considering how voltage is built up in the secondary of the output transformer. Assume that ib1 flowing through the top half of the primary produces a counterclockwise field. Then ib2 flowing up through the lower half of the primary will produce a clockwise field. This is so because the entire primary is wound in the same direction, but the current flows in opposite directions through each half. Thus, if an expanding counterclockwise field induces a positive voltage in the secondary (caused by an increase in ib1), the collapsing clockwise field caused by the decreasing ib2 will also induce a positive voltage. This will occur for one-half cycle of the inputs with conditions reversing during the other half cycle. This makes the outputs of the two tubes additive at all times. It should be noted that if both fields expand or collapse equally at the same time, there would be no voltage induced in the secondary. This explains the necessity of two input signals of opposite polarity.

When the dynamic characteristic curves of the two tubes are drawn on a single graph, the interaction between the two tubes may be illustrated (Fig.

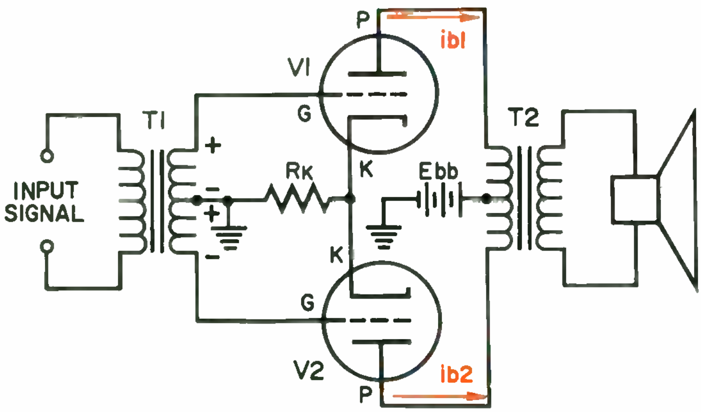


Figure 15 - Push-pull amplifier with signal applied.

16). The curve for V1 is similar to the plate current curve for bias point B shown in Figure 1. The curve for V2 is also identical, except that it is inverted. It is inverted to show that the plate current of V2 is decreasing at every instant that the plate current in V1 is increasing. This inverting of one of the characteristic curves also shows the 180° phase relationship that exists between the two tubes, while the output curves represent the *currents that appear across the secondary.*

When the grid voltage of V1 swings positive, the grid voltage of V2 is going in the negative direction. Consequently, the plate current of V1 increases as the plate current of V2 decreases. The plate current swings about the X -X axis for tube V1 is not symmetrical because the tube is operating on a non-linear portion of the ip—eg characteristic curve. The same condition is true of the plate current swing about the X'-X' axis of V2. It is not symmetrical.

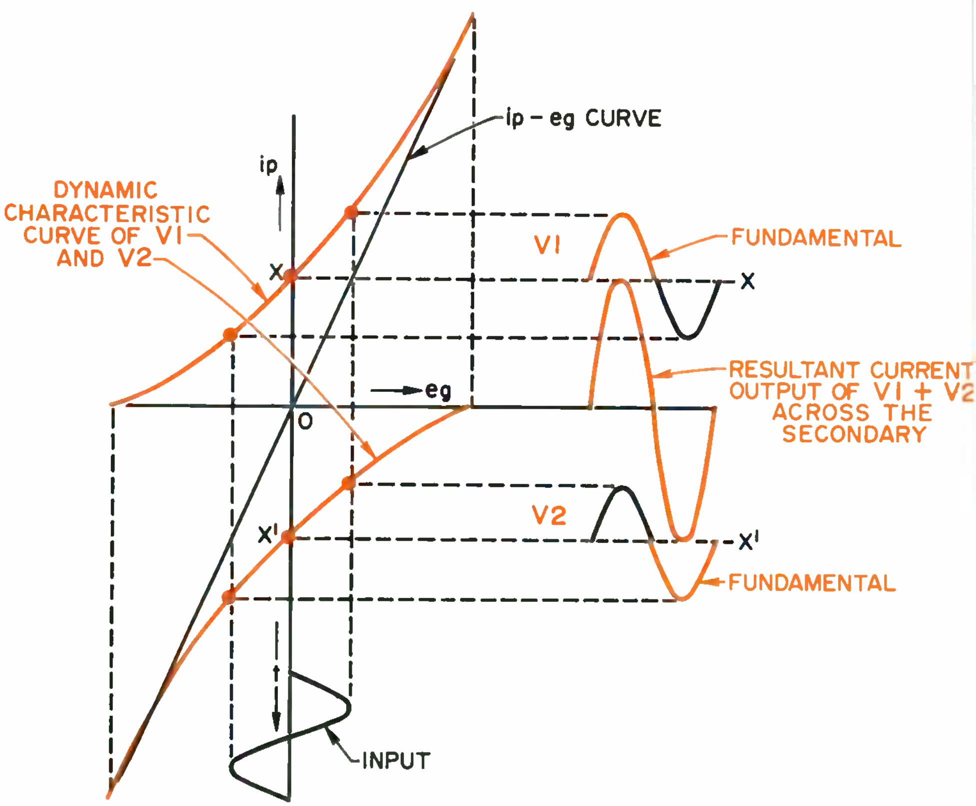


Figure 16 - Characteristic operating curves of tubes V1 and V2 in a push-pull amplifier are used to show how the two output currents combine in the secondary to produce a larger resultant.

This nonlinearity is balanced out in the resultant current output. An inspection of the V1 and V2 output curves will show that each one has one-half of the cycle smaller in amplitude, and also that they are one-half a cycle apart. Thus, their addition to form the full cycle of the output wave results in a perfect reproduction of the input sine wave. Some harmonic distortion that is created is also balanced out.

BALANCING NETWORKS

As mentioned previously, matched tubes are used in push-pull amplifier circuits to insure equal values of current and voltage in the output. No matter how well matched two tubes may be, there will be some differences in their characteristics, thus producing unequal outputs. The location of the center tap on the output transformer is critical when high fidelity is required in the output. If the tap is not physically located in the exact center of the winding there will be unequal outputs from the tubes. Therefore, a means to insure that the outputs of the tubes are the same is desired. This is provided by the use of *balancing networks*.

Cathode Balancing

When the direct component of the plate current through each tube is not equal, a cathode balancing network, such as the one shown in Figure 17 may be used to make the direct currents equal through the two tubes. By changing the potentiometer arm of R3, the value of the grid-to-cathode bias voltage to each tube may be adjusted. In this way, the tube currents may be adjusted exactly equal to each other. This adjustment is usually made while observing accurate ammeter readings in the individual plate currents.

Grid Balancing

The network shown in Figure 18 is another method of balancing, called grid balancing. By changing the position of the wiper arm of potentiometer R1, the magnitude of the input signals to the tubes may be varied to cause equal outputs. For example, if V1 has a slightly greater transconductance than V2, the potentiometer arm would be moved towards the top to decrease the magnitude of the input to V1, and at the same time increase the size of the input to V2. This adjustment is made by observing the voltage waveform across the cathode resistor, R2, on an oscilloscope. When the circuits are balanced the current increase through V1 is equal to the decrease in current through V2 and vice-versa. Thus, the current through the cathode resistor is constant, developing only a constant DC voltage across R2. Therefore, the circuits are balanced when a minimum signal appears across the cathode resistor R2.

AMPLIFIER CLASSES AND LINEARITY

The push-pull power amplifier may be operated class A, AB, or B. The class of operation used thus far has been class A. Class A operation is used where plate efficiency is not essential. Class AB operation exists when the tube conducts more than 180 degrees but less than 360 degrees of the input

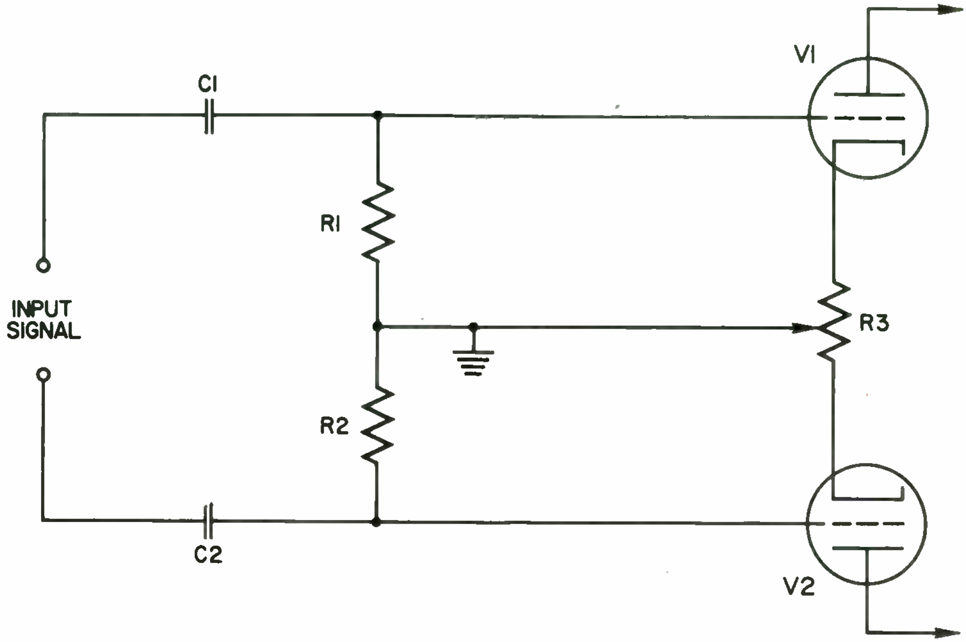


Figure 17 - Changing the position of the arm on potentiometer R3 will allow the plate current through each tube to be equalized.

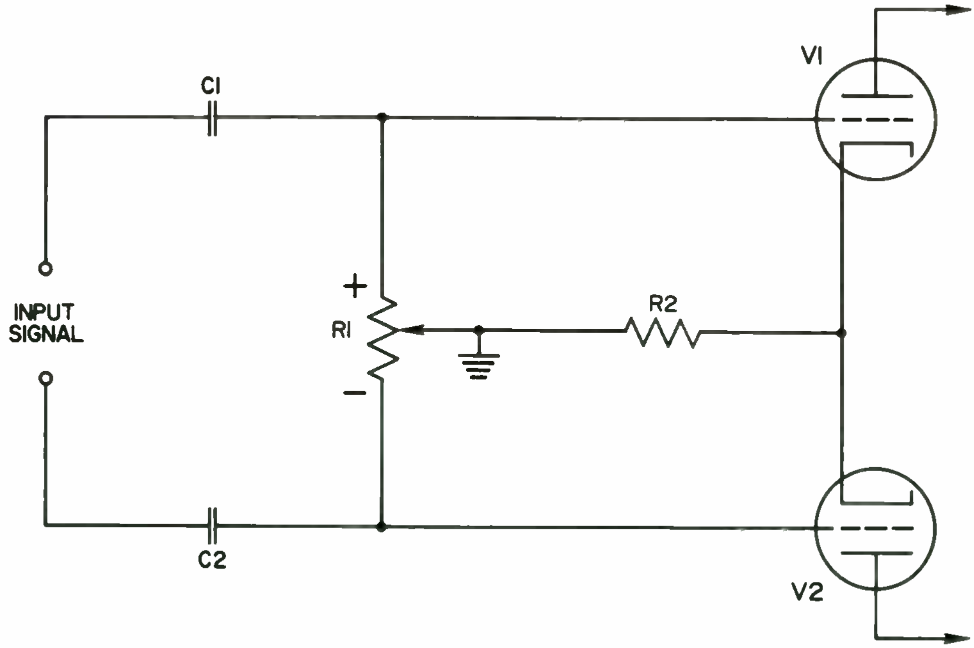


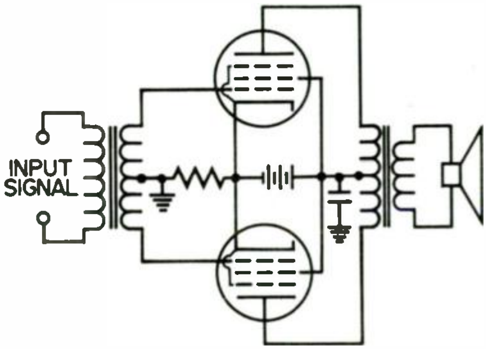
Figure 18 - Positioning the arm of potentiometer R1 adjusts the input signals to the two grids and equalizes the output signals.

cycle. It is used when class B operation causes distortion due to the non-linearity of the characteristic curves near plate current cut off. Class B operation is used when high efficiency from an audio amplifier is desired. When class B operation is used, each tube only conducts for 180° of the input cycle. Class C operation is never used with an audio amplifier of any type because of the high degree of distortion it produces.

TUBE SPECIFICATIONS

A push-pull amplifier circuit is shown in Figure 19, together with the specifications for a 6V6 power tube. The circuit is the same as that of the triode push-pull circuit except that provisions are made for the screen grid voltages. The screen grid voltage is usually the same as the plate voltage.

Referring to the manufacturer's tube manual, a comparison between the 6V6 class A single-ended and the 6V6 class A push-pull amplifiers can be made. With a plate voltage of 250 volts, the single-ended power output is about 4.5 watts. For the same plate voltage, the push-pull power output is about 10 watts. This larger output power is a result of using a larger input signal which is possible with push-pull operation.



TUBE TYPES

Tube Type and Name		Fil. or Heater V	Fil. or Heater Amp.	Capacitances pF Cin	Capacitances pF Cout	Capacitances pF Cgp	Plate Supply V	Grid Bias	Screen Volts	Screen mA	Plate mA	Plate Res. Ohms	Transconductance	Amp. Factor	Load Res. Ohms	Watts Output
6V6GTA Beam Pwr. Amp.	A_1 Amp.[1]	6.3	0.45	10	11	0.3	180	−8.5	180	3/4	29/30	50K	3700	8.5	5.5K	2
							250	−12.5	250	4.5/7	45/47	50K	4100	12.5	5K	4.5
							315	−13	225	2.2/6	34/35	80K	3750	13	8.5K	5.5
	AB_1 Amp.[2]						250	−15	250	5/13	70/79	60K	3750	30	10K	10
							285	−19	285	4/13.5	70/92	70K	3600	38	8K	14

(1) The first three lines give the data for operating a single tube, at three different plate voltages.

(2) The last two lines give the data for operating two tubes in push-pull, at 2 different values of plate voltage.

Figure 19 - A push-pull amplifier using 6V6 beam power tubes. Representative operating values from the tube manual are listed.

PARAPHASE AMPLIFIERS

Paraphase amplifiers (phase splitters) produce, from a single input waveform, two output waveforms that have exactly opposite instantaneous polarities. If these two waveforms were produced as the result of a single sine-wave input, they might be considered to be 180° out of phase, with one waveform having been displaced 180° along the time axis.

One type of phase inverter is the transformer, where 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 to the source. A conventional electron-tube amplifier also produces an output of opposite polarity to the input; and 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.

Every electron tube used as a conventional amplifier introduces polarity inversion—that is, a negative-going signal between grid and ground causes a positive-going signal to be produced across the plate load. If there is to be polarity inversion with no gain in amplitude, some method must be employed to reduce the normal gain to unity. One method of reducing the normal gain is through the use of degenerative feedback. Degenerative feedback is readily obtained by omitting the cathode bypass capacitor.

The gain may also be reduced by inserting a voltage divider in the input circuit, to permit a lesser voltage to be tapped off. Thus, if the normal gain of the tube is 100, the grid is tapped down on the divider so that one-hundredth of the available voltage is applied between grid and ground.

Single Tube Paraphase Amplifier

A simple single-tube paraphase amplifier circuit is shown in Figure 20. Resistors R2 and R3 have equal values of resistance. 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 are impressed across load resistors R4 and R5 through blocking capacitors C3 and C4. C2 is usually the plate supply bypass capacitor.

Two Tube Paraphase Amplifier

A two tube paraphase amplifier may utilize a single tube as a regular amplifier and a second tube as a phase inverter, or these functions may be performed by two sections of the same tube. A two tube paraphase amplifier is shown in Figure 21. V1 operates as a conventional amplifier having normal gain, and V2 operates as a *phase inverter*, the input of which is reduced to the same value as the input

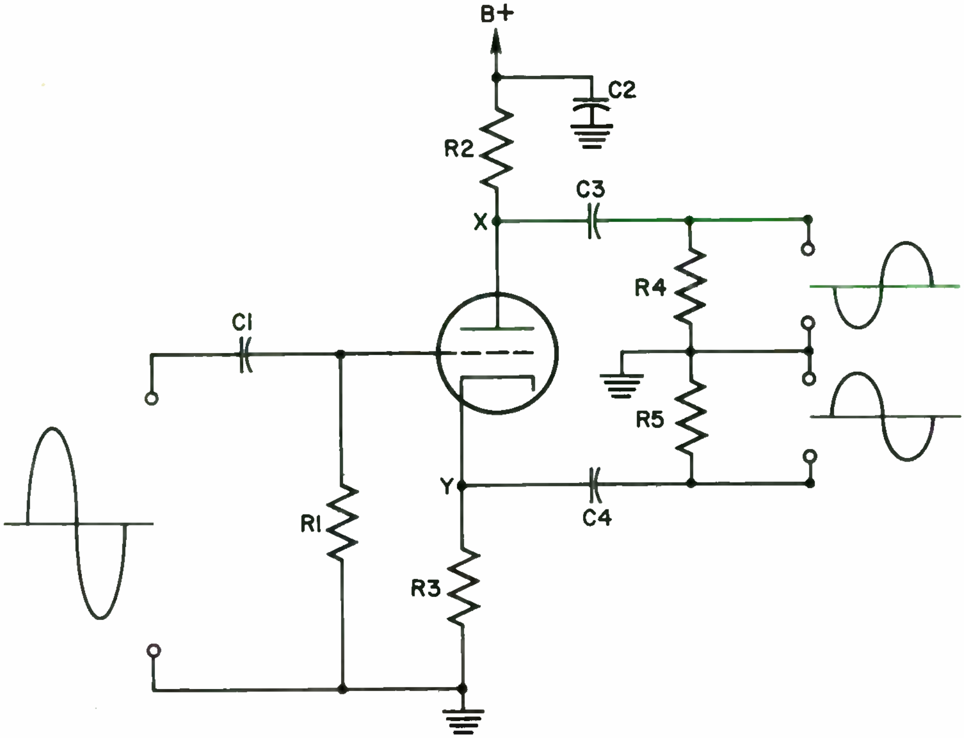


Figure 20 - A single tube paraphase amplifier.

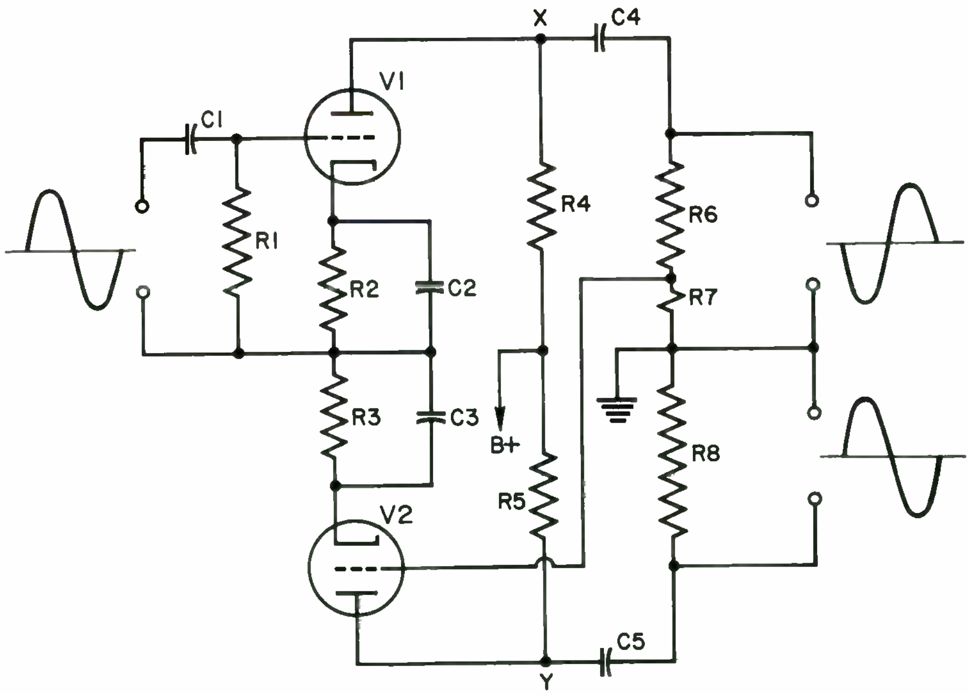


Figure 21 - A two tube paraphase amplifier.

of V1. Thus, V2 amplifies the signal as much as V1 and the output is essentially symmetrical about the zero-voltage reference line.

A positive-going signal on the grid of V1 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 C4 to resistors R6 and R7. The grid input to V2 is tapped down on resistors R6 and R7 to feed the proper magnitude of negative-going signal to V2. For example, if V1 and its associated circuit has a voltage gain of 50, the resistance of R7 should be one-fiftieth of the total value of R6 plus R7. At the instant a positive-going signal is applied to the grid of V1, a negative-going signal is thus applied to the grid of V2. The positive potential at point Y is increased, and a positive-going signal is applied to resistor R8, through coupling capacitor C5. At the same time the negative-going signal appears across resistors R6 and R7.

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. This circuit is widely used as a means of driving class A push-pull audio power amplifiers, but the adjustments are somewhat critical.

CATHODE FOLLOWER

7 The cathode follower is a single-stage class A degenerative amplifier whose output appears across the unbypassed cathode resistor. The high input impedance (and with no grid current flowing) and the low output impedance make it particularly useful for matching a high-impedance source to a low-impedance load.

One of the principal advantages of a cathode follower is its use in matching a high impedance to a low impedance. Thus, it can take the voltage developed across a high impedance and supply a low impedance load with only a slightly less voltage but with a correspondingly large increase in current. One or more of the circuit elements of a cathode follower may be varied to achieve a more precise impedance match if the match is critical.

The cathode follower has definite advantages in certain cases, where an increase in power output is required, at a lower impedance. But the voltage gain of the stage is always less than one.

A conventional cathode follower is shown in Figure 22. Under no-signal condition, a certain amount of plate current flows through R_k, and this flow establishes the normal bias. When a positive-going signal is applied to the grid, the plate current increases. The increase in the current flow causes an increase in the voltage drop across R_k, giving the cathode a higher positive potential with respect to ground than it had under the no-signal condition. When a negative-going signal is applied to the grid, the opposite effect occurs. Thus, the *output polarity follows the polarity of the input* voltage applied between grid and ground.

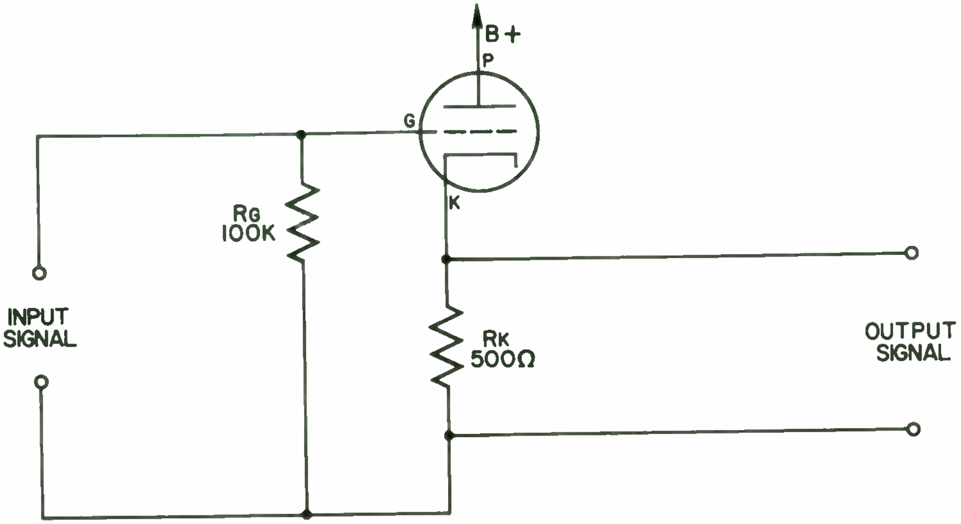


Figure 22 - A basic cathode follower circuit.

TRANSISTOR AMPLIFIERS

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 (Fig. 23). The class A biased transistor has a continuous flow of collector current during the entire cycle, whether a signal is present or not, which corresponds with the action of the electron tube. They may be operated in this manner, in either single-ended or push-pull circuits. A basic class A audio amplifier is shown in Figure 24.

Class B amplifiers can be biased either for collector current cutoff or for zero collector voltage (Fig. 25). 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 collector 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.

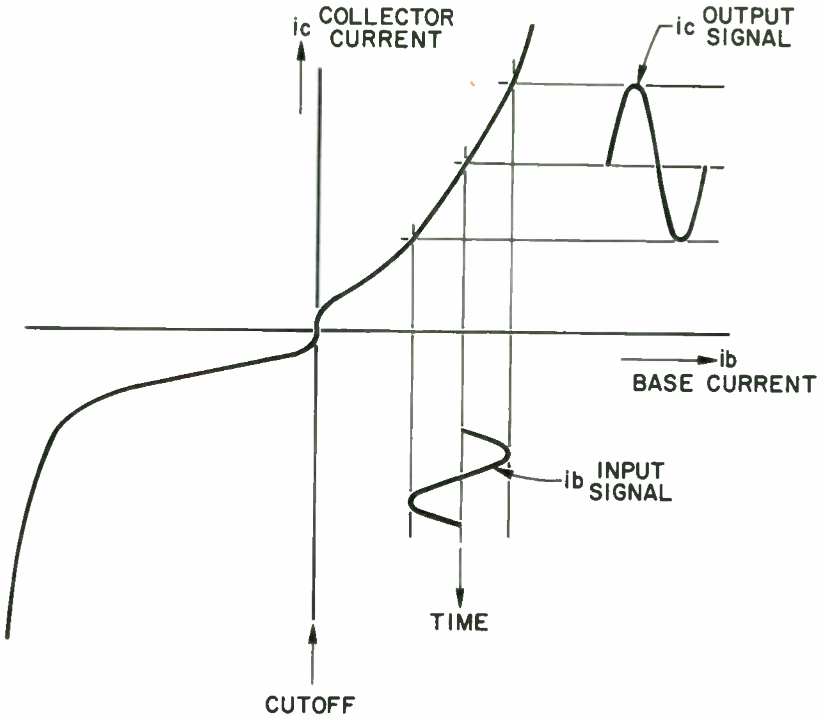


Figure 23 - Class A transistor amplifiers are operated on the linear portion of the curve. Output current flows during the entire cycle.

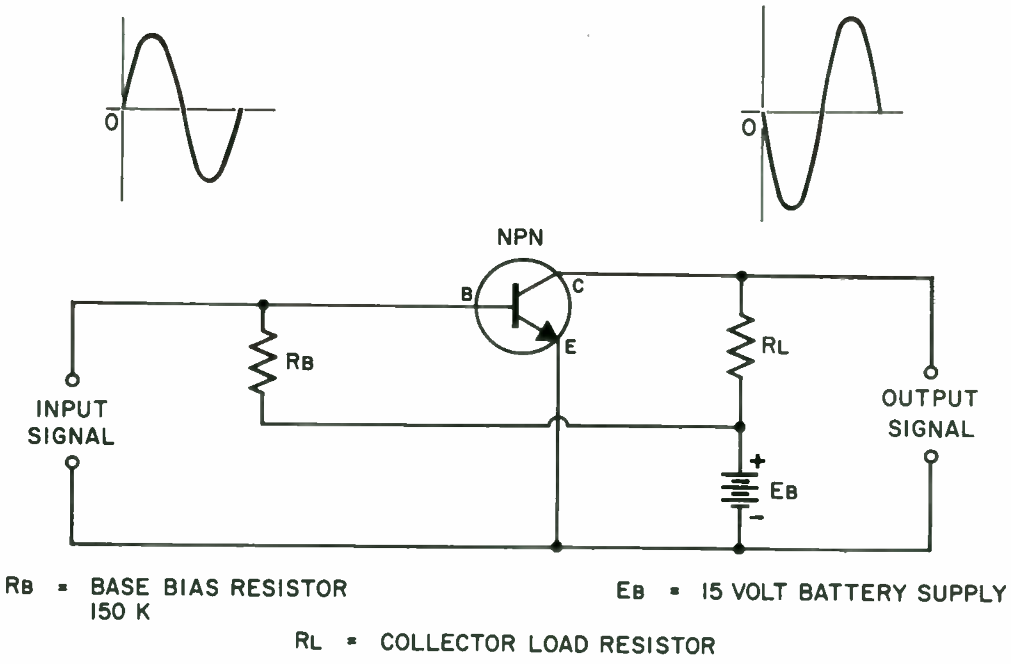


Figure 24 - NPN transistor circuit operated as a Class A audio amplifier.

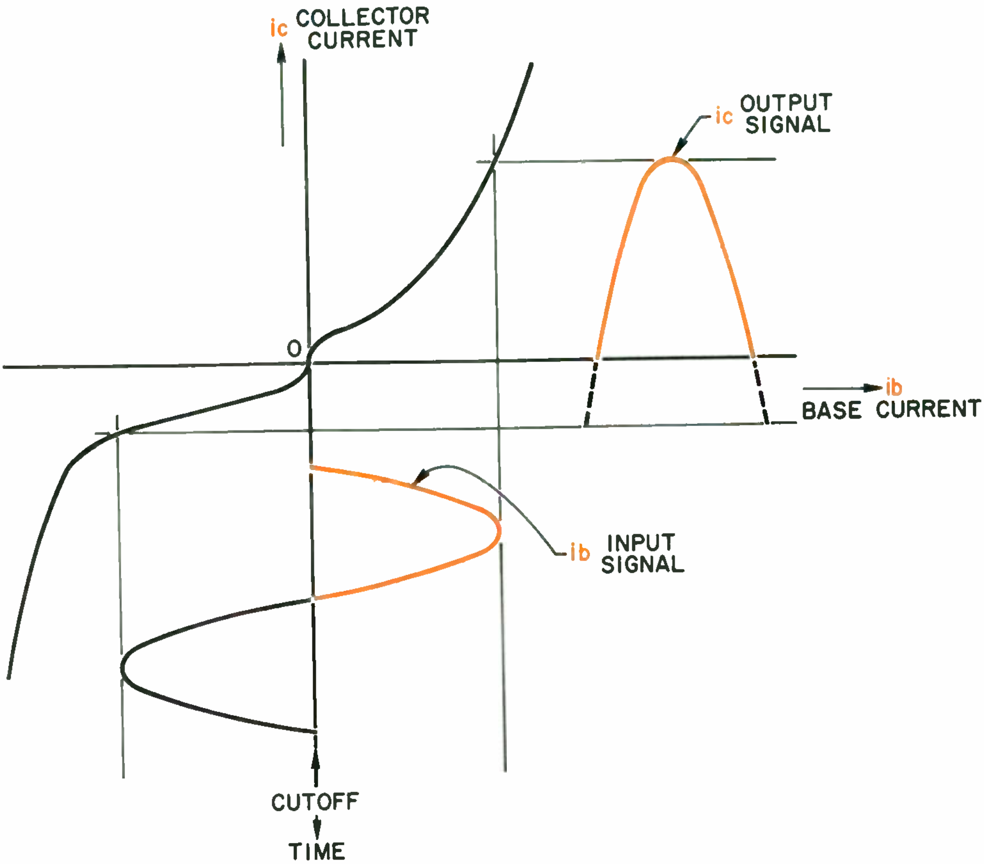


Figure 25 - A Class B amplifier is biased so that output current flows for approximately one-half of the input cycle.

The class AB transistor amplifier is biased so that the collector current or voltage is zero for less than a half-cycle of operation (Fig. 26). 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 (Fig. 27). They are used however, for RF applications.

Transistor amplifier stages may be connected in cascade (Fig. 28). Transistors Q1 and Q2 are PNP junction transistor audio voltage amplifiers, and Q3 is a PNP junction transistor power amplifier. Each stage shown is known as a single ended stage including the last power amplifier stage.

Single Ended

Transformer T1 is a step-down matching transformer that could couple a high or low impedance microphone, or a phonograph pick-up to a

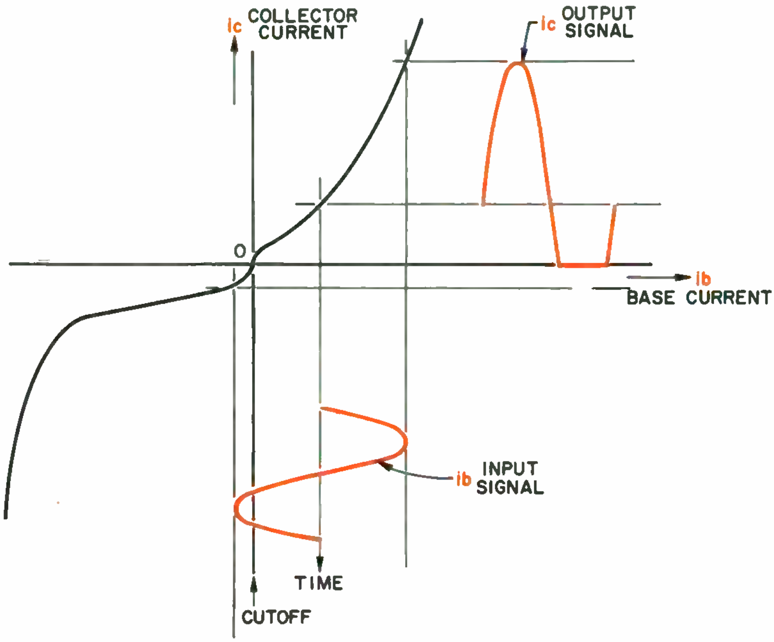


Figure 26 - Class AB amplifiers operate for more than one-half cycle but less than a full cycle.

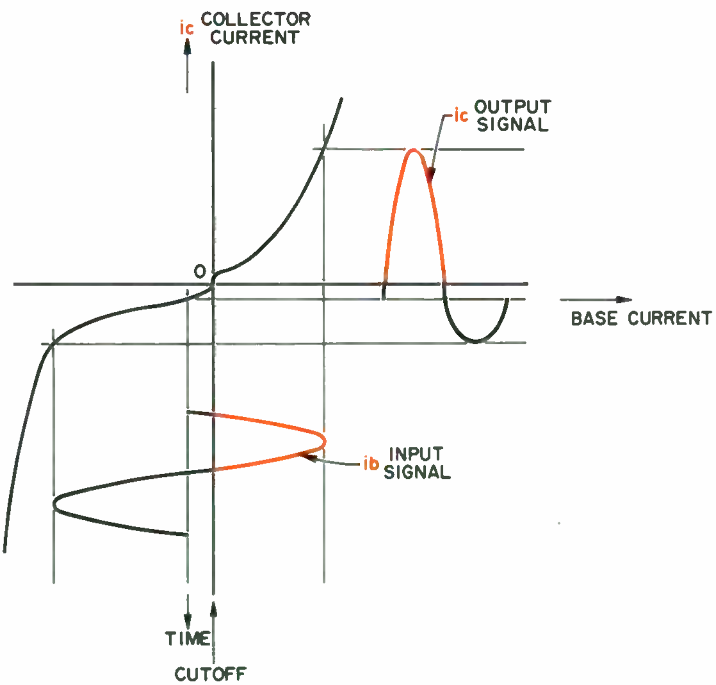
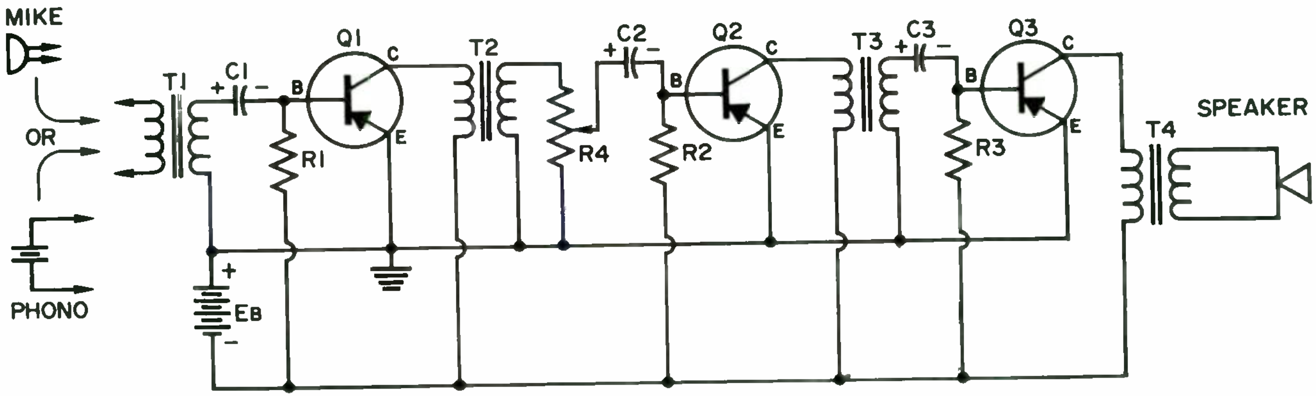


Figure 27 - A Class C amplifier is operated only on the positive portion of the input signal. Due to their high degree of distortion they are not used in AF amplifiers.



T1	— Transformer must be chosen to match the type of input.
T2, T3	— Interstage coupling transformers.
T4	— Output Transformer.
C1, C2, C3	— DC blocking and coupling capacitors.
Q1, Q2	— PNP audio voltage transistors.
Q3	— PNP power transistor.
R4	— Volume control.
R1, R2, R3	— Base bias resistors.

Figure 28 - A Single ended, three stage transistor amplifier.

low-impedance input circuit. Interstage coupling transformers T2 and T3 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 Q1 may be 2000 ohms and the input impedance of Q2 may be 1000 ohms. Transformer T4 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 speaker. Capacitors C1, C2, and C3, block the DC bias from the secondaries of T1, T2, and T3, and couple the signal to the input circuits. R4 serves as a volume control for the amplifier, with the volume increasing as the arm is moved toward the upper end of T2. Resistors R1, R2, and R3 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.

Push Pull

Transistor power amplifiers are usually connected in push-pull because of the advantages over single-ended operation (Fig. 29). The most important advantages are the reduction in distortion and the removal of DC core saturation from the output transformer.

A three stage transistor amplifier used in a commercially built record player is shown in Figures 30 and 31. The first figure shows the schematic diagram, the value of the components, and other data that are helpful to a service technician. Note that the schematic indicates the value of the voltages under a *no signal* condition, which means that they are DC voltages.

Due to variations in the value of some of the other components in the circuit, the power supply resistor R10 can vary. This is pointed out in the note in the lower left hand corner.

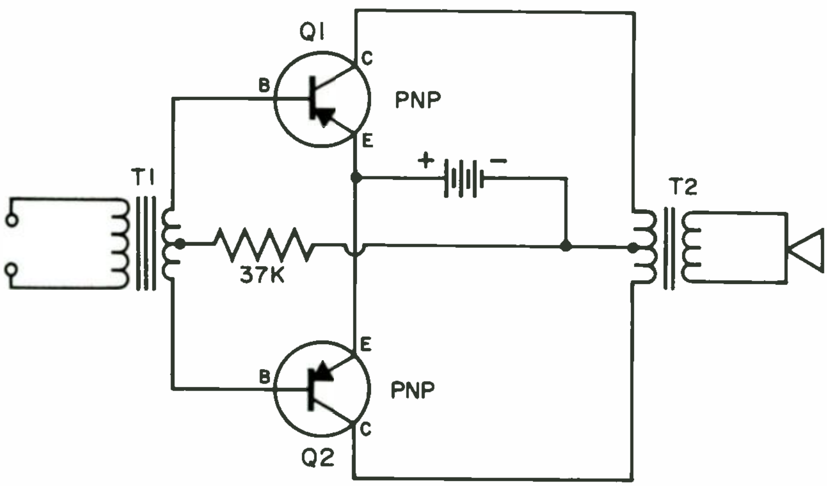
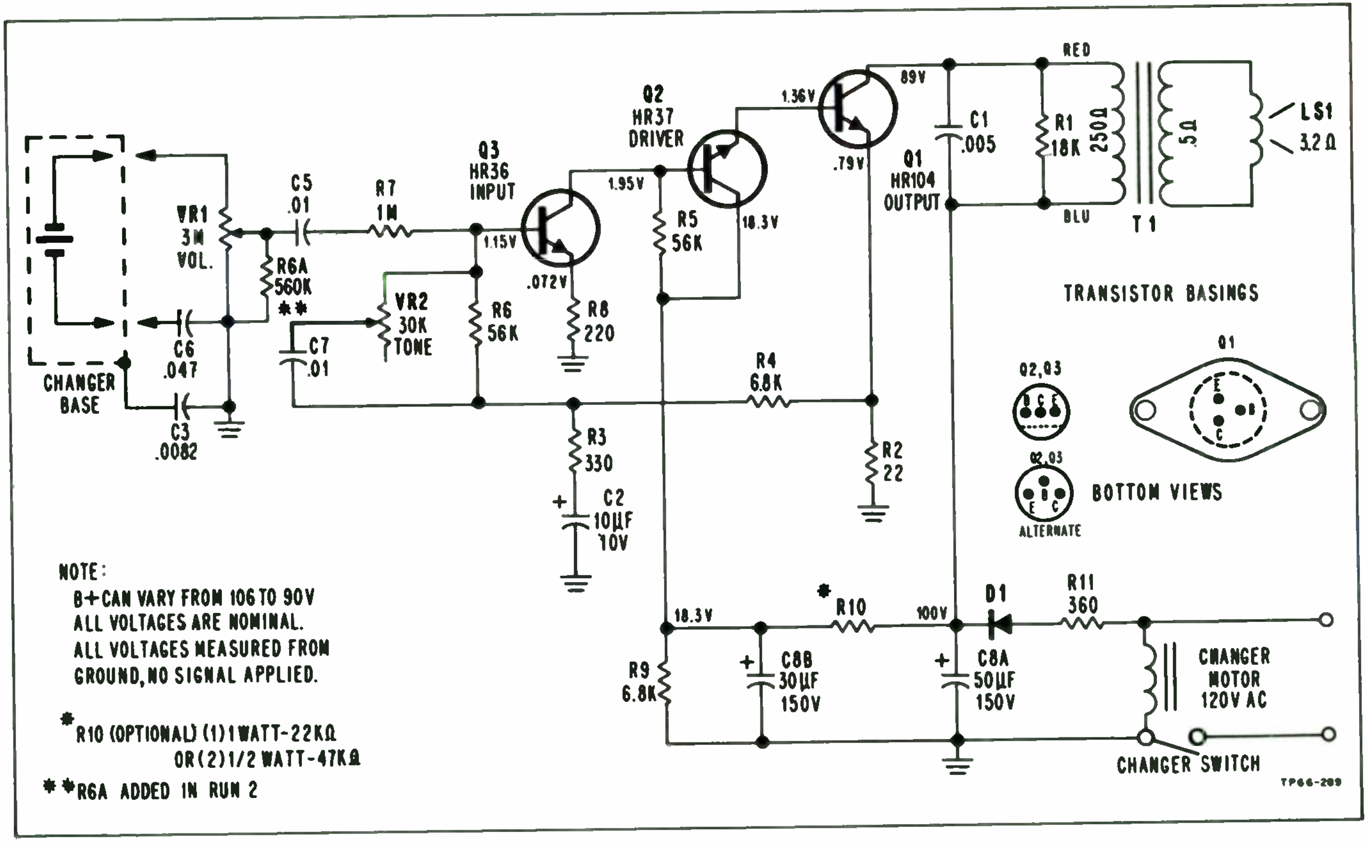
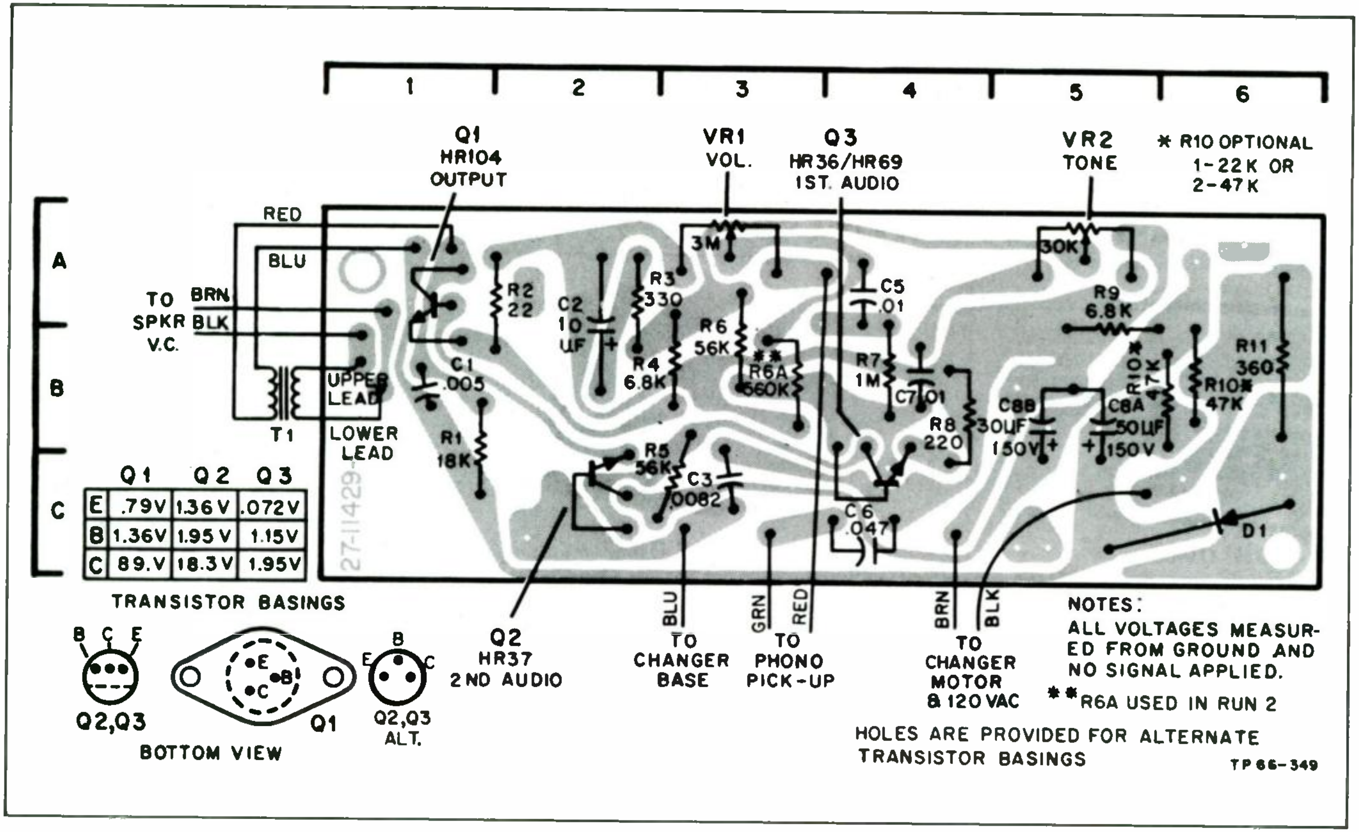


Figure 29 - A push-pull transistor amplifier.



Schematic–Models Q1460 & Q1462

Figure 30 - Schematic diagram of a three-stage transistor amplifier used in a commercial record player. Courtesy of Philco-Ford.



Bottom View-Perma Circuit Panel—Models Q1460 & Q1462

Figure 31 - Location of the components on the printed circuit (PC) board of the three stage monaural amplifier of Fig. 30. Courtesy of Philco-Ford.

Also a later version of these record players contains an added resistor R6A to improve the audio response.

The actual printed circuit board is illustrated in Figure 31, which is of great assistance in servicing as the parts may now be easily located. This manufacturer also gives the location of each part, by listing its cross-index number in the parts lists, like a road map locates a town (Fig. 32). As an example, C5 would be found at the intersection A4, D1 at C6, R6 at B3, etc. The colors of the wires leading to components not on the PC board (printed circuit board) are also identified whenever it is important to control the polarity. The function of most of the parts is also indicated on the schematic and on the parts list.

A push-pull transistor amplifier (Figs. 33 and 34) is similar to the previous single-ended amplifier, except for the two PNP's in the output. This amplifier is part of a combination type of record player, designed to operate on 120 volts AC or a 12 volt self contained battery. The specifications state that it has an audio power of 2 watts.

STEREO AMPLIFIERS

The stereophonic reproduction of sound, commonly called stereo, produces a much more lifelike presentation of an orchestra than a monaural signal. A stereo recording of orchestral music is produced by placing a microphone on the left side of the stage, and one at the right side. These two audio signals are kept entirely separate until each one is placed on a master stereo record, or they are combined into a composite signal for transmission as an FM stereo signal.

As each signal may be picked up separately by the *stereo pick-up arm* from a stereo record player, each signal must be amplified individually and delivered to a separate speaker. The FM stereo receiver is also able to separate the transmitted signal picked up by the microphone on the left of the stage, amplify it, and deliver it to a speaker placed on the left side of a room.

The audio signal from the right side of the stage is also amplified separately by the FM receiver and delivered to the speaker on the right. Then the sounds coming from each speaker combine to give both direction and depth to the music being reproduced.

A stereo record player with its stereo amplifier system (Figs. 35 and 36) is really two separate but complete amplifiers, with each amplifier supplying audio power to its own speaker. The circuit diagram in Figure 35 should be compared with the schematic in Figure 30. If either the Left Channel or the Right Channel is compared to Figure 30, it can be seen that they are identical, except for the change in value of a few components.

There are certain other components that have been added to the stereo system, such as a single shaft volume control, a single shaft tone control, and a balance control to equalize the sound level from each speaker. The two monaural amplifier circuits are identical electrically even though the

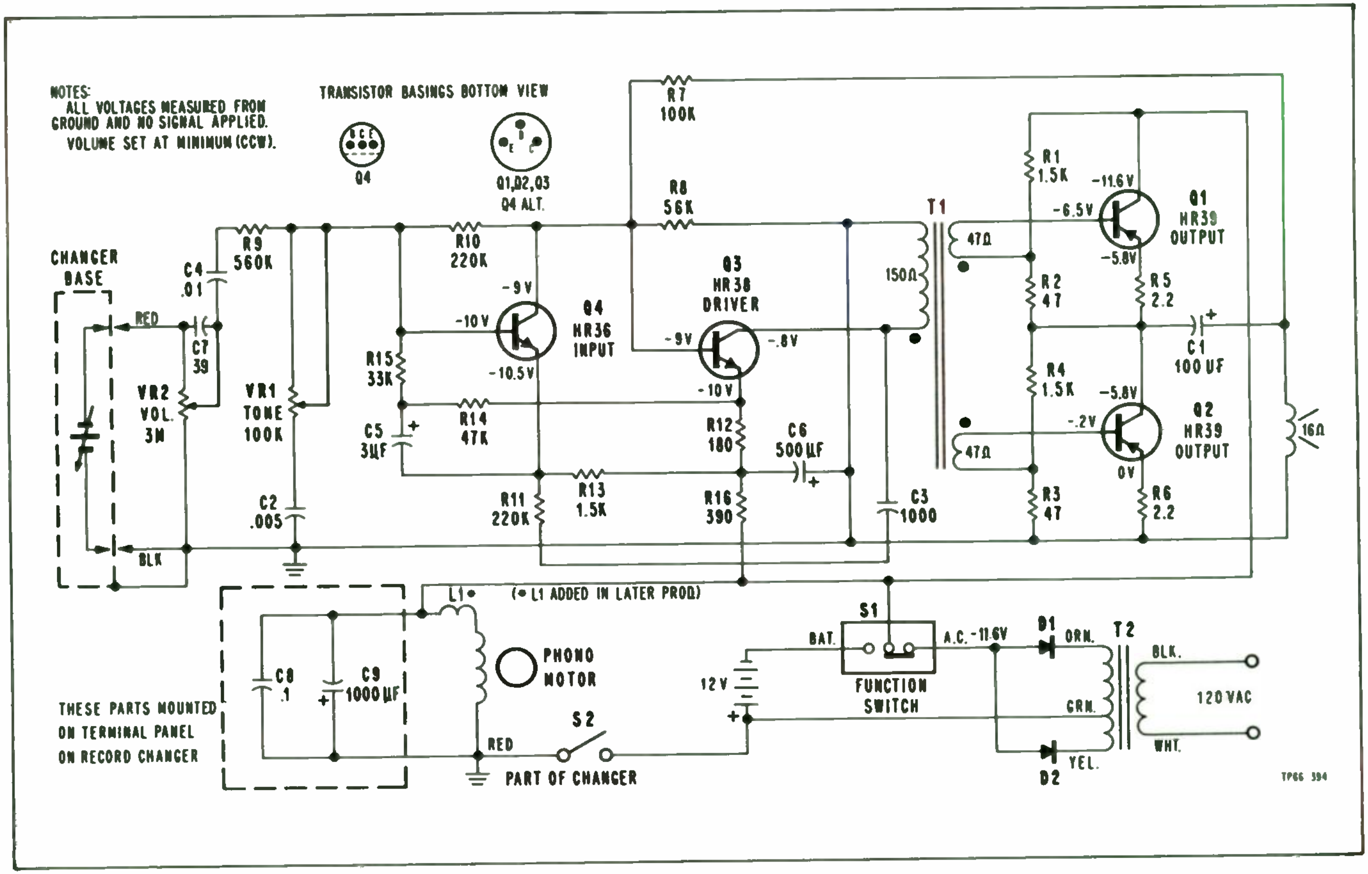
Q1460BR, Q1462BK PORTABLE PHONOGRAPH

New parts not previously carried are shown in bold face type

SYM-BOL	LOCA-TION	DESCRIPTION	SERVICE PART NO.
		CAPACITORS	
C1	B1	.005 mf, transf. pri.	30-1294-34
C2	A2	10 mf/10V, D.C. F.B. bypass	**30-2610-5**
C3	C3	.0082 mf, changer isol.	**30-4708-8**
C5	A4	.01 mf, input base	30-1294-6
C6	C4	.047 mf, pickup isol.	**30-4698-11**
C7	B4	.01 mf, input base	30-1294-6
C8A,B	B5	50-30 mf/150V, filter input	30-2585-18
		DIODES	
D1	C6	Rect.	34-8054-10
		SPEAKERS	
LS1		4 inch, 3.2 ohms (Q1460)	36-1716-5
LS1		2" x 6", 3.2 ohms (Q1462)	36-1704-3
		TRANSISTORS	
Q1	A1	HR104, output	**34-6002-21**
Q2	C2	HR37, driver	**34-6001-70**
Q3	C4	HR36/HR69	**34-6001-69**
		RESISTORS	
R1	B1	18K, transf. shunt	
R2	A2	22 ohms, output emit.	
R3	A2	330 ohms, feedback AC/DC	

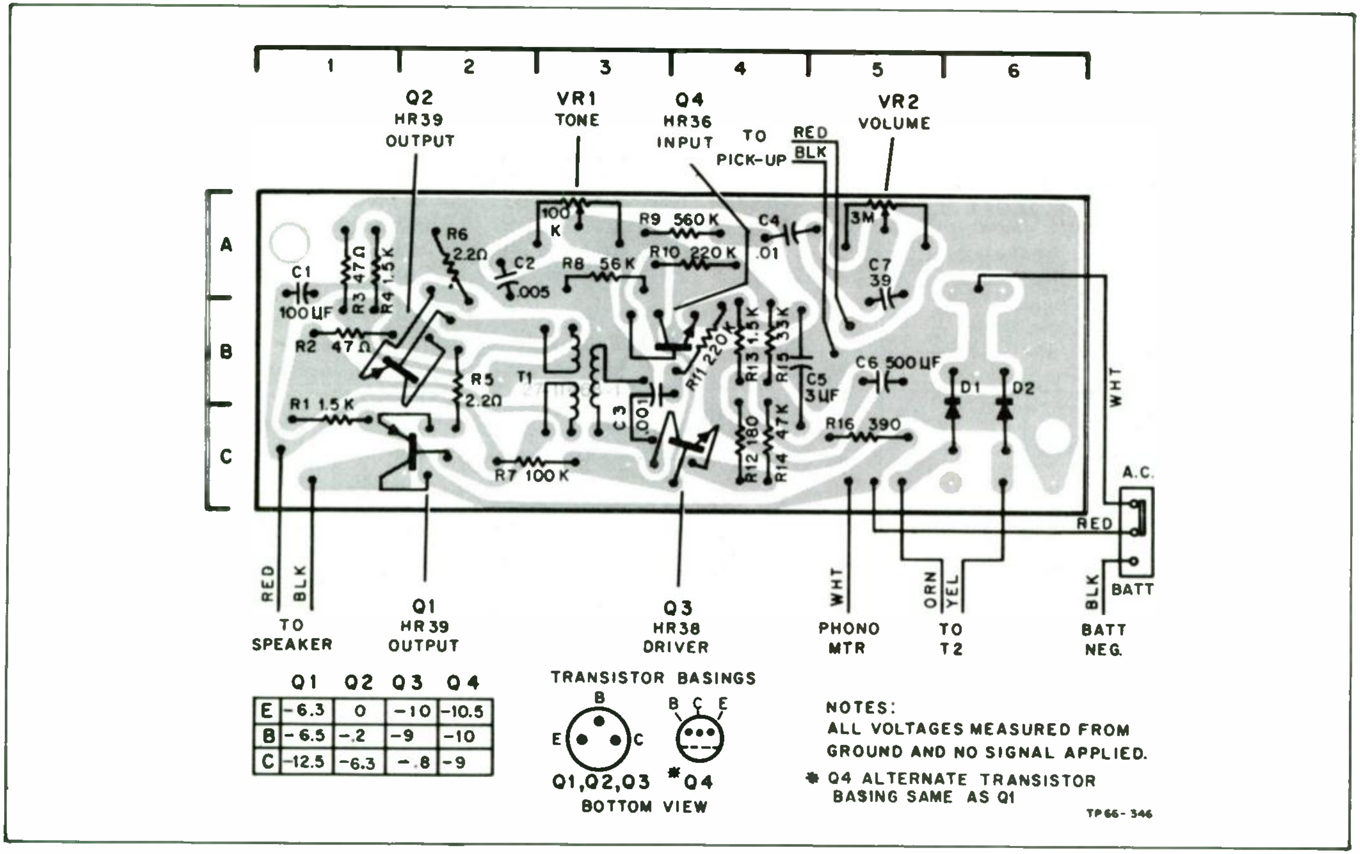
SYM-BOL	LOCA-TION	DESCRIPTION	SERVICE PART NO.
R4	B3	6.8K, feedback AC/DC	
R5	C2	56K, driver C-B	
R6	B3	56K, feedback AC/DC	
R6A		560K, vol. shunt (run 2)	
R7	B4	1 meg, input base	
R8	B4	220 ohms, input emit.	
R9	A5	6.8K, B+ stabilizing	
R10A,B	B5	22K, B+ drop (optional (2) 47K ohms)	
R11	B6	360 ohms, fuse ohm	**33-1366-17**
		SWITCHES	
S1		On/off power (Part of Changer)	
		TRANSFORMERS	
T1	B1	Output	**32-10036-3**
		CONTROLS	
VR1	A3	3 meg, volume	**33-5608-19**
VR2	A5	30K, tone	**33-5608-21**
		MISCELLANEOUS	
		Insulators, output xistors	**54-6860-2**
		Panel, perma-ckt.	**38-10267**

Figure 32 - Parts list for the portable record player shown in Figures 30 and 31. Courtesy of Philco-Ford.



Schematic—Model Q1464

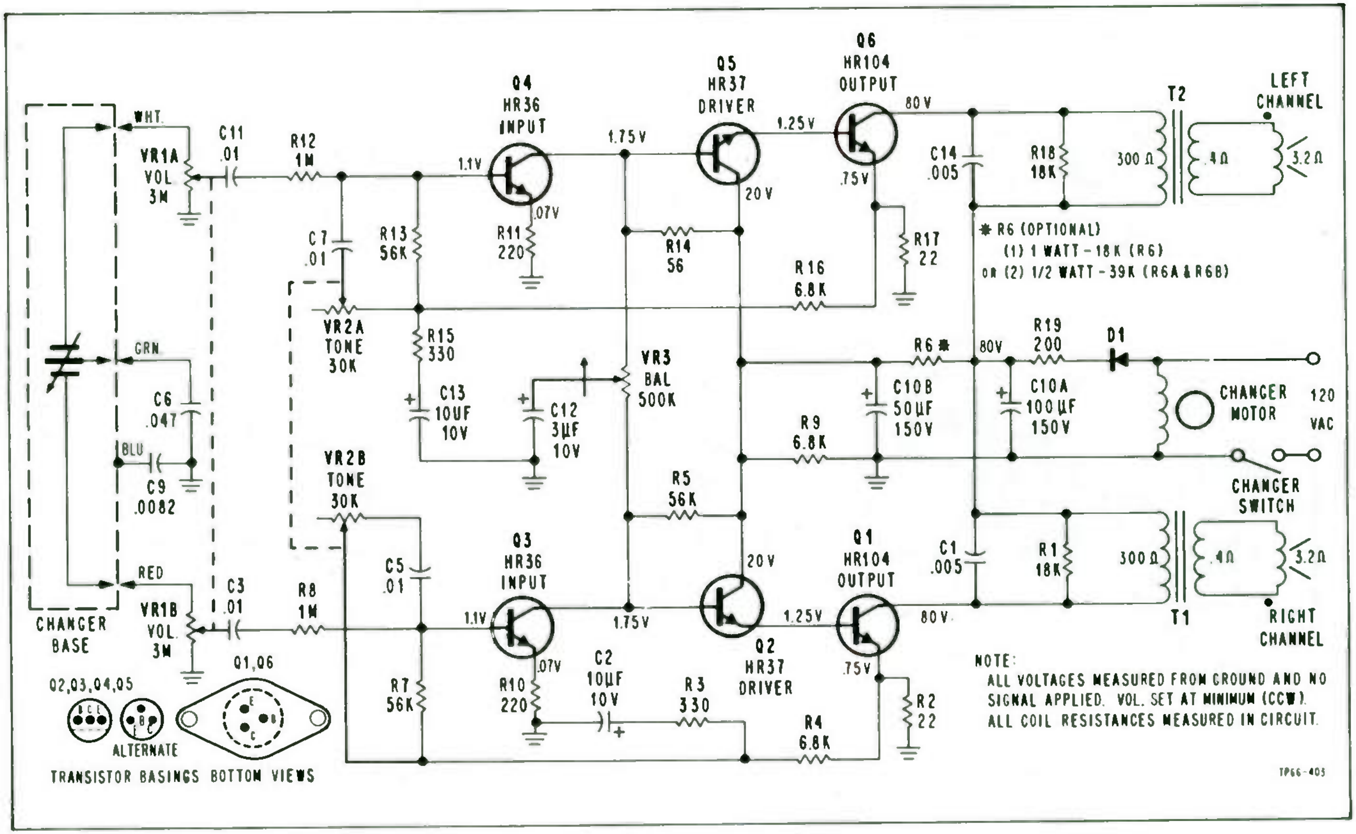
Figure 33 - A three-stage push-pull transistor amplifier, designed to use batteries for portable use or the conventional 120 volt AC supply. Courtesy of Philco-Ford.



	Q1	Q2	Q3	Q4
E	-6.3	0	-10	-10.5
B	-6.5	-.2	-9	-10
C	-12.5	-6.3	-.8	-9

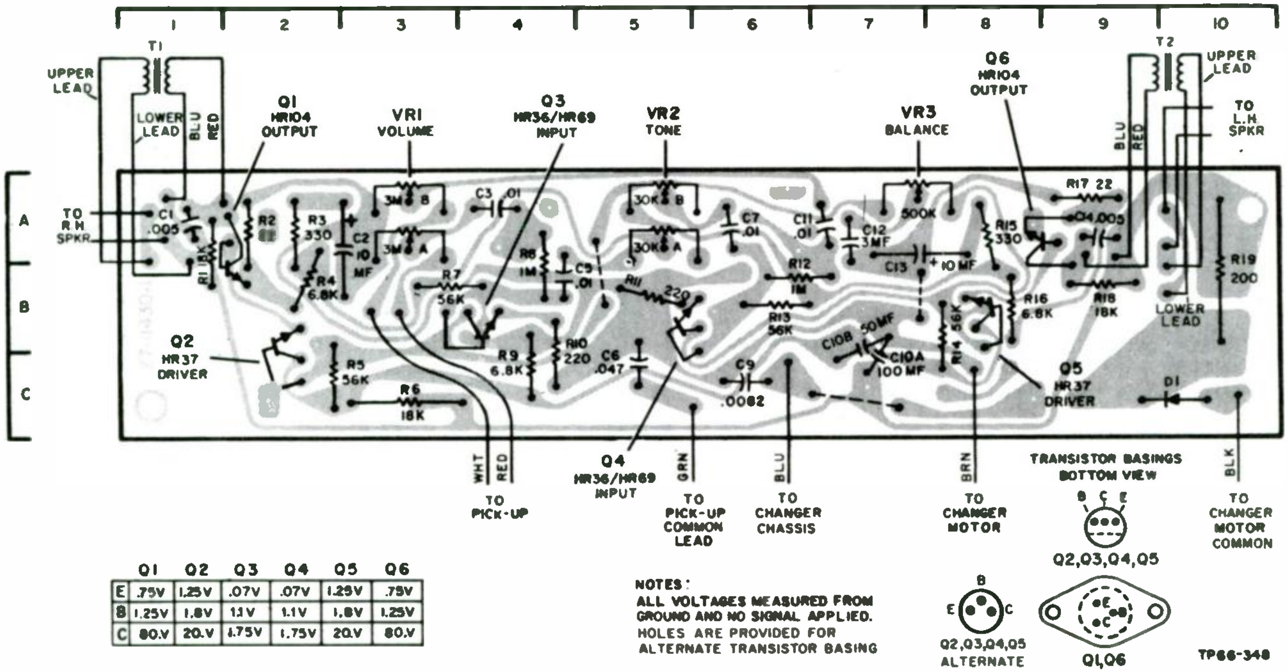
Bottom View-Perma Circuit Panel—Model Q1464

Figure 34 - PC board for the circuit shown in Figure 33. Courtesy of Philco-Ford.



Schematic–Models Q1466 & Q1468

Figure 35 - A stereo record player using identical amplifiers. Each amplifier is identical and consists of a three-stage direct coupled amplifier. Courtesy of Philco-Ford.



	Q1	Q2	Q3	Q4	Q5	Q6
E	.75V	1.25V	.07V	.07V	1.25V	.75V
B	1.25V	1.8V	1.1V	1.1V	1.8V	1.25V
C	80.V	20.V	1.75V	1.75V	20.V	80.V

NOTES:
ALL VOLTAGES MEASURED FROM GROUND AND NO SIGNAL APPLIED.
HOLES ARE PROVIDED FOR ALTERNATE TRANSISTOR BASING

Bottom View-Perma Circuit Panel—Models Q1466 & Q1468

Figure 36 - The printed circuit board of Figure 35 containing two complete amplifiers for stereo reproduction. Courtesy of Philco-Ford.

components might be located differently on the schematic drawing. A simple retracing of a portion of a circuit that appears confusing will usually clarify it.

AMPLIFIER SENSITIVITY

Microphonic effects are the result of slight vibrations in the tube elements. These vibrations can cause variations in the plate current and these are amplified in each succeeding stage and appear in the output of audio amplifiers. These slight displacements of the tube elements may be caused either by physical vibration of the chassis or by the sound vibrations emitted by the speaker.

The obvious remedy is to employ some method that will insulate the tube or tubes from the vibrating source. Some tubes, however, are less susceptible to microphonics than others, and occasionally simply replacing a tube will cure the trouble.

Noise in audio and video amplifiers may be caused by faulty or dirty contacts, faulty components such as resistors or capacitors or *thermal agitation noise.* Thermal agitation noise occurs because all electrical conductors contain electrons moving at random. Some of these electrons move at random even if there is an impressed voltage across the conductor. If by chance at any given instant more of these electrons move in one direction than in another, this creates a voltage. When amplified, this accompanying voltage results in thermal agitation noise.

Also inherent in electron tubes are other noises such as *shot effect*, which results from a variation in the rate of electron emission from a cathode; *gas noise*, which results from a variation in the rate of production of ions; and *secondary emission noise*, which results from a variation in the rate of production of secondary electrons. There are also other variations that produce noise in the output of a receiver.

In the final analysis, tube noise is the limiting factor that determines the ultimate sensitivity of an amplifier.

POWER RATING AND DISTORTION

The output of an audio amplifier is rated in watts. This wattage rating is the power that is delivered to the speaker(s), but as speakers are inefficient devices, most of this electrical power is not converted to sound power or acoustic power. A rating in watts is not fully descriptive of the capabilities of an audio amplifier, as we must also know the level of distortion contained in the output signal.

The distortion produced by the amplifier is a distortion of the harmonics contained in speech or music. Normal speech and music contain many groups of fundamental frequencies together with harmonics of these frequencies and any large amount of distortion becomes noticeable. A well designed amplifier should not have more than 1% of distortion, but simply stating it this way is meaningless. What is meaningful is a statement of the percentage of distortion at a given power level.

We have used, as an example, the distortion of the harmonics in describing the distortion that might be contained in the audio output signal. This effect is more properly called *harmonic distortion,* to be specific and to distinguish it from a poorly designed amplifier that may also produce *intermodulation distortion.* This is caused by poor design. The amplifier itself creates new frequencies that are the sum or difference frequencies.

One of the specifications of an audio amplifier system should state the amount of power in watts that it will produce, and at the same time give the amount of distortion, in percentage, that will be produced at that power level. A properly designed audio amplifier should deliver its rated output in watts at a maximum of 1% harmonic distortion.

DECIBELS

Power Ratio

The decibel is a measure of the *change in intensity* of sound. It is also used in many other measurements of power in electronic equipment, but it is of interest to us here, in measuring the *change in power* in audio amplifiers.

The word *change* has purposely been used twice to emphasize that a decibel is not an absolute unit of measurement like a watt, a yard, or a speed like 20 miles an hour. If we increased the speed of a car we were driving from 20 miles per hour to 40 miles an hour, we could say that we had changed our speed, and more properly we'd say we had doubled our speed. We could also say that the ratio of the second speed to the first speed — or 40 to 20 miles an hour — was in the ratio of 2 to 1. Likewise, an increase to 60 from 20 miles an hour is a ratio of 3, and 80 to 20 is a ratio of 4.

This ratio of a change in speed is similar to the ratio of a change in the electrical power level from one condition to another. This change, or this ratio, from one power level to another level has been given the name of decibel. A decibel is one-tenth of a bel, and decibel is used more than bel as decibel provides a larger number to describe the ratio being discussed.

The bel is a unit of gain equivalent to a 10 to 1 ratio of power gain. Thus the gain in bels is the number of times that 10 is taken as a factor to equal the ratio of the output power of an amplifier to the input power. For example, if the output power is 100 times the input, the ratio is 100 to 1, or 10^2 to 1. The gain is, therefore, 2 bels; and the gain in decibels (DB) is 10 times 2, or 20 decibels, (a decibel is equal to one-tenth of a bel).

Where the power ratio is 1000 to 1, it may also be written as 10^3 to 1, or 3 bels; and the gain in DB is 10 x 3, or 30 decibels.

Where the power ratio has been increased 10,000 times, that gain is 10^4 to 1, or 4 bels and the gain in decibels equals 40 DB. This relationship between the numbers can be extended and readily associated in the table below.

A Table Showing the Relation Between DB and Power Ratio

Power Ratio	No. of 10 factors	No. of BELS	No. of DB
1,000,000 to 1	10^6	6	60
100,000 to 1	10^5	5	50
10,000 to 1	10^4	4	40
1,000 to 1	10^3	3	30
100 to 1	10^2	2	20
10 to 1	10^1	1	10
1 to 1	10^0	0	0

The number of 10 factors contained in any ratio of the output power (P2) to the input power (P1) is the logarithm of the ratio to the base 10. The gain in decibels may, therefore, be expressed conveniently as:

$$DB = 10 \log_{10} \frac{P2}{P1} \qquad (1)$$

The human ear responds to ratio changes in intensity rather than to changes in absolute value. In other words, the ability of the human ear to detect changes in the intensity of sound is much greater at low levels of intensity than it is at high levels. A change in power level of 2 DB is barely perceptible to the ear, and for this reason attenuators in audio systems are frequently calibrated in steps of 1 DB.

Because the ear responds logarithmically to variations in sound-intensity levels, any practical system for measuring sound-intensity levels must necessarily vary logarithmically. The decibel system of measuring power levels is based on this concept.

Since the gains or losses in a system are expressed logarithmically, they are simply added or subtracted to determine the overall gain or loss. For example, transmission lines introduce a loss in power, amplifier stages produce a gain, and attenuators introduce a loss. The final result is the algebraic sum of the various gains and losses. A DB gain or loss is readily determined by the use of equation (1).

It is not necessary for the student to become familiar with logarithms or to attempt to determine the actual change in power levels of any equipment being worked on. This explanation of the use of decibels has been given solely so the student will understand how the term is applied in electronics. Additional background information about the application of decibels, the use of current or voltage ratios is explained next. It will help to clarify the point being made: decibels are ratios between two power levels.

Current and Voltage Ratios

Even though the decibel is primarily a unit of measure of power ratios, it can be used to compute current ratios as well, provided the resistances through which the currents flow are taken into account. The DB gain or loss expressed in terms of the currents and resistances is determined as follows:

$$DB = 20 \log_{10} \frac{I2\sqrt{R2}}{I1\sqrt{R1}} \quad (2)$$

where I2 and I1 are respectively the output and input currents in amperes, and R2 and R1 are respectively the output and input resistances in ohms. Thus, if the two currents and resistances are known, the DB gain or loss can be determined by substitution in equation (2). If the resistances are equal, they may be canceled out.

The same reasoning also applies to the voltage ratio provided the resistances across which the voltages are applied are properly considered. The equation for DB gain or loss when voltages and resistances are employed directly is determined as follows:

$$DB = 20 \log_{10} \frac{E2\sqrt{R1}}{E1\sqrt{R2}} \quad (3)$$

where E2 and E1 are respectively the output and input voltages, and R2 and R1 are respectively the output and input resistances in ohms.

If the voltages and resistances are known, the DB gain or loss may be determined by direct substitution in equation (3). If the resistances are equal they may, of course, be canceled out.

SUMMARY

Power amplifiers develop power to operate a load, as a speaker in an audio amplifier system. The power amplifier is designed to operate class A, B, AB, or C.

The class A amplifier allows plate current to flow throughout the entire input cycle, while class B amplifiers allow plate current to flow up to one-half of each grid cycle. Class AB amplifiers allow plate current to flow for more than one-half of the input cycle, and class C amplifiers have plate current flow for much less than a half-cycle.

Beam power tubes used in push-pull audio amplifiers can produce considerably more power output than the same tube operated singly. A push-pull amplifier must have input signals that are of opposite polarity, but of equal amplitude. Balancing networks are used to equalize the power output of each tube in a push pull circuit, and signals of opposite polarity may be produced by paraphase amplifiers, cathode followers, etc.

Transistor amplifiers may be operated in class A, B, AB, or C, similar to vacuum tubes. Transistors are used in many commercial record/tape/radio combinations, using either monaural or stereo amplifiers. They are designed to have adequate power output with a minimum of harmonic and intermodulation distortion. A change in power is measured in decibels.

TEST

Lesson Number 42

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 52-042-1.

1. Single-ended audio power amplifiers are always operated
   A. Class A.
   B. Class B.
   C. Class AB.
   D. Class C.

2. The subscript 2 after an amplifier designated as a "Class AB2," indicates that grid current
   A. flows only after cut off.
   B. flows at a value equal to the cathode current.
   C. flows during some parts of the input cycle.
   D. does not flow.

3. The transformer that matches the impedance of the plate circuit to the impedance of a speaker is called a/an
   A. audio transformer.
   B. speaker transformer.
   C. output transformer.
   D. all of the above.

4. A beam power tube will
   A. deliver less power output than a triode or a pentode.
   B. not suppress secondary electrons from the plate.
   C. deliver more power output for a given input voltage than a triode.
   D. not have the screen grid wires in line with the grid wires.

5. Balancing networks are used to insure that
   A. no RF is present in push-pull amplifiers.
   B. the amplifier operates at resonance.
   C. the outputs of each tube in a push-pull amplifier are equal.
   D. none of the above.

6. A single input to a paraphase amplifier will produce
   A. two output signals that are equal and in phase.
   B. two output signals that are equal but 180° out of phase.
   C. two output signals without any polarity inversion.
   D. all of the above.

7. A cathode follower is defined as an amplifier that
   A. has a high input impedance and a low output impedance.
   B. produces the effect of a degenerative amplifier.
   C. takes the output across the cathode resistor.
   D. all of the above.

8. Class B transistor audio amplifiers
   A. are never used.
   B. can use a single transistor.
   C. are always designed to operate at a low efficiency.
   D. are operated in push-pull to avoid serious distortion.

9. A high quality audio power amplifier will
   A. not have more than 1% of harmonic distortion at rated output.
   B. have sufficient power to operate the speakers without appreciable distortion.
   C. not have any noticeable intermodulation distortion.
   D. all of the above.

10. The decibel is of importance in audio amplifiers as a measure of
   A. harmonic distortion.
   B. intermodulation distortion.
   C. change in power.
   D. change in frequency.

Notes

Notes

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ROAD TO SUCCESS

There is no "easy road" to success. You must follow basic rules and work hard at them. If you do this your future in electronics will take care of itself.

Plan your program. Set up a definite schedule of what you will do – and then follow it step by step. This requires work – lots of work. With intelligent planning and work, it doesn't take long before you see results of your efforts.

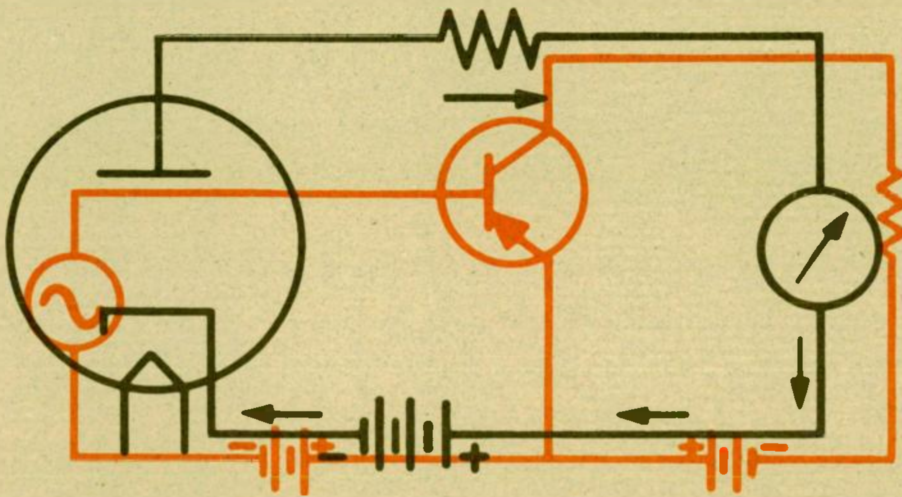
Just remember, anything worthwhile is gained with planning and carrying out the plan.

Your ASI lessons are set up in a certain order, so you advance step by step. As you advance you gain knowledge which will help you with the next step and so on. When you complete your training, you will have knowledge that nobody can take from you – knowledge that can repay you many times in increased earnings and self satisfaction – surely worth working and studying for.

S. T. Christensen

LESSON NO. 43

POWER SUPPLIES



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CONTENTS

POWER SUPPLIES

INTRODUCTION

Electronic equipment, by definition, uses either solid state devices or vacuum tubes in its operation. DC voltages are necessary for the plate and screen grids of vacuum tubes and the base, emitter and collector of transistors.

Batteries were used for years to supply power to portable equipment such as transistor radios, hearing aids and walkie-talkies. Even though these devices used only a small amount of power, batteries had to be replaced often. The high power portable equipment used today, such as portable television and stereo sets, would drain in a matter of days the best battery made. Some other means had to be found to supply the necessary DC voltage for today's modern electronic equipment.

BLOCK DIAGRAM

Figure 1 shows the block diagram of a typical electronic DC power supply. The purposes of the blocks are as follows:

Power transformer:
: Converts wall plug AC voltage to AC of a different voltage using either a step up winding or a step down winding. A step down winding is used to convert AC to low voltage AC for the filaments of vacuum tubes. The exact turns ratios of the windings used are determined by the equipment to be powered.

Rectifier:
: Converts AC into pulsating DC.

Filter:
: Removes AC variation from the pulsating DC and produces an almost pure DC.

Voltage regulator:
: It keeps the DC voltage from the power supply constant if wall plug voltage changes, or if the load requirement changes. The voltage regulator also removes any remaining AC variations (ripple) and yields pure DC.

Load:
: Represents all vacuum tube or transistor circuits connected to the DC power supply.

POWER TRANSFORMERS

Power transformers either increase or decrease AC line voltages to meet the requirements of the individual

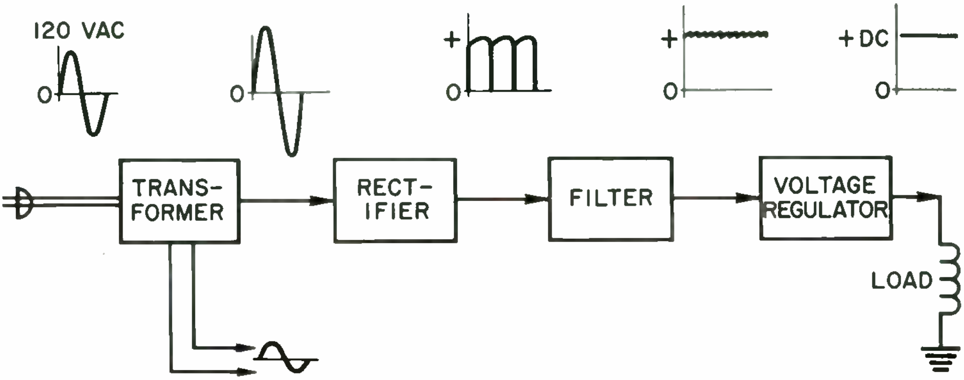


Figure 1 - Block diagram of a power supply.

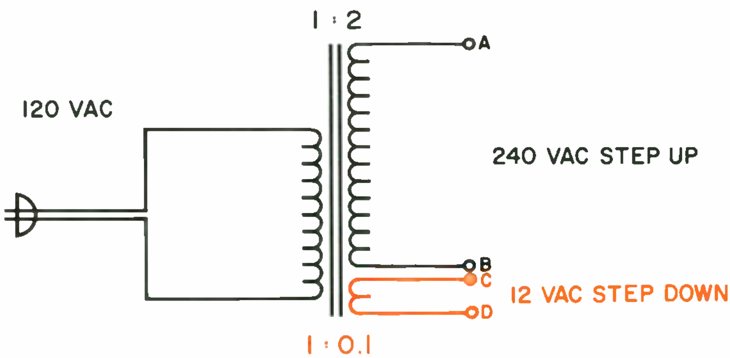


Figure 2 - Step up and step down of a transformer.

supply. A step up ratio between the primary and secondary causes the secondary voltage to be higher.

A step down ratio results in a lower voltage being developed across the secondary from that applied to the primary. Refer to Figure 2 for examples of step up and step down.

In Figure 2, secondary AB has twice the number of turns of the primary. Therefore, a step up in voltage of two to one results. The voltage across winding AB will be two times the value of that applied to the primary, or 240V AC.

Secondary winding CD (shown in color) is a voltage step down winding (Fig. 2). It has one-tenth the number of turns of the primary. It will, therefore, produce a ten to one reduction of the voltage applied to the primary. The voltage across winding CD will be 12V AC. Referring to Figure 3A, 6V AC will be developed across winding CD and 240 AC across winding AB. All AC voltages are r.m.s. (root mean square) values.

HALF-WAVE RECTIFIERS

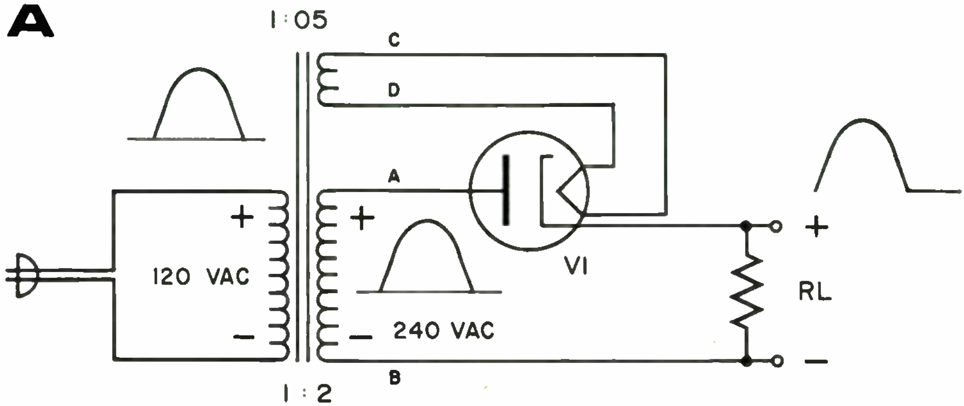
Assuming no phase inversion between primary and secondary, when the top of the primary is positive with reference to the bottom, A will be positive with reference to B. Since the transformer is a voltage source, the plate of V1 in Figure 3A will be positive, relative to the cathode, and V1 will conduct. Current flows from the negative side of the secondary (Point B) through RL, developing the polarities shown.

It then flows from V1's cathode to its plate and back to the positive side of secondary AB. The voltage across RL will be equal to the secondary voltage minus the voltage dropped across the plate to cathode resistance of V1. Figure 3B shows the resultant waveforms. The waveform across RL is called pulsating DC which is considered to be a form of DC because its current always flows in the same direction.

During the negative alternation when the top of the primary is negative with respect to the bottom, secondary point "A" is also negative. Since "B" is positive, V1 will not conduct, so the voltage across RL will equal zero.

In Figure 4, the vacuum tube has been replaced by a solid state diode (D1). This eliminates the need for a low voltage filament winding; therefore, it is omitted. Otherwise, the circuit's operation and voltage polarities are identical to those of the vacuum tube circuit of Figure 3. The waveforms illustrated in Figure 4B show the voltage, current and conduction characteristics of the circuit. The voltage across RL in Figure 4 is always positive at the rectifier's end with respect to the bottom. Since the output is taken between the top of RL and ground, the output is positive in polarity. Two methods are available by which the polarity of the output can be reversed.

1. Reverse the diode leads and the direction of current through the load reverses (Fig. 5A).
2. If, as in Figure 5B, the ground reference is placed at the top of



The step down ratio between the primary and secondary CD results in a 20 to 1 reduction from the primary voltage down to 6 volts. This winding provides current for the tube filament.

A step up in voltage occurs between the primary and winding AB by a ratio of 1 to 2. This results in a voltage equal to twice that of the primary being applied across the rectifier and load (RL).

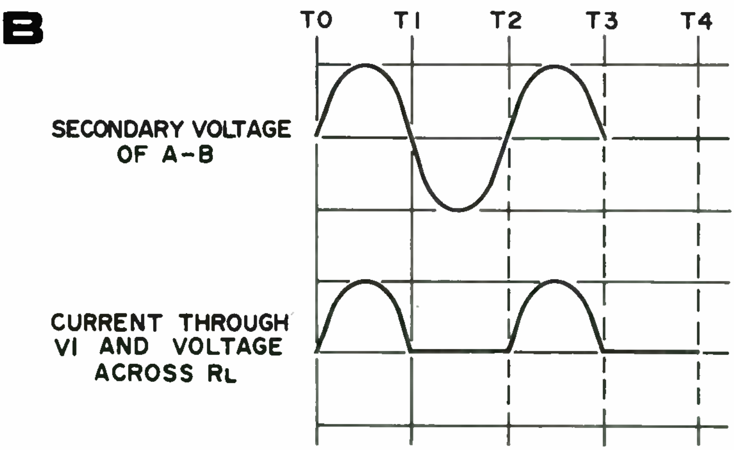
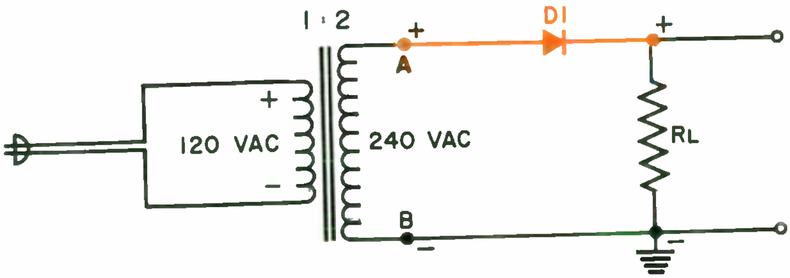


Figure 3 - Half-wave rectifier showing step up and step down ratios of secondary windings and waveforms.

A



B

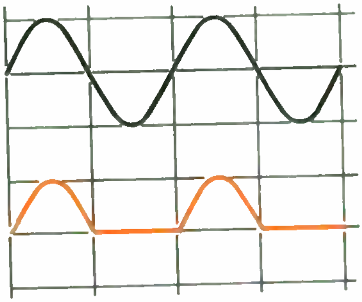
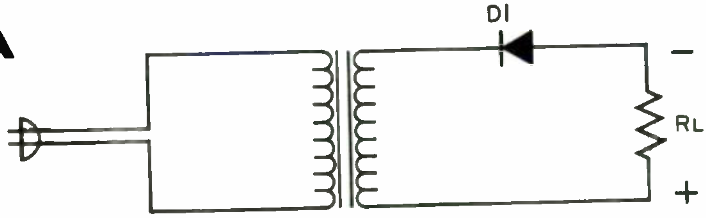


Figure 4 - Half-wave rectifier using solid state diode.

A



B

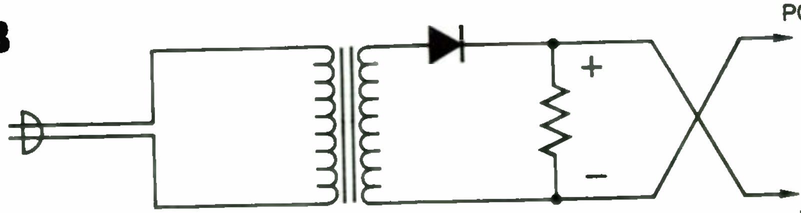


Figure 5 - Methods of providing reversed polarity from a half-wave supply: A. Reversed diode; B. Reversing output leads.

RL and the output is taken from the bottom, the output polarity will be negative.

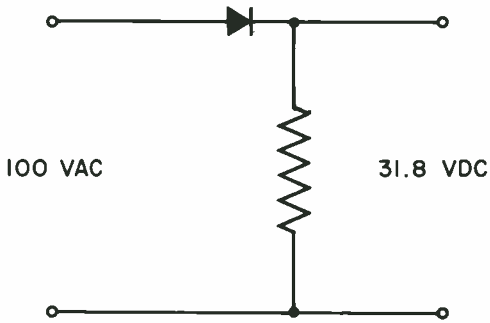


Figure 6 - Output relative to input of a half-wave rectifier.

The average DC obtained from a half-wave rectifier that is unfiltered is equal to .318 x peak value, which is very poor efficiency. With 100V AC supplied to a half-wave rectifier, the output DC will be 31.8 volts (Fig. 6). Full-wave rectifiers are more efficient because they conduct on both alternations of the cycle instead of on only one.

FULL-WAVE RECTIFIERS

A full-wave rectifier is one that supplies current in the same direction through a load during both alternations of the input sine wave. The major differences between a full-wave rectifier circuit and a half-wave rectifier circuit are that the full-wave circuit uses:

1. a center tapped transformer;
2. two rectifiers.

The circuits shown in Figure 7 illustrate these. The illustration in Figure 7A uses vacuum tubes. Figure 7B employs solid state diodes. Solid state diodes, of course, require no filament current and result in simpler power supply circuitry than vacuum tubes.

NOTE: Current flow in a diode is in opposition to the direction indicated by the arrow portion. The bar is the cathode, which supplies current carriers and the arrow represents the anode. Electron current flow is from cathode to anode.

The operation of a full-wave rectifier circuit can best be visualized by first relating it to two independent half-wave circuits. Two separate secondary windings are shown in Figure 8 with a diode rectifier in each winding. The diodes are placed in opposite ends of their respective windings, and each will conduct on opposite half cycles as illustrated by the waveforms shown in Figures 8A and 8B. Together the two diodes produce an output on each alternation.

Figure 9 shows the two circuits connected together in a parallel arrangement. The resulting waveforms show the effects on the output of combining the two circuits. Diode D1 conducts during the positive half cycles and diode D2 conducts on the negative half cycles. Together they supply current during both half cycles or throughout the full sinewave.

The common form of a full-wave rectifier circuit is shown again in Figure 10. Individual secondary windings have been replaced with one center-tapped continuous winding.

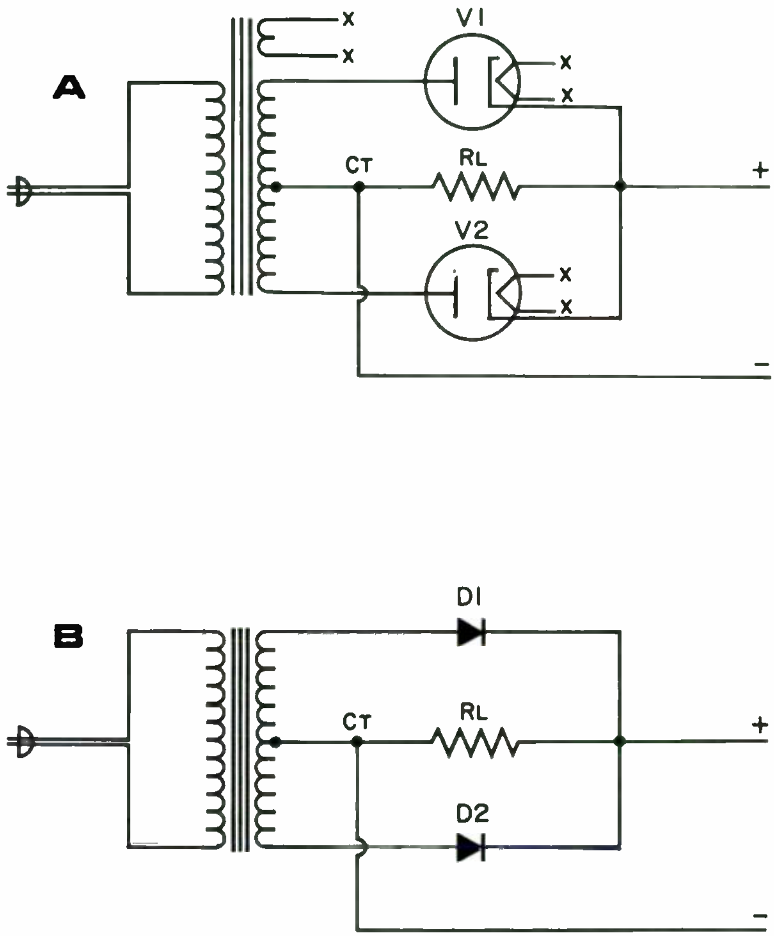


Figure 7 - Full-wave rectifiers: A. Vacuum tube; B. Solid state diode.

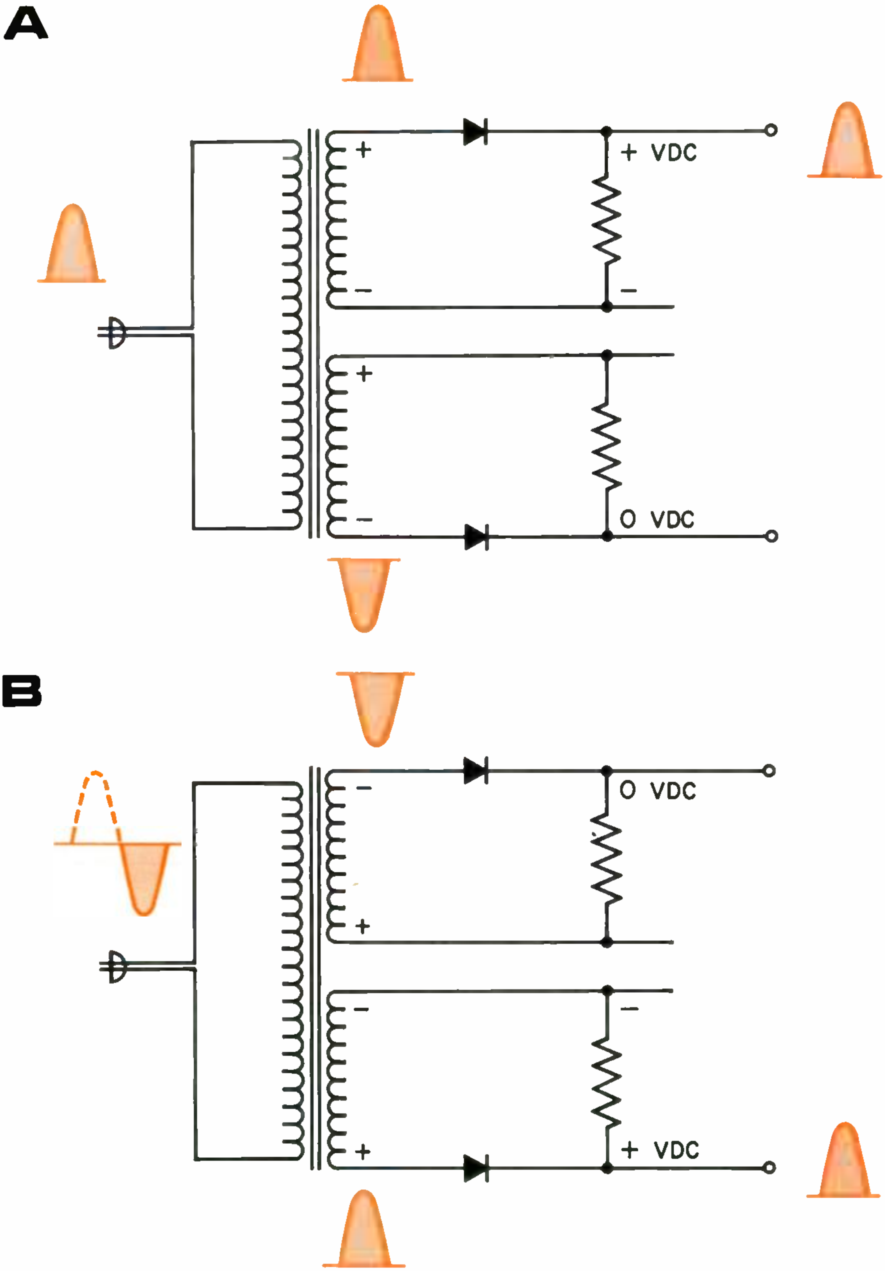


Figure 8 - Two oppositely polarized half-wave rectifiers.

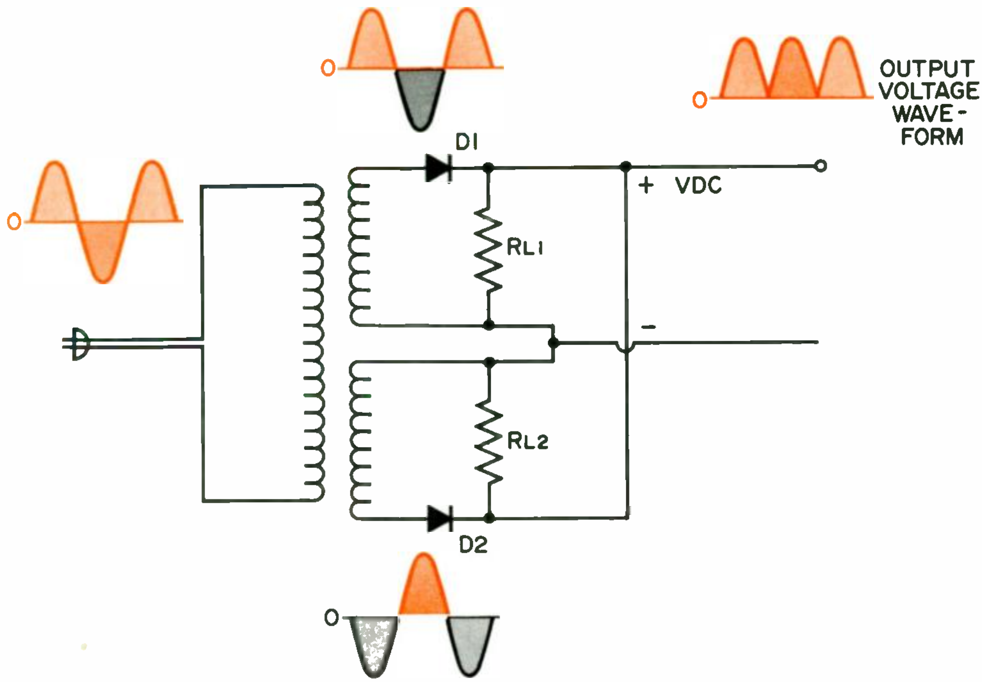


Figure 9 - Two half-wave rectifiers combined to form a full-wave circuit.

Load resistors RL1 and RL2 have been combined and replaced by a single load RL.

Full-wave rectifiers (both diode and tube) are available as a single device in one package or envelope. Figure 11 illustrates the use of dual diode rectifiers and their schematic appearance. Figure 11A shows the use of a solid state full-wave rectifier. The solid state device has two anodes and a common cathode. The vacuum tube used in the circuit illustrated in Figure 11B also has two anodes (plates) and a single cathode common to both anodes.

BRIDGE RECTIFIERS

In the absence of a center tapped secondary winding, it is still possible to provide full-wave rectification. This is accomplished with the use of four rectifiers.

If four rectifiers are connected as shown in Figure 12, the circuit is called a *bridge rectifier*. The input to the circuit is applied to diagonally opposite corners of the network, and the output is taken from the remaining two corners.

During one half of the input cycle, the upper end of the winding is positive and the lower end is negative. Only two of the diodes conduct, D2 and D4 (Fig. 13A). When the input reverses, diodes D1 and D3 conduct as shown by the arrows in Figure 13B. Thus, the circuit supplies output on each alternation of the input cycle. A full-wave output results as illustrated by the output waveform in Figure 12.

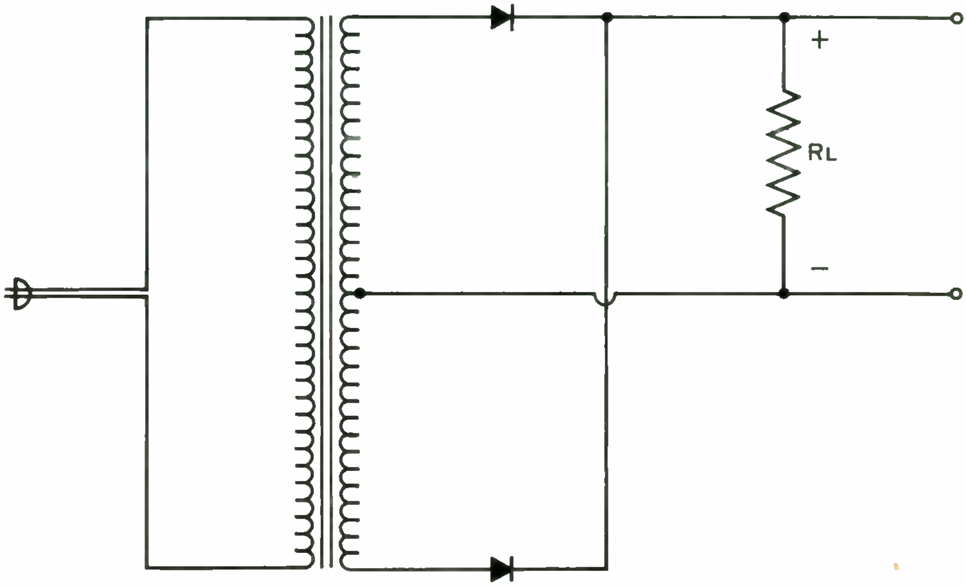


Figure 10 - Configuration of a full-wave rectifier.

A simplified version of a vacuum tube full-wave bridge rectifier is shown in Figure 14. Its input and output waveforms are shown along with waveforms that show current direction through the tubes on alternate half cycles. The filaments and their supplies are omitted for simplicity. The basic operation of the vacuum tube circuit is the same as a solid state diode type and produces an identical full-wave output.

HALF-WAVE VOLTAGE DOUBLER

If a rectifier unit and a capacitor are connected in series across a source of alternating current, as shown in Figure 15, the DC output voltage will be doubled. The arrow in the doubler circuits in this lesson acts as the anode, and electron flow is in the direction opposite to this arrow. When the input voltage is as indicated in Figure 15A, the capacitor charges to the peak value of the line voltage. On the next half cycle, the condition is as shown in Figure 15B. The peak voltage across the capacitor is retained, but because of the polarity reversal of the source, the rectifier no longer conducts, and as a result, the voltage across the capacitor adds to that of the source. Therefore, the total voltage across the rectifier has a peak value twice that of the source. Thus, the output voltage varies between zero and twice the peak input voltage during each cycle.

The output voltage can be maintained over the entire cycle if a second rectifier unit and capacitor are added, as shown in Figure 16. The second

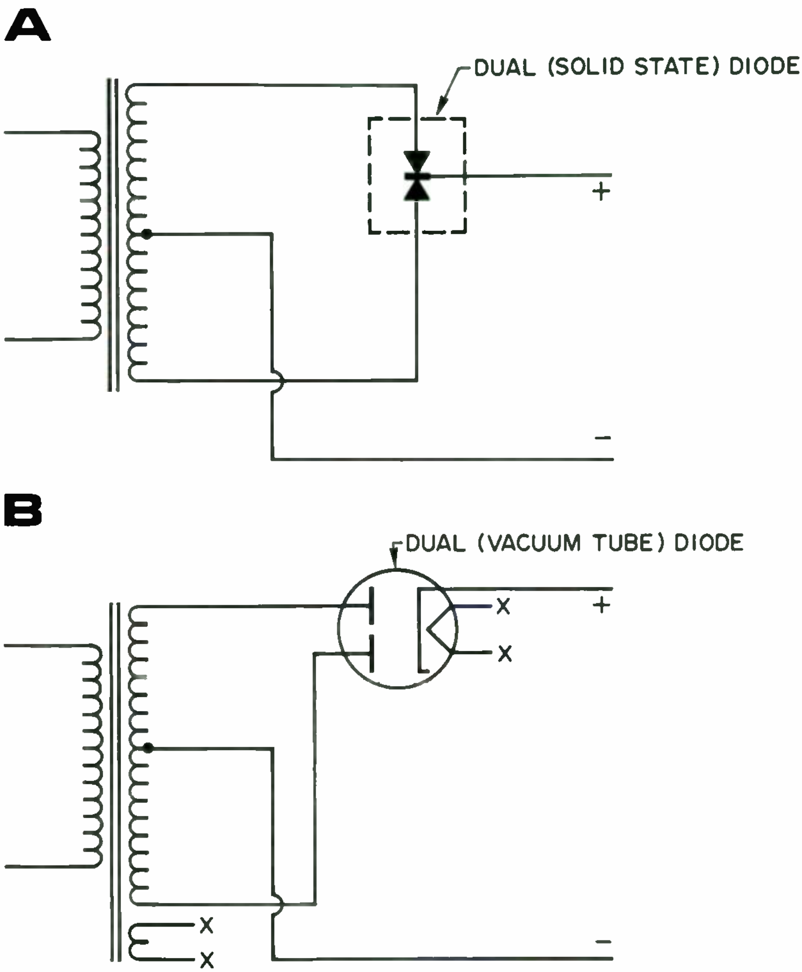


Figure 11 - Dual diodes: A. Solid State; B. Vacuum tube.

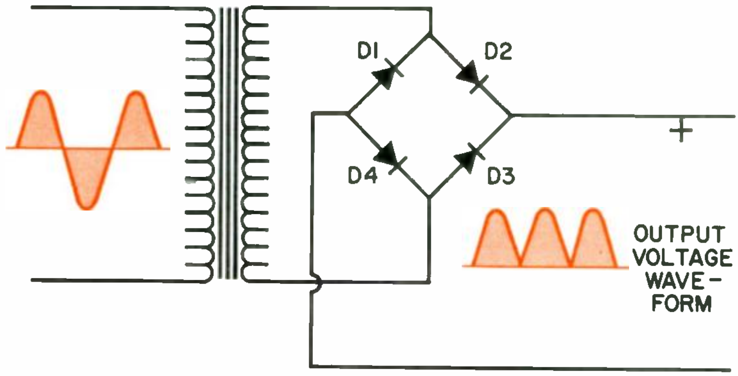


Figure 12 - Bridge rectifier.

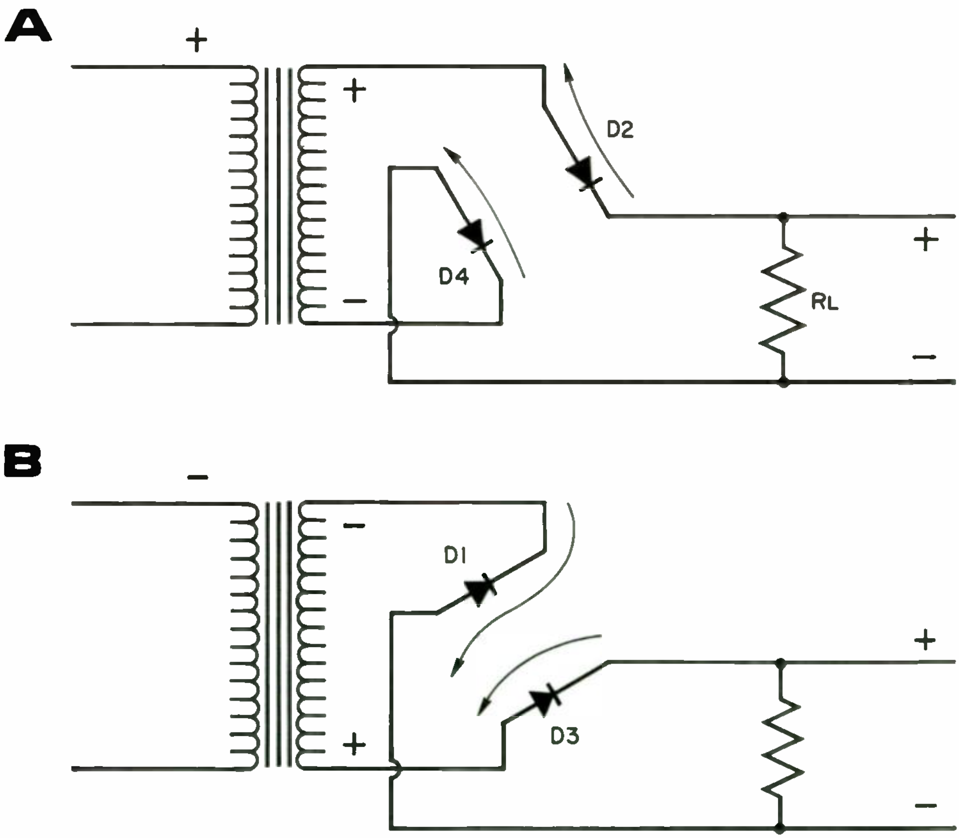


Figure 13 - Diode conduction during the two alternations in a bridge rectifier.

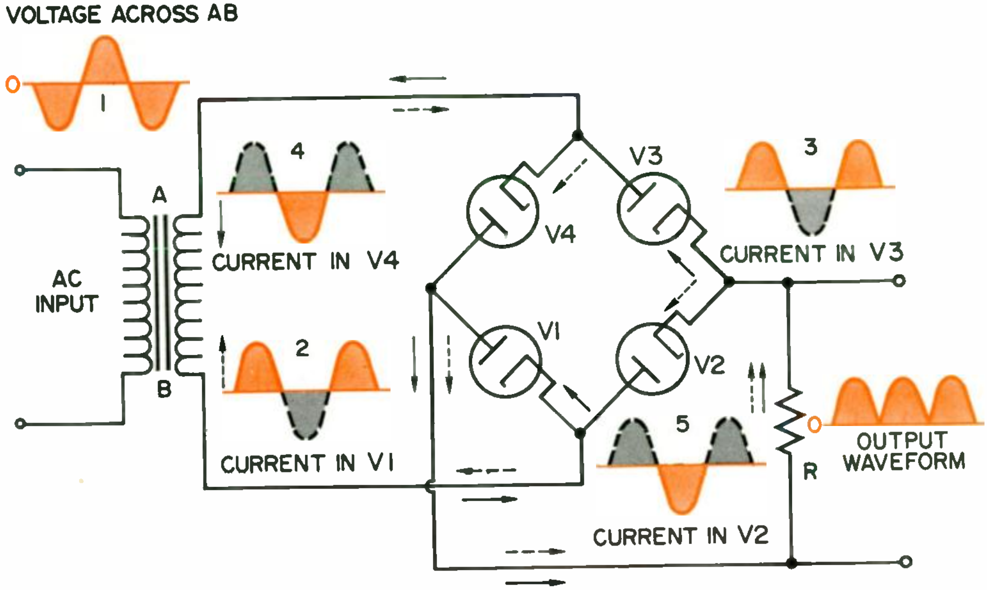


Figure 14 - Bridge rectifier with vacuum tubes.

capacitor C2 charges to twice the peak input voltage when rectifier D2 conducts and holds its charge during the time D2 is non-conducting.

Capacitor C2 cannot, however, maintain the full output voltage over the complete cycle if there is any appreciable load. This limitation results from the fact that when rectifier D2 is non-conducting, no current is drawn from the input circuit. Thus, C2 supplies the load current during discharge, and the output voltage falls proportionately. Because current is drawn from the source for only one-half of a cycle, this circuit is called a *half-wave voltage doubler.* The half-wave characteristic and the size of capacitor C2 limit the use of this circuit to applications requiring only a small output current.

FULL-WAVE DOUBLER

A voltage doubler operating as a full-wave rectifier is shown in Figure 17. Actually, this connection is equivalent to connecting a pair of half-wave rectifiers across the voltage source so that the direction of their conducting paths will be opposite to each other. As a full-wave rectifier, this circuit draws current from the voltage source during both halves of the input cycle. For one half cycle, C1 charges to the source voltage through rectifier D1, and for the next half cycle C2 charges to the source voltage through rectifier D2. The voltage impressed across C1 and C2 will combine in series across the load to give the polarity and current flow indicated in Figure 17.

VOLTAGE MULTIPLIERS

The process of increasing the voltage can be performed at higher levels of multiplication such as tripling and quadrupling. Theoretically, the voltage could be multiplied an infinite number of times by this process. Practical considerations, however, gen-

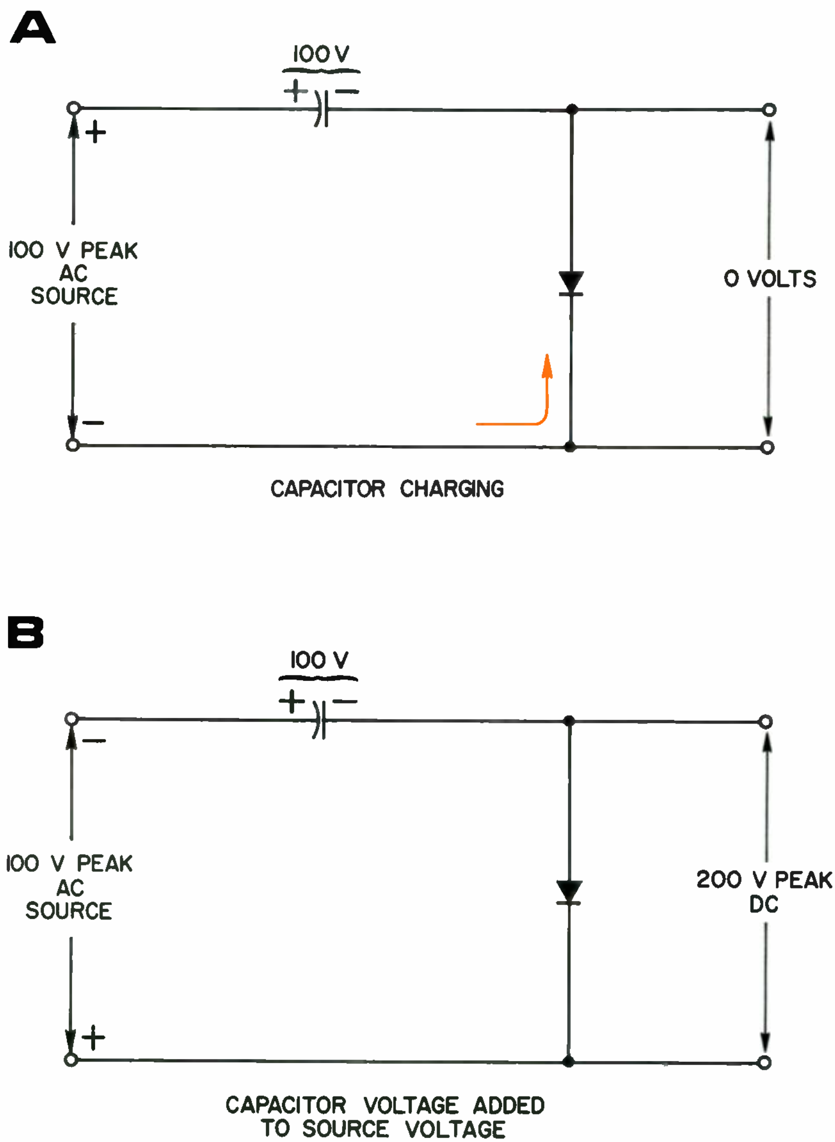


Figure 15 - Basic voltage doubler.

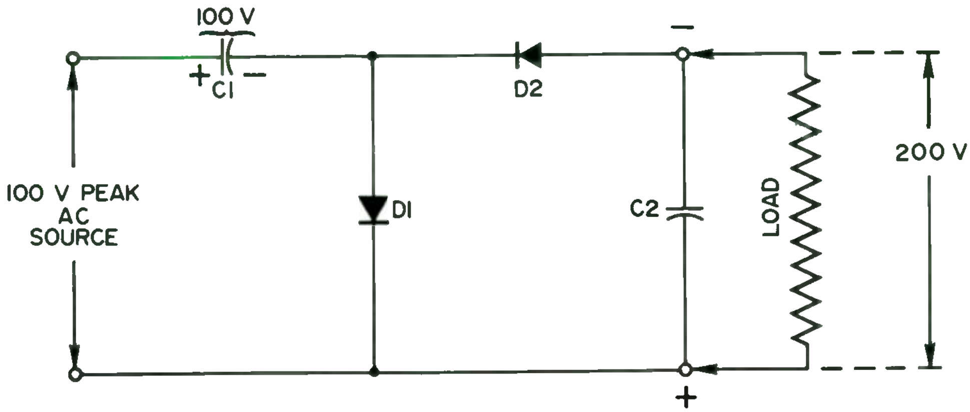


Figure 16 - Half-wave voltage doubler.

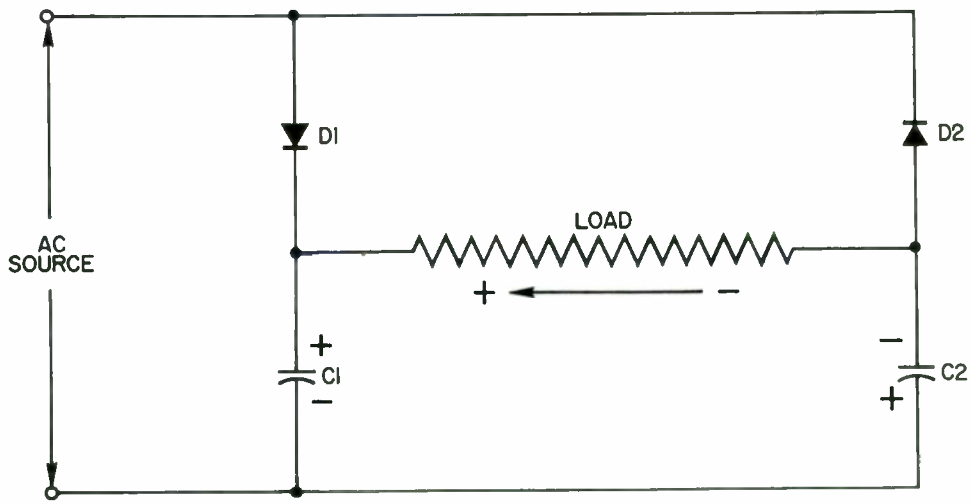


Figure 17 - Full-wave voltage doubler.

erally limit the multiplication to four or five times. Figure 18 shows a schematic diagram in which an output voltage equal to seven times the peak of the input voltage is developed. The number of sections in this type of circuit could be extended to give high output voltages, but with each additional section the *voltage regulation* is adversely affected. The circuit acts as a half-wave multiplier and, thus, large capacitors must be employed to maintain current flow during alternate half cycles.

The operation of this circuit is as follows: When the upper terminal is negative, electrons flow through all of the diodes, charging C1, C3, C5, and C7 to the peak voltage of the source. When the upper terminal is positive, the charges stored on these capacitors act in series with the input voltage to charge C2, C4, and C6 to twice the value of the input voltage. This reasoning may be continued through the first seven half cycles, and at this time the voltage across C7 will have been built up to seven times the input voltage.

Note that the inverse peak voltage across any one of the rectifiers does not increase with the number of stages. Actually the peak inverse voltage across each rectifier, regardless of its position in the circuit, is twice the peak value of the input voltage.

MERCURY-VAPOR RECTIFIERS

The introduction of mercury-vapor (mercury-pool) tubes to the electronics industry was one of the greatest

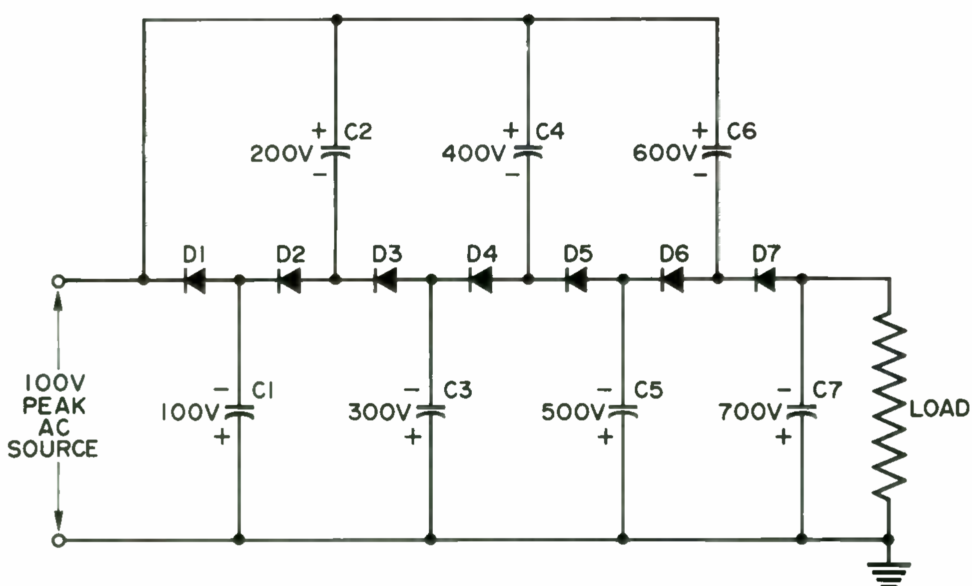


Figure 18 - Voltage multiplier.

single contributions to the development of high-powered electronic equipment. As a help in understanding the importance of the mercury-vapor tube, consider the foremost disadvantage of vacuum tube rectifiers. As stated previously, the voltage drop across a vacuum tube varies with the load current, and when the current varies widely, the regulation is poor. The vacuum tube rectifier used on heavy loads has a relatively high loss and low efficiency. In some high-power applications a water cooling system is employed to carry the heat from the tube elements. The power loss in a vacuum tube rectifier is usually 15 percent of the input power to the rectifier. In comparison, the power loss in a mercury-vapor tube rectifier is only about 1.5 percent of the total input.

The greater efficiency of the mercury-vapor rectifier is a result of the low-voltage drop across the tube. In normal operation this voltage drop rarely exceeds 15 volts, even when the tube is operating at very high values of load current. The filament of a vacuum tube rectifier is surrounded by a space charge which acts as a shield to impede electron flow between cathode and plate. This action results in a large voltage drop across the rectifier tube.

In a mercury-vapor type rectifier, a small amount of mercury is introduced into the tube envelope. Because of the low pressure within the tube, the mercury vaporizes completely as the unit reaches normal operating temperature. With a positive potential applied to the anode of the tube, electrons are emitted from the filament and move toward the anode. Because the tube envelope is filled with mercury vapor, collisions occur between the moving electrons and the atoms of mercury.

Each collision knocks an electron of a mercury atom away from the influence of the nucleus. The atom, now minus an electron, becomes a positive ion. This ion is then drawn toward the negative filament and is promptly neutralized by one of the electrons forming the space charge around that element. Ionization of mercury vapor occurs when the potential voltage between the plate and cathode is 10.4 volts. Any further increase in plate voltage will ionize more atoms — each in turn neutralizing a space electron — until the drop reaches 15 volts, and at that time the tube will no longer show a plate-voltage rise for a proportional rise in current.

Figure 19 shows graphically the i_p-e_p relation during ionization. This figure indicates the most useful characteristic of a mercury-vapor tube: *The voltage drop across the tube remains at a constant value of 15 volts regardless of the current flowing through the tube*, provided the rated tube current is not exceeded. On overload the voltage drop increases to some extent. When the tube drop exceeds 22 volts, the filament may be damaged by excessive bombardment of positive ions. At potentials below 22 volts, this bombardment is insufficient to cause damage to the filament.

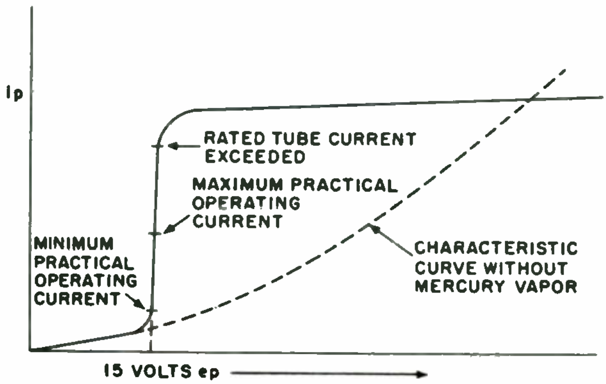


Figure 19 - Current vs voltage relation in a mercury-vapor tube.

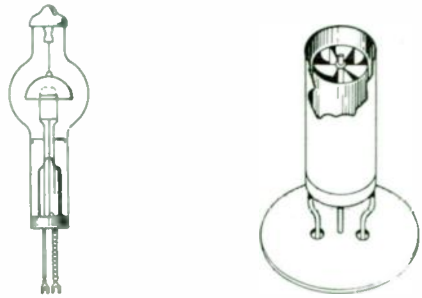
Another important characteristic of the mercury-vapor tube is its maximum inverse-voltage rating. This is the sparking voltage through the mercury vapor in a direction opposite to that of normal flow and is always less than it would be if the vapor were not present. A mercury-vapor tube always has a lower flashback voltage than a high-vacuum tube of similar construction. Nevertheless, mercury-vapor tubes with high inverse-voltage ratings have been developed. For example, a mercury-vapor diode having an output of 10 amperes and a maximum safe peak inverse voltage of 22,000 volts is used extensively in broadcast-transmitter power supplies.

In the practical operation of mercury-vapor rectifiers, the vapor must reach its proper operating temperature before plate voltage is applied. If this precaution is not taken, the high voltage drop across the tube causes secondary emission from plate to cathode, and arcback occurs. In vacuum tube rectifiers, the only factor considered in cathode heating is the emission of electrons. The cathode of the mercury-vapor tube must not only emit free electrons for conduction, but must also heat the surrounding space in order for the mercury-vapor temperature to be in the range of 20° to 60° centigrade. The cathode construction indicated in Figure 20 facilitates this heating.

The heat given off by the inner turns of the spiral filament is absorbed by the outer turns. Radiation from the outer surface is reduced by a polished shield surrounding the filament. The plate (anode) is a metal cup fitting over the cathode. This arrangement reduces the tendency to arcback. It also shields the plate-cathode region from external electric fields. Below the operating range of temperatures, the tube drop is excessive with inherent danger of positive-ion bombardment. At high operating temperatures, flashback potentials drop to an intolerably low value.

MULTIPLE VOLTAGE SUPPLIES

It is not uncommon for solid state equipment to require more than one



MERCURY-VAPOR TUBES WITH HEATER DETAILS

HOT-CATHODE EMITTING STRUCTURES

Figure 20 - Construction of mercury-vapor rectifier.

voltage level or polarity for its operation. Opposite polarities are required when NPN and PNP devices are intermixed in a single unit.

Frequently, different voltages are obtained from the same winding by including additional sets of rectifiers. Taps can be included in the winding to provide different voltage levels.

Figure 21A shows a dual voltage supply for use with solid state equipment. Diodes D1 and D2 are connected across the extreme ends of the winding and produce +15V DC output. Diodes D3 and D4 are supplied from taps on the winding which is effectively the same as supplying them from a winding with fewer turns. Together they produce +5V DC. These voltages are common when IC logic is intermixed with other IC devices requiring a higher voltage. It is also a common supply for use when IC logic is mixed with transistors in the same unit.

Figure 21B shows a dual polarity power supply, which is now commonly called a bipolar supply. It develops two output voltage sources of like voltage, but they are opposite in polarity. The polarity reversal is produced by inverting diodes D3 and D4 relative to D1 and D2. This type of supply is common in industrial instruments that use differential amplifiers.

There is such a variety of multi-voltage power supplies used that it would be impossible to list them. The foregoing illustrations are given to acquaint you with their existence.

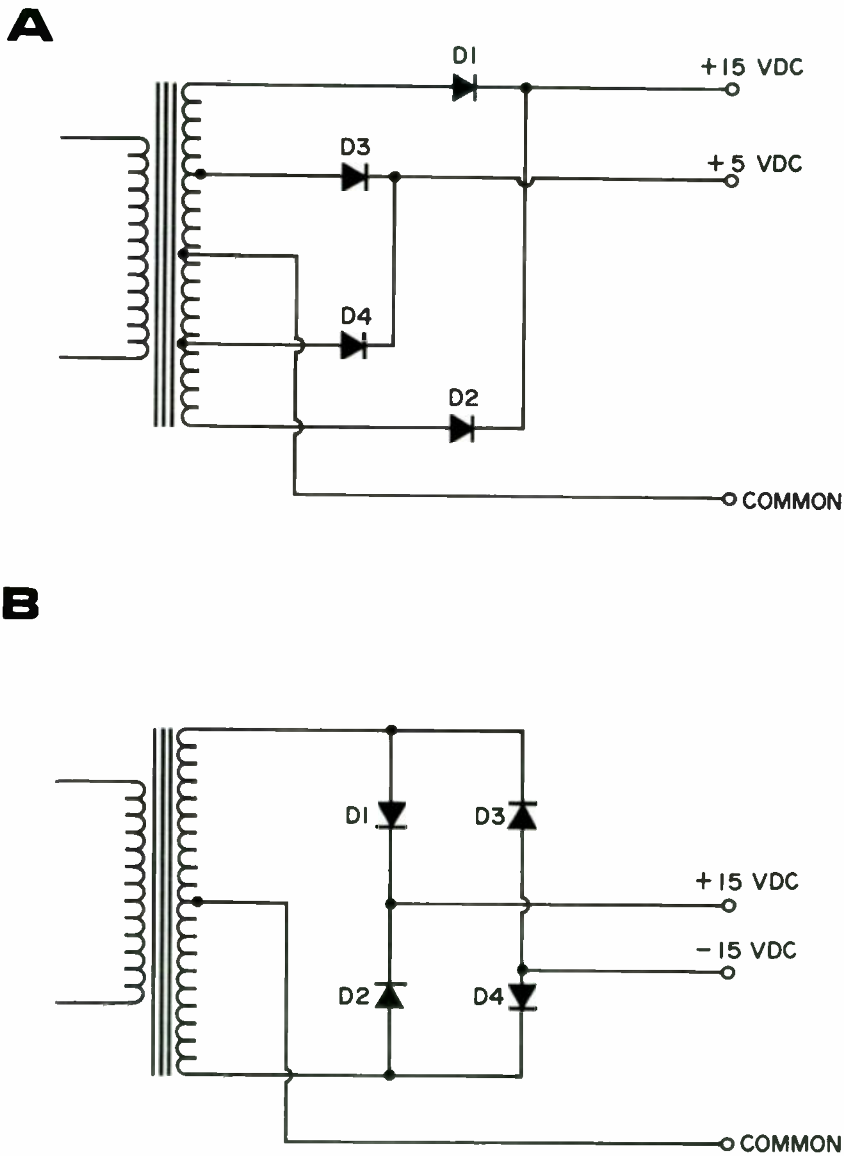


Figure 21 - Multi-voltage supplies.

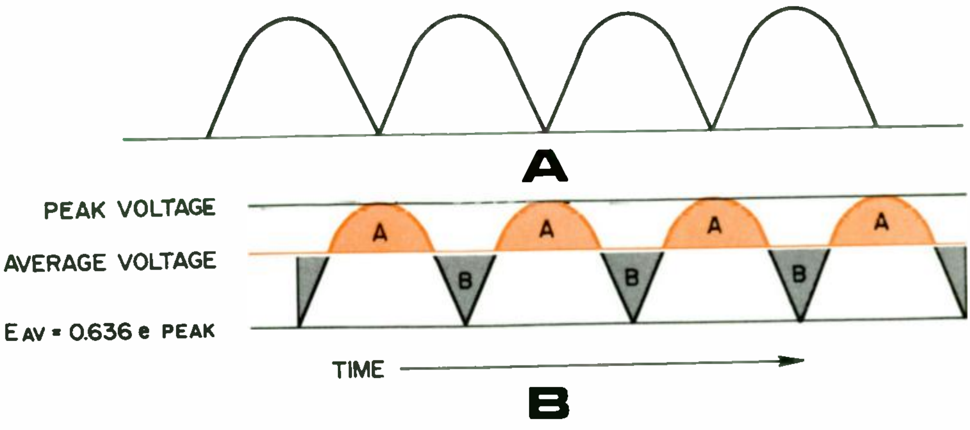


Figure 22 - Unfiltered output voltage of a full-wave rectifier.

FILTER CIRCUITS

The preceding paragraphs have discussed methods of converting alternating current into pulsating direct current. Most electronic equipments require a smooth DC supply, approaching the ripple-free output of a battery. Conversion of pulsating direct current to pure direct current is accomplished by the use of properly designed filters.

The unfiltered output of a full-wave rectifier is shown in Figure 22A. The polarity of the output voltage does not reverse, but its level fluctuates around an average value as the successive pulses of energy are delivered to the load. In Figure 22B, the average voltage is shown as the line that divides the waveform so that area A equals area B. The fluctuation of voltage above and below this average value is called *ripple*. The frequency of the main component of the ripple for the full-wave rectifier is twice the frequency of the input voltage that is being rectified. In the case of the half-wave rectifier, the ripple has the same frequency as the input alternating voltage. Thus, if the input voltage is obtained from a 60 hertz source, the main component of ripple in the output of a half-wave rectifier is 60 hertz. In the full-wave rectifier, the ripple frequency is 120 hertz.

The output of any rectifier is composed of a direct voltage and an alternating or ripple voltage. For most applications, the ripple voltage must be reduced to a very low amplitude. The amount of ripple that can be tolerated varies with different applications.

The PERCENTAGE OF RIPPLE is 100 times the ratio of the RMS value of the ripple voltage at the output of a rectifier filter to the average value, Eo, of the total output voltage. Figure 23 indicates graphically how the percentage of ripple may be determined. It is assumed that the ripple voltage is a sine waveform.

A circuit that eliminates the ripple voltage from the rectifier output is

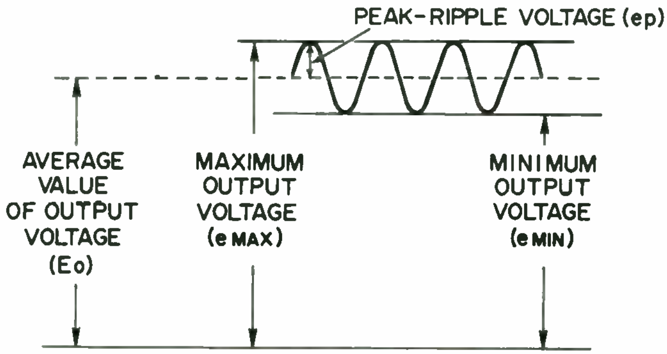


Figure 23 - Percentage of ripple.

called a FILTER. Filter systems in general are composed of a combination of capacitors, inductors, and, in some cases, resistors. Fluctuations can be reduced considerably if some energy can be stored in a capacitor while the rectifier is delivering its pulse, and can be allowed to discharge from the capacitor between pulses.

Figure 24 shows the output of a half-wave rectifier. This pulsating voltage is applied across a filter capacitor (C1 in Fig. 24 C) to supply the load, R. Because the rate of charge of C1 is limited only by the reactance of the transformer secondary and the plate resistance of the rectifier tube, the voltage across the capacitor can rise nearly as fast as the sinewave voltage output from the rectifier. In other words, the RC charge time is relatively short. The capacitor C1 is charged to the peak voltage of the rectifier within a few cycles. The charge on the capacitor represents a storage of energy. When the rectifier output drops to zero, the voltage across the capacitor does not fall immediately. Instead, the energy stored in the capacitor is discharged through the load during the time that the rectifier is not supplying energy (when the plate is negative). The voltage across the capacitor (and the load) falls off very slowly if it is assumed that a large capacitance and a relatively large value of load resistance are employed. In other words, the RC discharge time is relatively long. The amplitude of the ripple, therefore, is greatly decreased, as may be seen in Figure 24D.

Figure 24B shows the input voltage to the filter when a full-wave rectifier is used, and Figure 24E shows the resulting output voltage waveform.

After the capacitor has been charged (with either half-wave or full-wave input), the rectifier cannot begin to pass current until the output voltage of the rectifier exceeds the voltage across the capacitor. Thus, in Figures 24D and E, current begins to flow in the rectifier when the rectifier output reaches a voltage equal to the capacitor voltage. This occurs at some

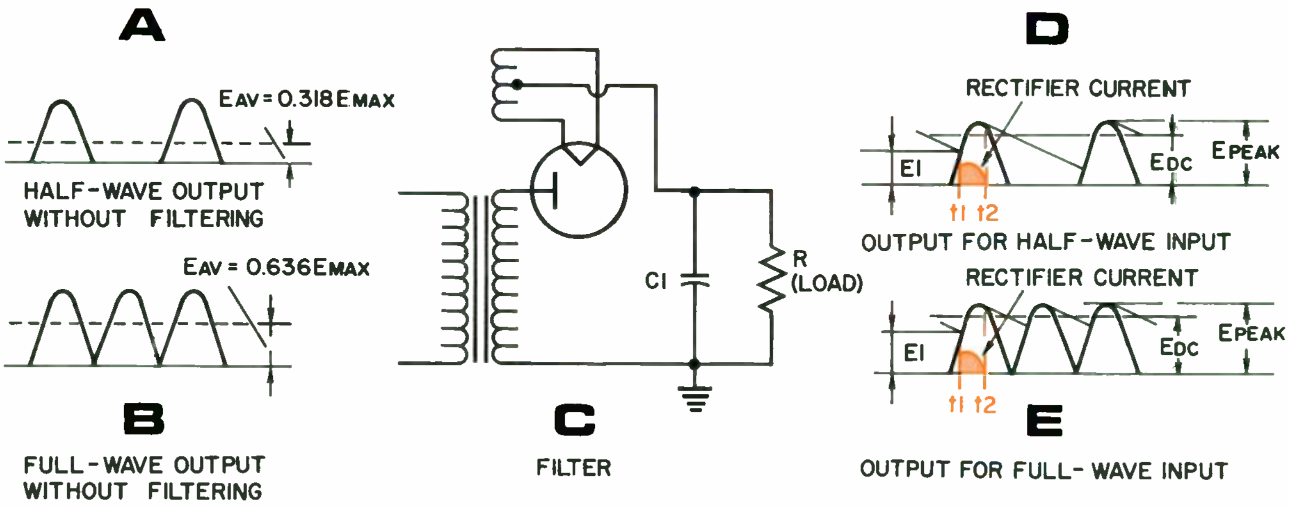


Figure 24 - Capacitance-type filter and waveforms.

time, t1, when the rectifier output voltage has a magnitude E1. Current continues to flow in the rectifier until slightly after the peak of the half-sine wave, at time t2. At this time the sinewave voltage is falling faster than the capacitor can discharge. A short pulse of current, beginning at t1 and ending at t2, is, therefore, supplied to the capacitor by the power source.

The average voltage of the rectifier output is shown in Figures 24A and 24B. Because the capacitor absorbs energy to the load between pulses, the output voltage can never fall to zero. Hence, the average voltage of the filtered output (Fig. 24, D and E) is greater than that of the unfiltered input (Fig. 24, A and B). However, if the resistance of the load is small, a heavy current is drawn by the load and the average or direct voltage falls. For this reason, the simple capacitor acts like a short circuit across the rectifier while the capacitor is charging. Because of this high peaked load on the rectifier tubes, the capacitor input filter is seldom used with gas tubes in high-current installations.

INDUCTANCE FILTER

Because an inductor resists changes in the magnitude of the current flowing through it, an inductor can be placed in series with a rectifier output to help prevent abrupt changes in the magnitude of the current. An inductance-type filter, together with its input and output waveforms, is shown in Figure 25. The input waveforms from a half-wave and a full-wave rectifier are shown respectively in Figures 25A and 25B. Figure 25C shows the inductance-type filter, and Figures 25D and 25E show the output currents for the half-wave and full-wave inputs, respectively. When no inductor is used in series with R, the output current waveforms are indicated by dotted lines. The solid lines indicate the output current waveforms when an inductor is used. The use of

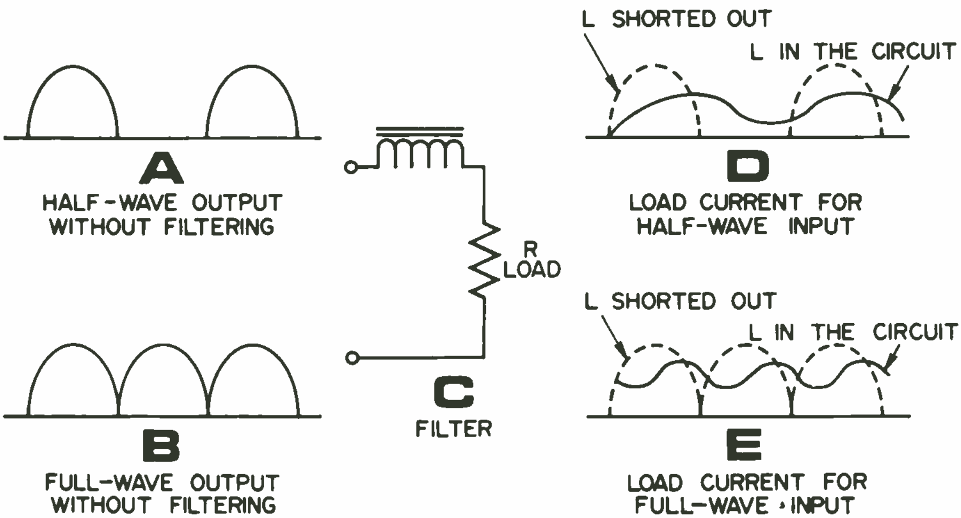


Figure 25 - Inductance-type filter and waveforms.

an inductor prevents the current from building up or dying down quickly. If the inductance is made large enough, the current becomes nearly constant.

The inductance prevents the current from ever reaching the peak value that is reached without the inductance. Consequently, the output voltage never reaches the peak value of the applied sinewave. Thus, a rectifier whose output is filtered by an inductor cannot produce as high a voltage as can one whose output is filtered by a capacitor. However, this disadvantage is partly compensated for because the inductance filter permits a larger current drain without a serious change in output voltage.

PI-SECTION FILTER

The ripple voltage present in a rectifier output cannot be eliminated adequately in many cases by either the simple capacitive or inductive filter. Filters that are much more effective can be made if both inductors and capacitors are used. The function of the capacitor is to prevent a change in the magnitude of the voltage. The result of these two actions is to remove the ripple from the rectifier output and to produce a voltage having a nearly constant magnitude.

Figure 26 shows a circuit diagram of an inductance/capacitance filter used primarily with receiver power supplies and other low-current power supplies.

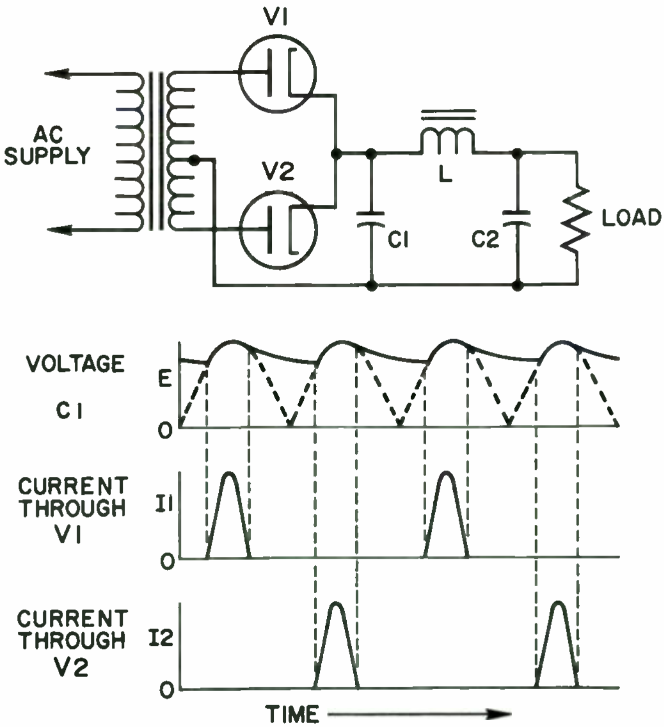


Figure 26 - Current and voltage waveforms in full-wave rectifier with pi-section filter.

This type of filter is given the name *pi-section* because the configuration of the schematic diagram resembles the Greek letter π. It is also called a *capacitor input filter.* With this type of filter, the output waveform closely approximates that of pure direct current. The input capacitor C1 acts to bypass the greatest portion of the ripple component to ground. In all filters, the major portion of the filtering action is accomplished in this first component. The series choke in the pi-section filter serves to maintain the current at a nearly constant level during the charging and discharging cycles of the input capacitor.

The waveforms of current through V1 and V2 and the voltage across C1 are shown at the bottom of Figure 26. The final capacitor, C2, acts to bypass residual fluctuations existing after filtering by the input capacitor and inductor. The current flow through the rectifier tubes is a series of sharp-peaked pulses, because the input capacitor acts like a short circuit across the rectifier while the capacitor is charging. Because of this high-peaked load on the rectifier tubes, the pi-section filter is used only in low-current installations, such as radio receivers.

L-SECTION FILTER

A second type of filter used primarily in high-current applications is the L-section filter, so named because of its resemblance to an inverted "L." A schematic diagram of this type of filter is shown in Figure 27. The components perform the same functions as in the pi-section filter, except that the inductor, or choke, input reduces the voltage output of the filter. This filter is also called a *choke input filter.* The input choke allows a continuous flow of current from the rectifier tubes rather than the pulsating current flow demanded by the capacitor input filter. The L-section filter is seldom used with half-wave rectifiers because there is no device to maintain current flow between half cycles.

Because of the uniform flow of current, the L-section filter has applications in most high-power circuits where voltage regulation is important, and is used with mercury-vapor rectifiers. In this respect, its advantage lies in the fact that it allows each rectifier tube to operate at a relatively constant level of current flow during its half-cycle of operation. This type of operation allows a rectifier to supply the maximum current to the load that it is capable of delivering. A disadvantage of the L-section filter is that instead of delivering a voltage equal to the peak value of the transformer secondary, it supplies a voltage equal to the average of the AC voltage delivered to the rectifier. Two L-section filters are sometimes used in series to obtain a higher degree of filtering action.

VOLTAGE REGULATION

The output voltage developed by any source of power tends to decrease when current is drawn from the source. The amount of change in the output voltage is usually expressed by a quantity called the PERCENTAGE OF VOLTAGE REGULATION.

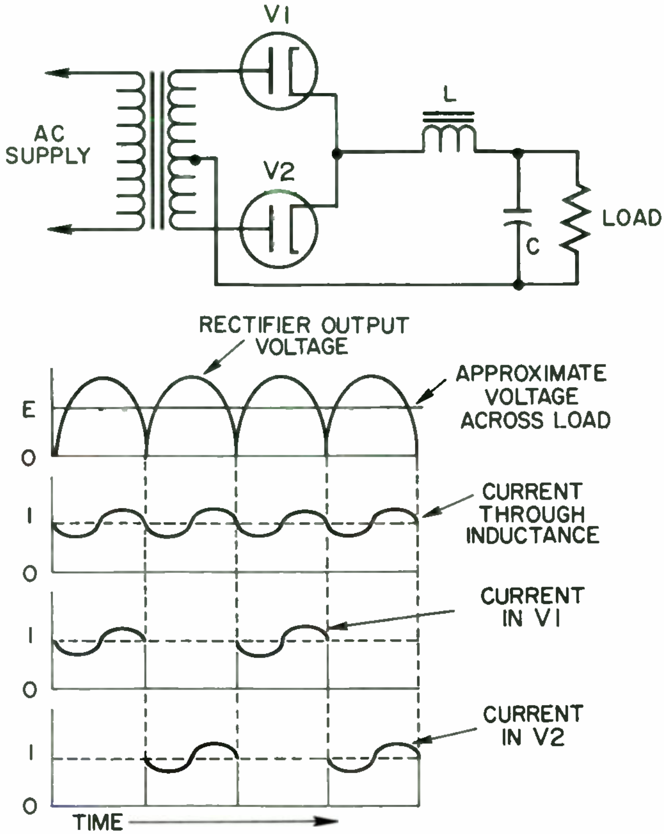


Figure 27 - Current and voltage waveforms in full-wave rectifier with L-section filter.

The difference between the no-load voltage and the full-load voltage is caused by the flow of the load current through the internal resistance of the power supply. The IR drop caused by the load current within the supply circuit is subtracted from the voltage available for the load resistance at the output terminals. A perfect power supply would have zero internal impedance and the percentage of regulation would be zero. Such a supply would provide the same voltage under full-load that it develops with no-load current flowing. In general, the lower the percentage of regulation, the better the power supply in furnishing direct voltage and direct current for electronic equipment.

The regulation of the choke-input filter circuit is superior to that of the capacitor-input circuit as long as current is flowing in the filter choke. In this condition the output voltage changes very little when the load current changes in value. If, however, the load current should become zero, the choke coil can no longer prevent the first capacitor in the filter from charging to a value equal to the peak value of the applied voltage.

If the load current is a low value, or if it varies between a low value and zero, the regulation of the circuit is poorer than when larger currents are being drawn by the load. In order to improve the regulation of the choke-input filter, a resistor is often connected across the output terminals so that at least a minimum current will always flow through the choke.

Most electronic equipment can operate satisfactorily with a certain amount of variation in the supply voltage without suffering severe operational deficiency. However, some circuits are very critical and even a slight deviation from the normal supply voltage will cause unsatisfactory operation. These circuits require the use of some type of voltage-regulating device.

A voltage-regulating device may be inserted in the circuit at one of two points — either between the rectifier and its load, or at the power source that supplies electrical energy to the rectifier. The regulators that are used within a power supply are generally electronic.

FUNDAMENTAL VOLTAGE REGULATOR

The regulator that is used to stabilize the output voltage of a rectifier usually takes the form of a variable resistance in series with the output. This variable resistance and the load resistance form a voltage divider. The variable element is controlled so that the voltage across the load is held constant.

Figure 28 shows a simple circuit that demonstrates this principle. The variable resistor R and the resistance of the load comprise a voltage divider that is connected across the rectifier output terminals. All the load current passes through R and causes a voltage drop across it. If the rectifier output voltages rises, the voltage across the load rises in proportion. To counteract this rise, the resistance of R is increased (manually) so that a greater proportion of the available voltage appears across R. The voltage across the load, therefore, is held constant if the resistance of R is increased sufficiently to neutralize the increase of the rectifier output. If the resistance of the load increases, a greater fraction of the available voltage appears across the load. Therefore, the resistance of R must be increased in order to hold the voltage across the load constant.

In the system shown in Figure 28, the resistor R must be varied manually in order to keep the voltmeter reading constant. If the voltmeter reading increases, R must be increased; if the voltmeter reading decreases, R must be decreased. This same type of action must take place in all of the voltage regulators that are to be discussed, but the action is automatic. The more complicated circuits that follow are more desirable than the simpler circuits because they are more accurate and can respond more quickly.

AMPERITE VOLTAGE REGULATOR

A regulator tube that consists of an iron wire enclosed in a hydrogen-filled

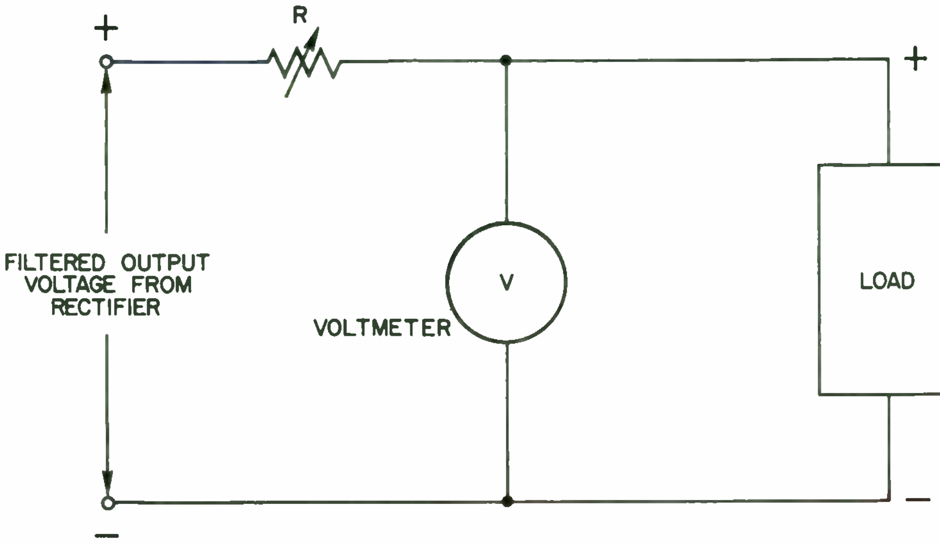


Figure 28 - Basic principle of voltage regulator.

envelope is called an AMPERITE TUBE or BALLAST TUBE.

An AMPERITE regulator circuit is shown in Figure 29. The resistance of the iron wire in the ballast tube varies as the current through it changes. If the filtered output voltage from the rectifier tends to increase, more current flows through the ballast tube. The resistance of the tube then increases and more of the voltage drop takes place across the tube. Therefore, the voltage across the load remains nearly constant.

The AMPERITE regulator does not regulate the voltage if the load changes. If the load increases, more current is drawn from the power supply and the load voltage falls. In addition, the greater current drawn causes the resistance of the AMPERITE to increase, and the load voltage is made even lower by this additional drop.

Although the ballast tube may be used to compensate for line voltage variations, it is generally inserted in series with several additional elements through which it is desired to maintain a constant current. In such applications, the resistance of the ballast tube changes to counteract the effect of changing voltage across the circuit.

GLOW-TUBE VOLTAGE REGULATOR

In a glow-discharge tube, such as the neon glow tube, the voltage across the tube remains constant over a fairly wide range of current through the tube. This property exists because the degree of ionization of the gas in the tube varies with the amount of current that the tube conducts. When a large current is passed, the gas is very highly ionized and the internal impedance of the tube is low. When a

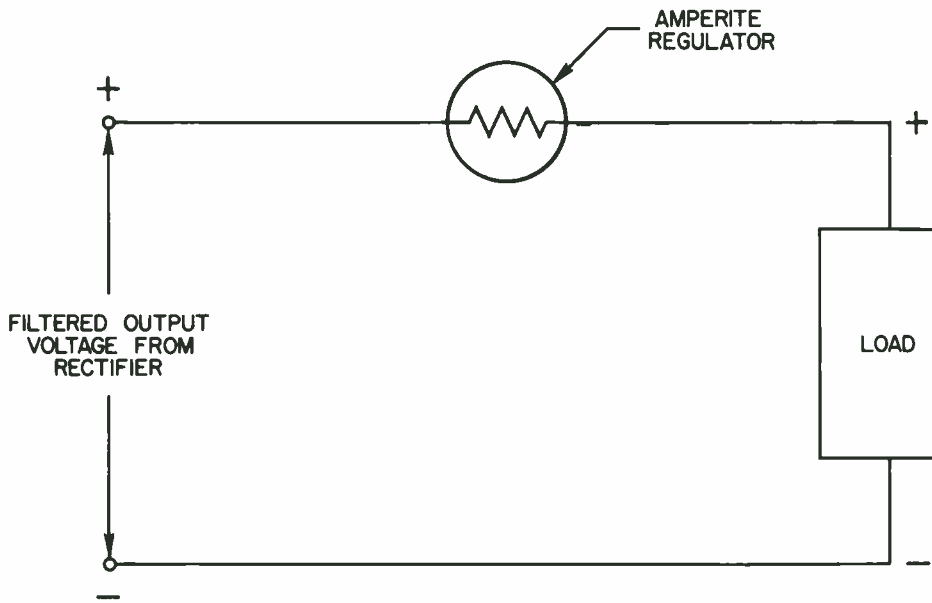


Figure 29 - AMPERITE regulator circuit.

small current is passed, the gas is lightly ionized and the internal impedance of the tube is high. Over the operating range of the tube, the product of the current through the tube and the internal impedance of the tube are practically constant.

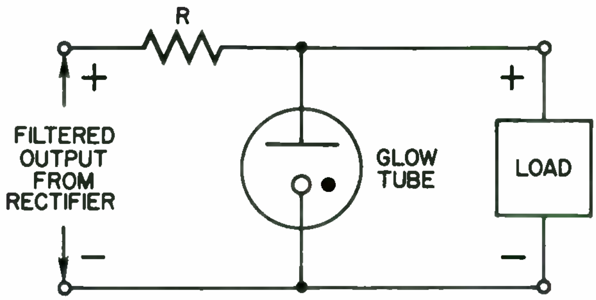
A simple glow-tube regulator is shown in Figure 30A. The load current and the current that flows in the neon glow tube both pass through the series resistor R. If the supply voltage drops, the voltage across the neon tube tends to drop. Therefore, the gas in the neon tube de-ionizes slightly, and less current passes through the tube. The current through R is decreased by the amount of the current decrease in the tube. Because the current through R is less, the voltage drop across R is less. If the resistor is of the proper value relative to the load and to the glow tube that is used, the voltage across the load is held fairly constant. In any case, the value of R must not be so large that the neon tube fails to ionize.

Glow tubes are designed to operate at various useful values of voltage. When a regulated voltage in excess of the maximum rating of one glow tube is required, two or more tubes may be connected in series, as in Figure 30B. This arrangement permits several regulated voltages with small current drains to be obtained from a single rectifier power supply.

ELECTRON-TUBE VOLTAGE REGULATOR

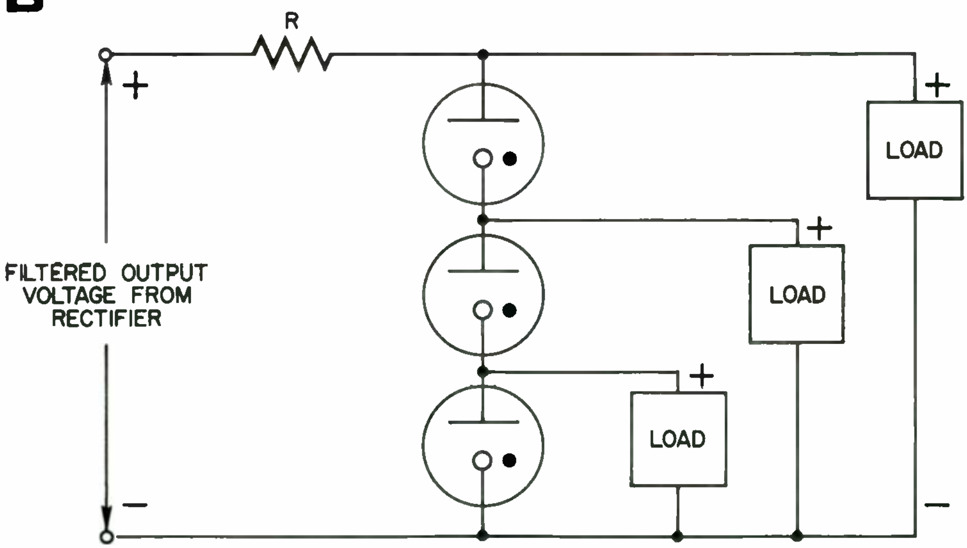
An electron tube may be considered a variable resistance. When the tube is passing a direct current, this resistance is simply the plate-to-cathode voltage divided by the current through the tube, and is called the DC

A



SIMPLE GLOW-TUBE VOLTAGE REGULATOR

B



GLOW TUBES CONNECTED IN SERIES TO
OBTAIN STABILIZED HIGH VOLTAGE

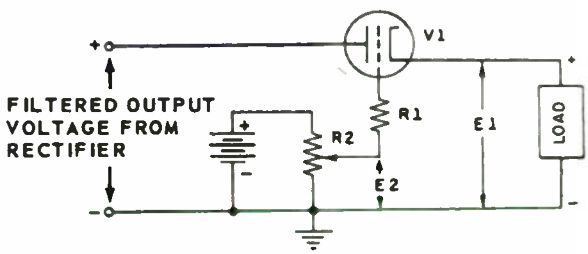
Figure 30 - Glow-tube regulators.

plate resistance, RP. For a given plate voltage, the value of RP depends upon the tube current, and the tube current depends upon the grid bias.

The variable resistor R of Figure 28 can be replaced by an electron tube (Fig. 31A), because the electron tube has a variable resistance. The resistance of V1 is established initially by the bias on the tube. Assume that the voltage across the load is at the desired value. Then the cathode is positive with respect to ground by the voltage E1. The grid can be made positive, relative to ground, by a voltage E2, that is less than E1. The potentiometer R2 is adjusted until the bias (grid-to-cathode voltage), which is E1-E2, is sufficient to allow V1 to pass a current equal to the desired load current. With this bias, the resistance of V1 is established at the proper value to reduce the rectifier output voltage to the desired load voltage.

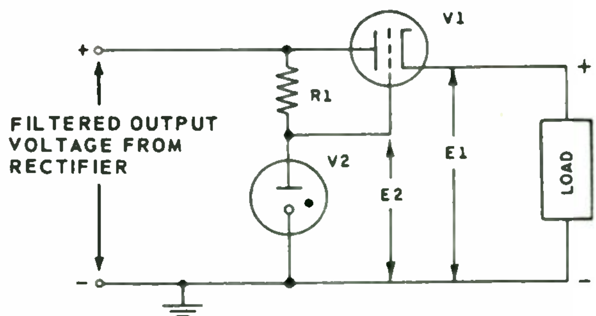
If the rectifier output voltage increases, the voltage at the cathode of V1 tends to increase. As E1 increases, the negative bias on the tube increases and the plate resistance of the tube becomes greater. Consequently, the voltage drop across V1 increases with the rise in input voltage. If the circuit is properly designed, the increased voltage drop across V1 is approximately equal to

A



ELECTRON-TUBE VOLTAGE REGULATOR
EMPLOYING A BATTERY FOR THE
FIXED BIAS

B



ELECTRON-TUBE VOLTAGE REGULATOR
EMPLOYING A GLOW TUBE FOR THE
FIXED BIAS

Figure 31 - Electron tube voltage regulator.

the increase in voltage at the input. Thus the load voltage remains essentially constant.

The resistor R1 is used to limit the grid current. This is necessary in this particular circuit because the battery is not disconnected when the power is turned off. However, the battery can be eliminated from the circuit by the use of a glow tube (V2 in Figure 31B) to supply a fixed bias for the grid of the tube. The action of the circuit is the same as the action of the circuit in Figure 31A.

The output voltage of the simple voltage regulators shown in Figure 31 cannot remain absolutely constant. As the rectifier output voltage increases, the voltages on the cathode of V1 must rise slightly if the regulator is to function.

The voltage regulators shown in Figure 31 compensate not only for changes in the output voltage from the rectifier, but also for changes in the load. For example, in Figure 31B, if the load resistance decreases, the load current will increase. The load voltage will tend to fall because of the increased drop across V1. The decrease in load voltage is accompanied by a decrease in bias voltage on V1. The bias voltage on V1 is equal to E1-E2. Thus, the effective resistance of V1 is reduced at the same time the load current is increased. The IR drop across V1 increases only a slight amount because R decreases about as much as I increases. Therefore, the tendency for the load voltage to drop when the load current is increased is checked by the decrease in resistance of the series triode.

IMPROVED VOLTAGE REGULATOR

A very stable voltage regulator (more stable than those shown in Figure 31) can be designed by taking advantage of the high amplification of a pentode. A voltage regulator employing this type of tube is shown in Figure 32. It produces an output that is independent of fluctuations in the AC supply and changes in load over a wide range.

The output voltage of this regulator is developed across bleeder resistors R3, R4, and R5 in parallel with the resistance of the load. These resistors make up the resistance of one part of the total voltage divider. The other resistance, through which all of the load current must flow, is the cathode-to-plate effective resistance of V1. The other elements of the circuit are used to control the resistance of V1 and, thereby, to maintain a constant voltage across the load.

The potential of the cathode of V2 is held at a constant positive value with respect to ground by the glow tube, V3. In other words, current flowing from ground through V3 causes an IR drop across V3 that maintains the cathode of V2 positive with respect to ground. The grid potential of V2 is a voltage selected by potentiometer R4. This potentiometer is set so that the grid-to-ground voltage is less positive than the cathode-to-ground voltage by an amount (the bias) that causes V2 to pass a certain plate current. In other words, the IR drop between the moving contact on R4 and ground is less than the IR drop across V3 by an

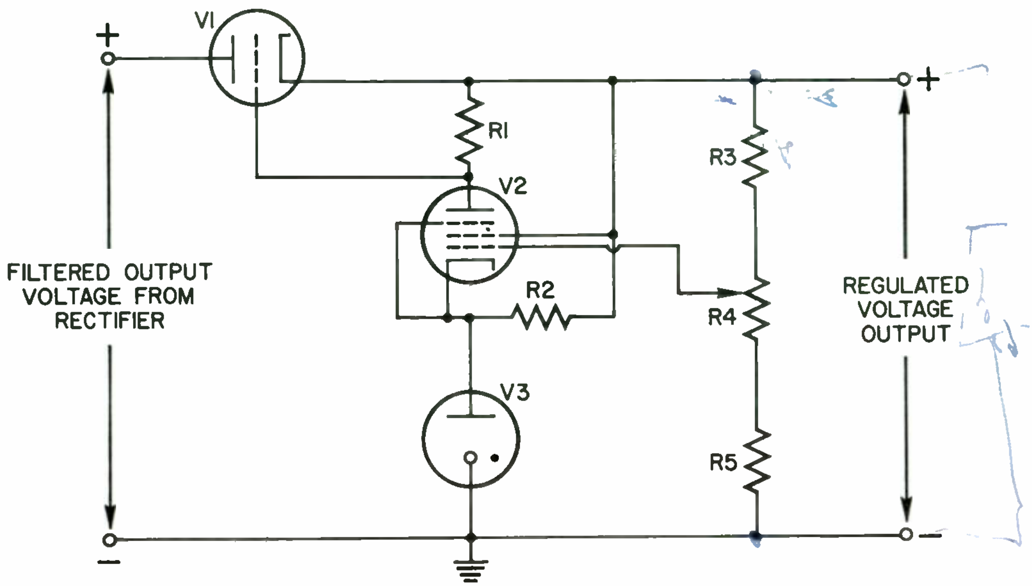


Figure 32 - Improved voltage regulator.

amount that is equal to the bias on V2. The plate current of V2 flows through R1 and causes a drop across it. The magnitude of the voltage across R1 is the bias on tube V1. Therefore, the adjustment of potentiometer R4 establishes the normal resistance of V1. This adjustment is used to set the value of load voltage that the regulator is to maintain.

If the load voltage tends to rise, whether from a decrease in load current or from an increase in the input voltage, the voltage between the moving contact on R4 and ground will increase. The difference in this voltage and the fixed voltage across V3 decreases. These two voltages are in opposition, and the voltage between the moving contact on R4 and ground is less than the fixed voltage across V3. Thus, the grid bias of V2 decreases, and the plate current of V2 increases through R1. The increase in voltage across R1 increases the effective resistance of V1. If the load voltage tends to rise because of an increase in input voltage, this increase is accompanied by an increase in voltage across V1 and the rise in load voltage is checked. If the rise in load voltage is caused by a decrease in load current, this rise is checked because the IR drop across V1 remains constant, because the decrease in I is accompanied by an equal increase in R.

The anode of the glow tube, V3 is connected to the cathode of V2 and to the plus terminal of the regulated voltage output through resistor R2. It is necessary to connect the glow tube to B+ in this way in order to cause the gas in this tube to ionize when the power supply is first turned on.

All of the load current must pass through V1; therefore, this tube must be capable of passing a large current. In some regulators, a single tube does not have sufficient capacity to pass the required current. In such cases, several identical tubes may be connected in parallel.

The type of regulator shown in Figure 32 is used very widely to stablize the output voltage of rectifier power supplies. Because of its excellent sensitivity to small changes in input voltage, this regulator is very effective in removing ripple from the output of rectifier power supplies. The regulator, then, serves also to filter the output of a rectifier, although conventional filter systems usually are used in connection with a regulator.

Figure 33 is a complete power-supply showing the power transformer, the full-wave rectifier tube, the filter circuit, the voltage regulator, and the voltage divider. This figure summarizes much of the foregoing power-supply discussion.

SEMICONDUCTOR VOLTAGE REGULATORS

Semiconductor voltage regulators perform the same functions in electronic power supply circuits as electron tube voltage regulators. Although there are various circuit arrangments for semiconductor voltage regulators, the two basic types are the *shunt type* and the *series type.*

Shunt Type

The shunt type voltage regulator is used to provide a regulated output where the load is relatively constant, the voltage low to medium, and the output current relatively high. A simple Zener diode shunt voltage regulator arrangement is shown in Figure 34A.

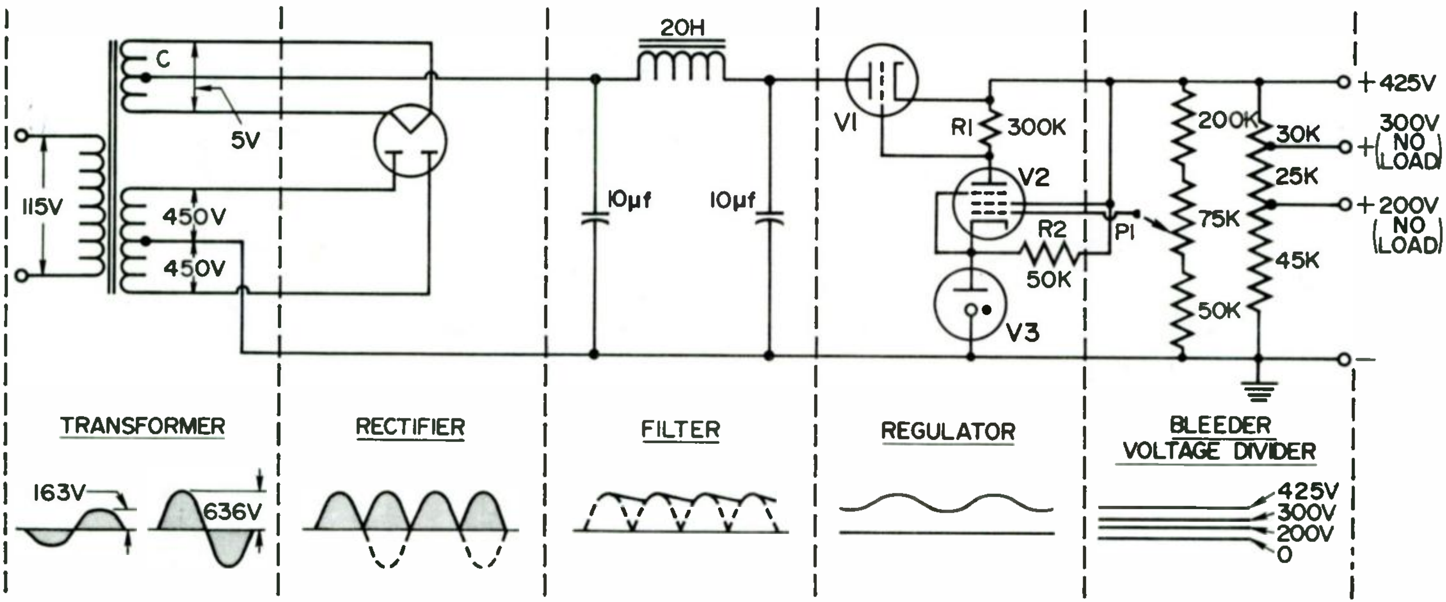
The regulator (Fig. 34A) holds the output voltage constant with a variable input voltage. For example, if E_{IN} increases, the voltage drop across R2 increases. (The voltage across break-down diode CR1 remains constant.) This action increases the forward bias on Q1, and the increase in collector current through R1 increases the voltage drop across R1 to hold the output voltage E_{OUT} constant.

Conversely, if the input voltage decreases, the drop across R2 decreases and the forward bias across the Q1 base-emitter decreases. This action decreases the collector current through R1 to decrease the voltage drop across R1 and again hold the output voltage constant.

For improved stability with respect to line and load changes, the arrangement shown in Figure 34B is used. The constant voltage across breakdown diode CR1 is one input to a differential-input, direct-coupled amplifier and the other input is a fixed percentage of the output voltage provided by divider R3 and R4. As E_{IN} changes, the amplifier output varies the Q1 base-emitter bias to maintain a constant voltage drop across Q1.

An overload or shortcircuit on the output of the regulators in Figure 34B will decrease the voltage across and the current through Q1 toward zero

Figure 33 - Complete power supply.



Low voltage is stepped up by the transformer from 115 volts to 900 volts. Center tap provides a dividing point so that 450 volts are applied to each section of the 5U4G rectifier. The ends of the transformer alternately become positive and negative.

Center tap C on heater winding is used to force plate current to divide equally in each filament lead. If there is no center tap, a voltage divider of two equal 50 ohm resistors may be put across the secondary to produce the same effect.

Alternately positive and negative voltage is applied to the plates of the rectifier.

The two plates conduct alternately as each plate is made positive in turn by the secondary of the transformer. Pulses of current flow from the filament line to each plate in turn. The plates alternately become positive and negative with the applied a. c., but the filament line will show a one-directional flow.

Capacitors charge when the rectifier conducts, and they discharge through the bleeder resistor when the tube is not conducting.

Choke builds up a magnetic field when the tube draws current. The field collapses as current decreases, tending to keep a constant current flowing in the same direction through the bleeder resistor and the load.

Capacitor input (illustrated) gives higher voltage output with low current loads.

Choke input gives steadier output with less ripple under load conditions.

If the load draws more current or if the a-c input voltage falls, the terminal voltage of the power supply falls.

Resistor R1, tube V2, and gas-tube V3 are in series across the rectifier terminals. V3 holds the cathode of V2 at a constant positive potential with respect to ground, and setting of P1 determines bias on V2. A fall in terminal voltage causes more negative bias on V2, less current through V2, hence, less current through R1. Less IR drop across R1 causes less negative bias on V1. V1 then acts as a lower value resistor, and terminal voltage decrease is checked.

As a bleeder, the resistor is for safety to discharge the capacitors when power is removed.

As a load resistor, it acts as a stabilizer to protect the voltage regulator at no load, and to improve the regulation.

A voltage divider meets the requirements of a load resistor and a bleeder, but in addition has taps placed at intervals for voltage at less than the maximum.

It is usually grounded at the lower end but may be grounded at any higher point to get a negative output.

Figure 33 - Complete power supply.

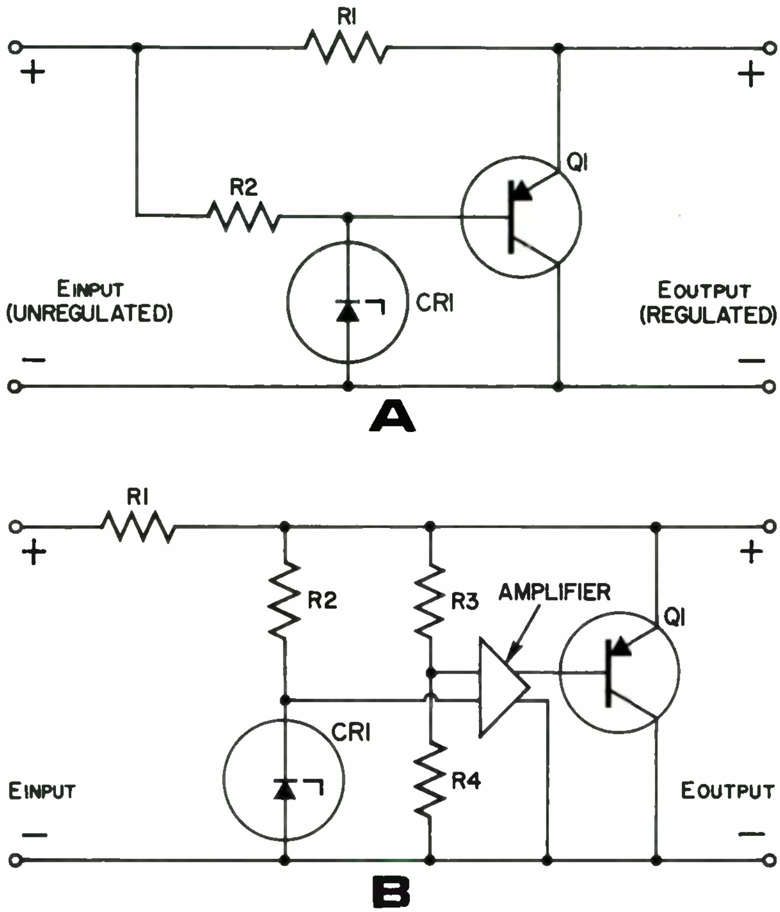


Figure 34 - Basic semi-conductor shunt voltage regulators.

so that there is no possibility of damaging Q1 or its driving amplifier. It is also important to note that at no load, Q1 must dissipate the full output power. For this reason, this type of regulator has a low efficiency and is used mostly in fixed voltage, fixed load applications.

Series Type

The series voltage regulator places the regulating transistor in series with the load. Regulation occurs as the result of varying the voltage drop across the series transistor. No output current is diverted through a path shunting the output as with the shunt regulator; therefore, the efficiency of the series regulator is somewhat greater than that of the shunt regulator. The series regulator does not have inherent overload protection, and can be damaged by a momentary short circuit unless suitable protection is provided by fuses or other means.

A simple series semiconductor voltage regulator is shown in Figure 35A. The resistance of transistor Q1 varies

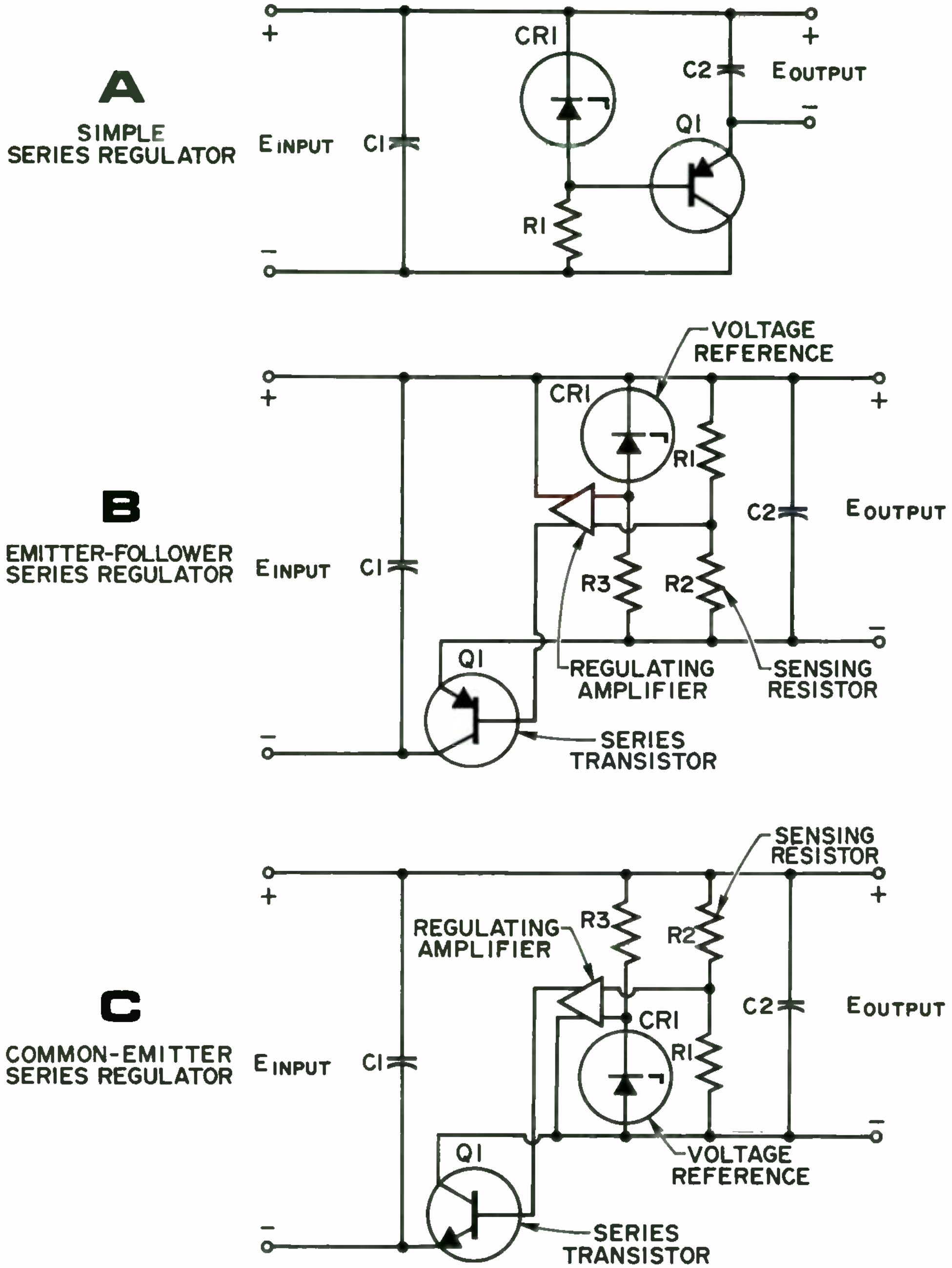


Figure 35 - Basic semi-conductor series voltage regulators.

with changes in the unregulated input voltage to maintain a fairly constant output voltage in the same manner as described for the electron tube voltage regulator (Fig. 31).

For improved stability, an amplifier is included as shown in Figures 35B and 35C.

There are two general methods of applying voltage gain to a series-regulating transistor. Both have about the same performance but they differ in the method of operating the series transistor. The first method, illustrated in Figure 35B, uses the series transistor as an emitter-follower.

The second method, shown in Figure 35C, utilizes the series transistor as a common emitter amplifier stage, since its input signal is applied between base and emitter, while its output is taken between collector and emitter.

Resistor R2 (Fig. 35B and C) senses the output voltage and provides, with R1, an input to the regulating amplifier. A constant reference voltage input is provided by the breakdown diode CR1. Any change in output voltage (representing an error voltage) is amplified and used to control the effective resistance of transistor Q1 to hold the output voltage constant.

VOLTAGE DIVIDERS AND BLEEDERS

A resistor is frequently placed across the output terminals of a rectifier power supply to bleed off the charge on the filter capacitor when the rectifier is turned off, or to apply a fixed load to the filter and, thus, to improve the voltage regulation of the power supply. In the latter case, the resistor is designed to draw at least ten percent of the full-load current in order for the change in power supply current to be less for a given change in load and thus reduce the magnitude of the variation in output voltage. In both cases, the resistor is called a *bleeder resistor.* If leads are connected to the resistor at various points to provide a variety of voltages that are less than the total output voltage, the resistor is called a *voltage divider.*

A resistor that is used as a load resistor may also serve as both a divider and a bleeder. A simple voltage divider composed of three equal resistors in series is shown in Figure 36. As long as no load current is drawn from any terminal (except the top or line terminal), the voltages across the resistors will divide in proportion to the resistance of each, as shown in Figure 36.

It is common practice to ground one side of voltage dividers. Therefore, ground potential is normally used as a reference for measurement of voltages as indicated at point D in Figure 37A. If a rectifier and its filter are connected so that no parts of the system are grounded, the divider can be grounded at any point without affecting the operation of the rectifier, provided the insulation of all parts is sufficient to withstand the voltage involved. Thus, in Figure 37B, point C is grounded, and point D becomes negative with respect to ground. Such a circuit may be used to

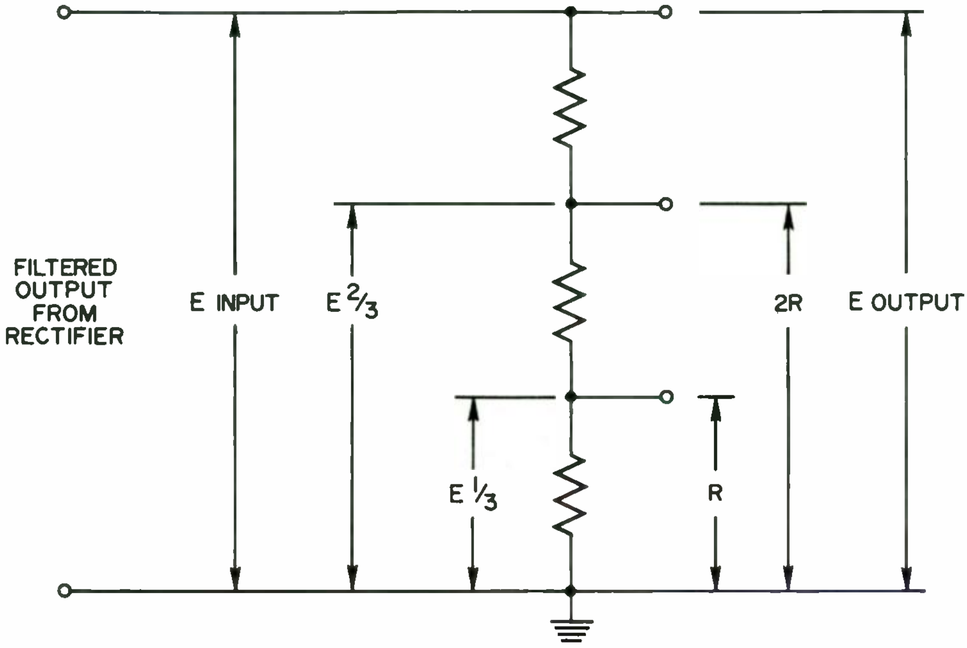


Figure 36 - Simple voltage divider.

furnish both plate and bias voltages from the same power supply. In Figure 37C, point A is grounded, and all voltages along the divider are negative with respect to ground. Note, however, that point A will always be positive with respect to points B, C, and D as long as the electron flow is maintained from D to A as shown in Figure 37C.

In the voltage divider circuits (Fig. 37) it has been assumed that no load was attached to the divider except across terminals A and D, and that voltages could be measured without drawing appreciable current. As soon as a load is connected across the divider at any intermediate terminals, however, the voltage division shown in Figure 37 is no longer correct. The resistance of the attached load forms a parallel circuit with that part of the divider across which it is placed, and there is a change in the resistance of that part of the divider in relation to the total resistance between terminals A and D. The resistances in a divider are usually adjusted to provide correct voltages at normal load conditions.

SUMMARY

An electronic power supply must be capable of furnishing its associated electronic circuit with the correct voltage and current to assure proper operation. A transformer is used to step-up or step-down the AC line voltage. A rectifier converts the AC into pulsating DC. A filter is employed to remove the AC ripple voltage

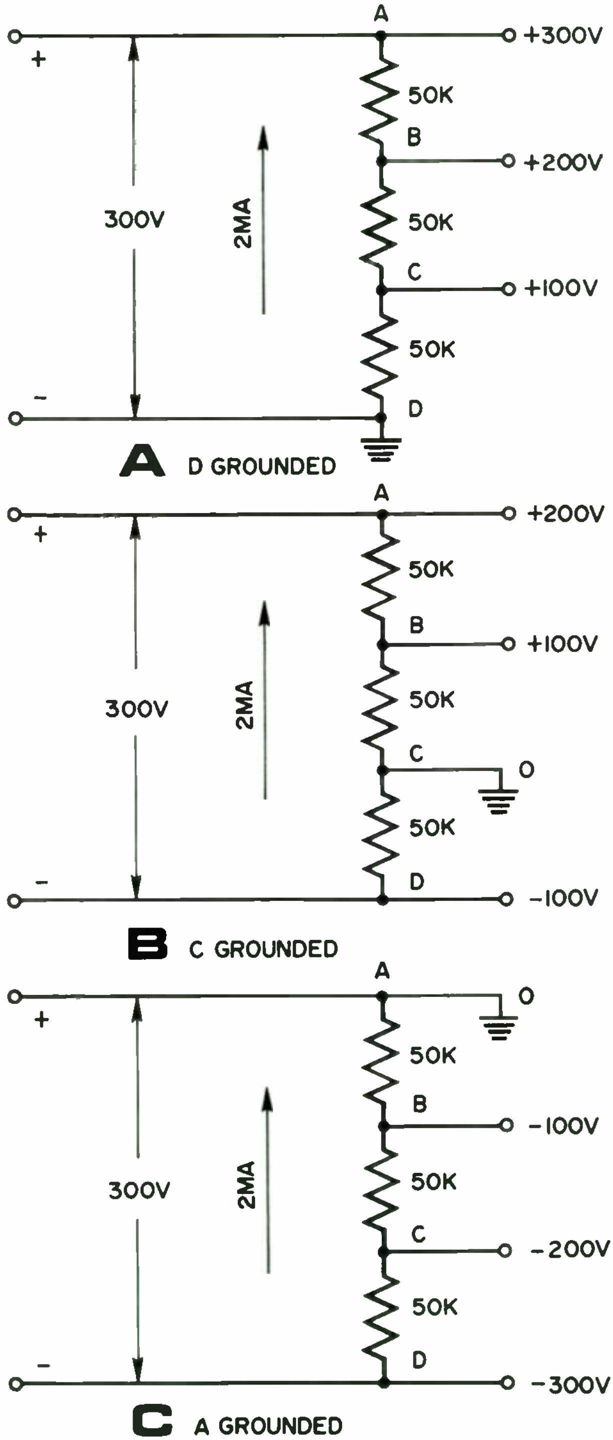


Figure 37 - Effect of moving the ground point on a voltage divider.

and produce an almost pure DC voltage.

The capacitance filter is the most simple and least expensive of the power supply filters. The capacitance filter is seldom used in high current applications. Inductance filters provide good filter action but the output voltage never reaches the peak value of the sine wave. Hence, the output voltage is lower than the input voltage. The Pi-section filter combines the capacitance filter and inductance filter to remove ripple and produce a voltage of nearly constant magnitude.

Voltage regulation is necessary to compensate for line voltage fluctuations and load current changes. The voltage regulator functions to provide a nearly constant voltage output for all line or load variations.

....

TEST

Lesson Number 43

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 52-043-1.

1. The purpose of the power transformer used in an electronic power supply is to
   - A. increase or decrease AC line voltage to meet the requirements of the supply.
   - B. convert AC into DC.
   - C. remove all ripple voltage from the pure DC voltage.
   - D. provide a load for the voltage regulator.

2. The purpose of a rectifier circuit is to
   - A. convert AC into pure DC.
   - B. convert pulsating DC into pure DC.
   - C. convert AC into pulsating DC.
   - D. keep current in the load resistance flowing in both directions.

3. Current flows through the diode in a half-wave rectifier for ________ degrees of the 360 degree sine wave input.
   - A. 90
   - B. 180
   - C. 260
   - D. 270

4. The minimum number of diodes necessary in a full-wave rectifier circuit using a center tapped transformer would be
   A. 1.
   B. 2.
   C. 3.
   D. 4.

5. In a full-wave rectifier, current flows in a load resistance for ______ degrees of the 360° AC sine wave input.
   A. 90
   B. 180
   C. 270
   D. 360

6. The purpose of a filter in a power supply is to
   A. convert AC to pulsating DC.
   B. keep current flowing continuously through the diodes.
   C. make the output appear more like the AC input.
   D. remove AC variations from the pulsating DC.

7. A Pi-section filter contains
   A. 3.14 resistors.
   B. 3 resistors and 1 inductor.
   C. 1 capacitor and 1 inductor.
   D. 2 capacitors and 1 inductor.

8. The purpose of the glow tube V3 in Figure 32 is to
   A. bypass all excess current around the load.
   B. filter the power supply output.
   C. indicate when the circuit is operating.
   D. maintain the cathode of V2 at a constant positive value with respect to ground.

9. If the load current from a power supply decreases, the output voltage will increase and the current through the bleeder resistor, which is across the output, will
   A. increase.
   B. remain the same.
   C. decrease.
   D. none of the above.

10. One purpose of a bleeder resistor connected across the output of a filter is to
   A. discharge the capacitors when the power supply is turned off.
   B. discharge the capacitors while the power supply is energized.
   C. increase current surges.
   D. shunt AC variations present at the output to ground.

Notes

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SET YOUR SIGHTS HIGH

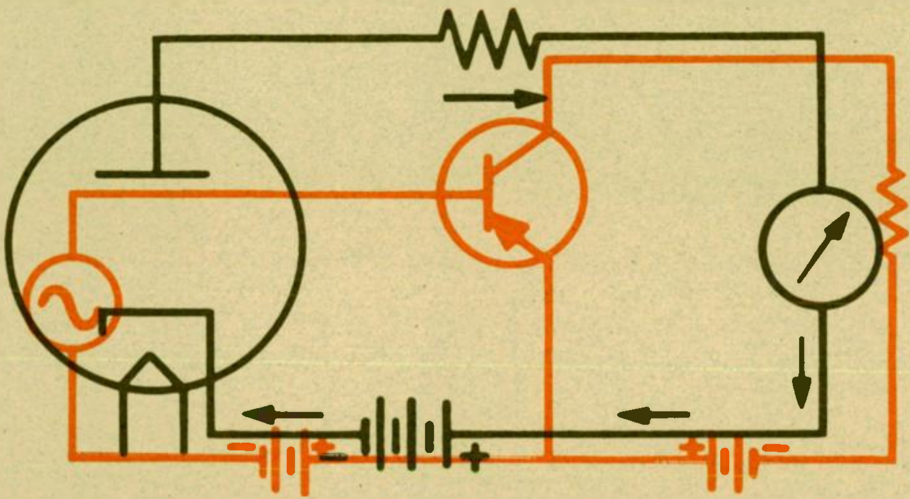
This year, like every other year, will be just as good and no better than you make it. The man satisfied to hold his own will learn, as so many other men have learned, that to stand still is to fall behind.

To get ahead this year. . .think big. This is no year for little men with little plans. No matter what goal others may set for you, resolve to do better. Never forget that "the higher you aim, the farther you shoot".

Your personality is your most important asset. Strive to improve your appearance, to keep your health, to strengthen your relations with your friends, employer, or customers through better service. Act more friendly, talk more interestingly about what you are doing and show genuine enthusiasm for your profession, your company and your future in this great field.

S. T. Christensen

REVIEW FILM LESSONS 40-43 BOOKLET



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LESSON CODE
NO. 52-044

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REVIEW FILM TEST

Lesson Number 44

The ten questions enclosed are review questions of lessons **40, 41, 42, & 43** 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

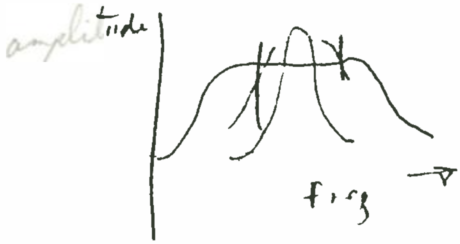
Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-044-1.

1. An audio frequency amplifier stage can be coupled to another audio frequency stage by________coupling. Imp High Cost
   - A. R-C
   - B. transformer
   - C. direct
   - D. all of the above

2. Audio frequency amplifiers cannot be operated________!
   - A. Class A
   - B. Class B
   - C. Class AB
   - D. Class C

3. Radio frequency amplifiers using triodes are efficient until their upper limit is reached. What factor in triode tubes causes them to fail at high radio frequencies?
   - A. Inter-electrode capacitance.
   - B. Distributor capacity.
   - C. By-passed RF.
   - D. DC saturation.

4. Audio amplifiers are considered to have a frequency range of
   - A. 50 to 5,000 hertz.
   - B. 20 to 20,000 hertz.
   - C. 10 to 10,000 hertz.
   - D. 50 to 15,000 hertz.



5. The frequency response of an amplifier will determine the
    - A. amount of amplitude distortion in that amplifier.
    - B. voltage gain of the amplifier.
    - C. type of bias used in the amplifier.
    - D. amount of frequency distortion in that amplifier.

6. The term "push-pull output" means
    - A. the output signal is out of phase.
    - B. two tubes pushing and pulling together.
    - C. two output transformers.
    - D. two tubes 180° out of phase into one output transformer.

7. The impedance of the speaker used with a transformerless transistorized power amplifier is generally
    - A. 3 ohms.
    - B. 50 ohms.
    - C. 16 ohms.
    - D. less than 16 ohms.

8. The half wave rectifier is __________ the full wave rectifier.
    - A. less efficient than
    - B. more efficient than
    - C. as efficient as
    - D. better than

9. Comparing a bridge rectifier to a full wave rectifier, the bridge rectifier
    - A. requires four diodes.
    - B. does not require a center-tapped transformer.
    - C. output waveforms are alike.
    - D. all of the above.

10. The most common type of filter network found in electronic power supplies today is the
    - A. inverted "L".
    - B. RC PI type.
    - C. inductive.
    - D. L-C.

Notes

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COMPONENTS

The Audio Frequency, Radio Frequency Amplifiers and Power Amplifiers you are reviewing in this film are known as "components" of an electronic circuit.

They are just a few of the many "components" that make up different electronic circuits. Each "component" has an important function to perform in the electronic circuit.

Failure of just one of them will affect the operation of the circuit and can prevent the proper operation of the equipment in which it is used.

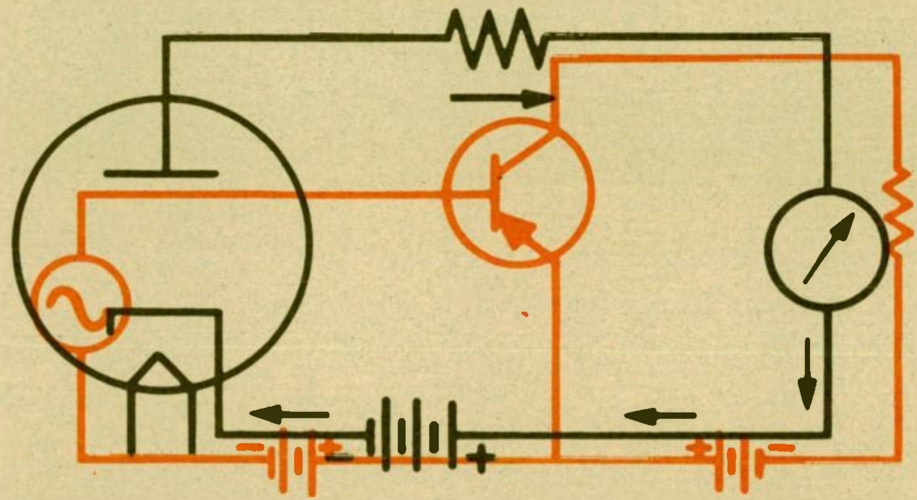
Failure of the volume control in your radio will prevent the radio from playing. Failure of the wall plug will prevent current from flowing to the TV. Failure of a switch can prevent your unit from operating. Each has an important function to perform in the circuit for which it was designed.

These are fundamentals you will find important, as you advance in your ASI Training. Make it a point to study and learn all about each circuit "component" and you will find it easy to handle even the most complicated circuits.

S. T. Christensen

LESSON NO. 45

SWITCHES AND RELAYS



RADIO and TELEVISION SERVICE and REPAIR

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CONTENTS

SWITCHES AND RELAYS

INTRODUCTION

A switch is a component that makes and breaks (connects or disconnects) continuity paths within a circuit. It either closes and permits current to flow or opens and prevents current from flowing. Switches must be able to withstand both the voltage applied to their contacts and the current flowing through their contacts. They are rated in volts and amperes, a rating that is usually stamped on the body of each unit.

Ratings

Volt-amp ratings are usually specified for a maximum voltage, such as 240 VA (volt-amps) at 120 volts AC or DC. In this case, the maximum voltage that should be applied across the open contacts of this particular switch is 120 volts. This voltage can be either AC or DC. The kind of load the switch can handle is not specified in the above example; therefore, it may be either resistive or inductive.

Some switches have multiple ratings. An example is a switch that is marked with the two following sets of figures:

Rating 1. 480 VA at 240 volts AC or DC Resistive
Rating 2. 240 VA at 120 volts AC or DC Reactive

The ratings in example 1 are more liberal than those in rating 2 because resistive loads do not store energy that must be dissipated when the switch contacts are opened. Components in a reactive load (a load containing capacitance or inductance) on the other hand, do store energy. When the contacts supplying current to a reactive circuit break, an arc occurs across the contacts. This arc continues until either the stored circuit energy is dissipated or the contact separation is too great for the existing voltage to force current across the gap. The reactive current that causes an arc is often many times greater than the normal circuit current and can cause destruction of the contact surfaces unless the current is specifically limited.

Relays

Electrically operated switches called *relays* are used to control circuits; sometimes from remote locations. They consist of a coil, an iron core, and a set of mating fixed and movable contacts. The movable contacts are part of the armature assembly. Wires connect the coil terminals to a source of power through a remote switch, tube or transistor. When the control switch is closed, or the tube or transistor conducts, an electromagnetic field is set up around the coil. The magnetic field pulls the armature with its contacts toward the fixed contacts until they meet, completing the circuit.

When the control source is opened, the field around the coil collapses. A spring returns the armature toward its resting position breaking the connection. In this lesson you will be introduced to construction and application of both manually operated switches and electrically operated relays.

Basic Operations

Switch contacts close in one of two basic ways. In some types the contacts simply come together face to face. In other kinds the contacts slide together with a *slide-by* wiping action. Common among the latter are units with dual fixed contacts that press together with pincer-like action, due to spring tension. The movable contact is a blade that "knifes" between the fixed contacts making a solid contact. The "wiping" action of contacts serves to remove any dirt or oxide from their surfaces.

Switches are designed to make and break swiftly. This rapid action prevents sustained arcs from occurring and damaging the contacts. *Snap-action* is the name usually applied and it is accomplished by designing the throw mechanism in such a manner that it works against spring tension. The physical resistance encountered opposes any attempt to change positions until sufficient force is built up to overcome the opposition. At this time the switch suddenly snaps to another position.

When a switch position is selected, some provision must be included to keep the switch in this position. This is done with mechanical stops called *detents* and this action has been named *detent-action*. One popular kind of detent mechanism uses a spring loaded metal ball that is attached to, and moves with, the switch arm. Depressions or holes smaller than the ball are punched into the channel in which the ball moves. These depressions or holes are located at spots where the mechanism is intended to be stopped. At these positions the ball drops into the hole and halts the travel of the throw mechanism, holding the switch securely in this position. Many other kinds of detents are used in various switches. A knowledge of all these would be of interest only to the switch designer or engineer.

A single set of switch contacts is called a pole and one pole will make and break one connection. If a unit has only one pole it is called a *SP* (single pole) switch. If it has two poles, it can switch two connections and is identified as a *DP* (double pole) switch. Each additional pole can switch an additional connection. When the amount of poles are greater than two, they are identified by number; such as 3P, 4P ...... 7P, etc.

The *throw* (T) of a switch refers to the mechanism or action of selecting a contact. If a switch (for example) selects only one contact or group of contacts it is referred to as a *ST* (single throw) switch. If it has two individual positions and selects contacts in either one, it is identified as a *DT* (double throw) switch. When three or more positions are selected, it is then identified by the number it selects. Examples:

> 3T indicates a three throw switch capable of opening and closing three separate contacts or groups of contacts.
>
> 4T indicates a four throw switch.

The number of poles in a switch is combined with the number of throws to describe its switching capability. Thus:

> SPST indicates that a *single pole* is opened or closed by a *single throw* of the actuating mechanism.

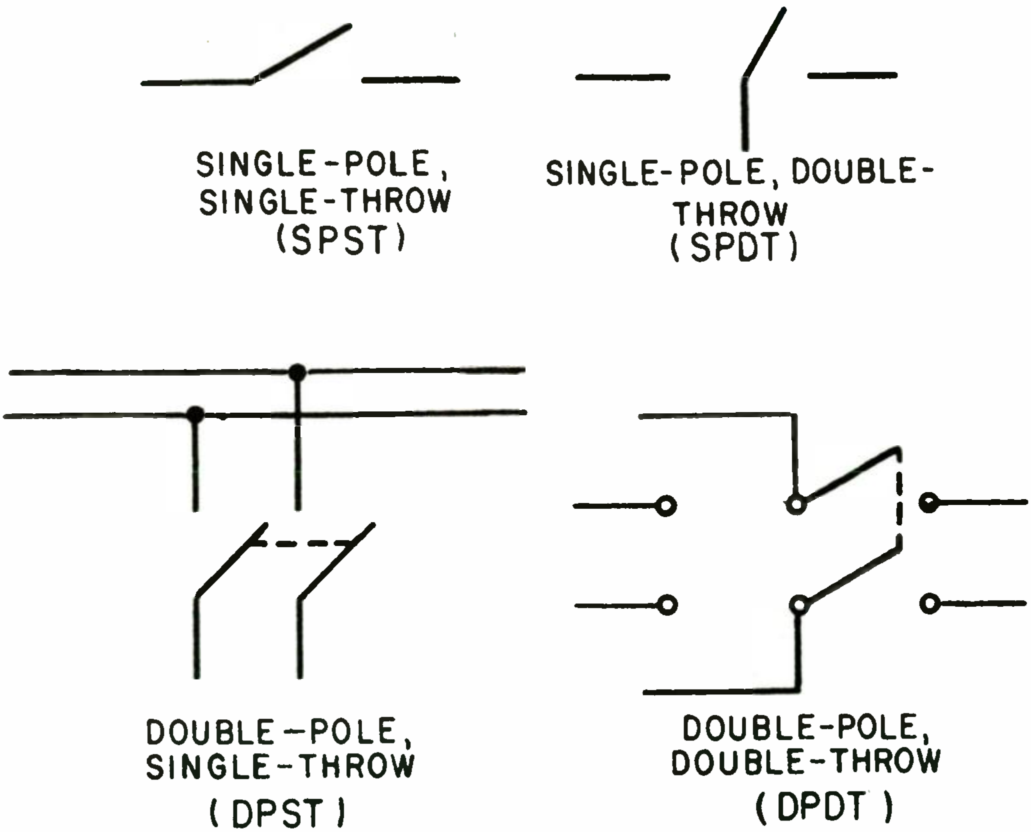


Figure 1 - Single pole and multi-pole switches.

DPDT indicates a double set of contacts and the DT indicates that the two movable contacts mate with a different pair of fixed contacts in each of the two throws (Fig. 1).

ROTARY SWITCHES

The most common example of a rotary switch is the "On-Off" switch of most radios. Turning the knob on the shaft in a clockwise direction, places the switch in the "On" position and rotating it counter-clockwise (to the limit of its travel) snaps it to the "Off" position. For this application a SPST (single pole-single throw) switch is the kind most often used. Other applications require the use of rotary switches with many more positions and/or poles, such as a TV channel selector which has at least twelve and more often thirteen positions. Figure 2A pictures an eleven position rotary switch. The schematic symbol of a nine-position rotary switch is shown in Figure 2B.

Most rotary switches are of open frame construction with their contacts readily visible for inspection. However, once the switch is mounted on a chassis, some portions are concealed from view. A small mirror similar to a dental mirror, must then be used to examine them. Rotary switches are used in nearly all electronic products including radio and TV receivers.

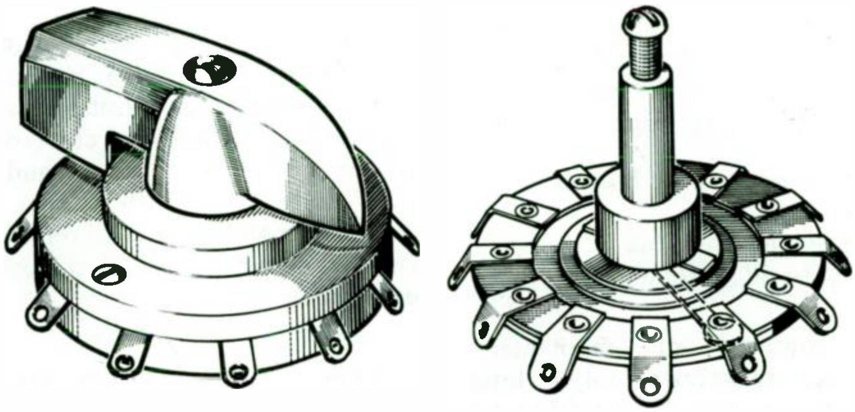
Controls with Rotary Switches

Rotary switches are often attached to function controls (volume, tone, etc.) to form a combination that controls more than one action. The most common example of a control mounted switch is the combination of volume control and power switch used in many radio and TV sets. Rotating the volume control counter-clockwise to its limit of travel engages the power switch and interrupts power to turn the set off. Clockwise rotation, only a short distance from the Off position, snaps the power switch on.

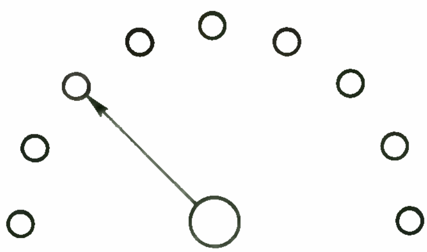
Many Hi-Fi sets and amplifiers have the power switch mounted on a tone control. This allows the listener to adjust the volume to a comfortable level. The volume control position is not changed when the receiver is tuned on or off.

Simple audio amplifiers discriminate differently against high and low frequencies at different volume control settings. What is pleasant listening at one volume control setting, lacks high-, low-, or mid-frequencies at other settings. This discrepancy is due to the different RC time constants at various resistance settings of the control.

High quality amplifiers use various forms of compensation to maintain correct frequency balance. One of these systems uses a switch (or switches) that engage at specific control settings and activate networks that normalize the levels of all frequencies. This system provides the proper balance between frequencies regardless of volume control setting.



A



B

Figure 2 - Rotary switches.

Push Button Switches

Push button switches are activated from a button attached to the mechanism (Fig. 3). These can be classified into three groups:

1. *Momentary* push button switches
2. *Push-push* switches
3. *Push-pull* switches

The contacts of momentary switches remain activated only so long as the button is pressed. Releasing the button allows the contacts to return to their normal resting state. The normal resting state may be either normally open (NO) or normally closed (NC) as the application demands.

Push-push switches change state when the button is pressed and remain in that state until the button is pressed a second time. If the contacts are open before they are activated, the first push causes the contacts to close and a second push opens the contacts. Push-push switches are available with a mixture of NO and NC contacts.

Push-pull switches have a plunger attached to the switch's mechanism. This plunger has two positions, either in or out. The "On" state corresponds to one of these positions and the "Off" state to the other. They too, allow power to be switched on and off without disturbing the loudness adjustment.

Push-pull or *push-push* are frequently attached to volume or loudness controls, a feature that allows the listener to turn a set on or off without altering the setting of the control.

TOGGLE AND SLIDE SWITCHES

Slide and *toggle* action switching is used frequently in industrial instruments and test equipment and occasionally in radio or TV sets. A toggle switch operates from a bat-like handle that pivots at some point within the switch (Fig. 4A). These

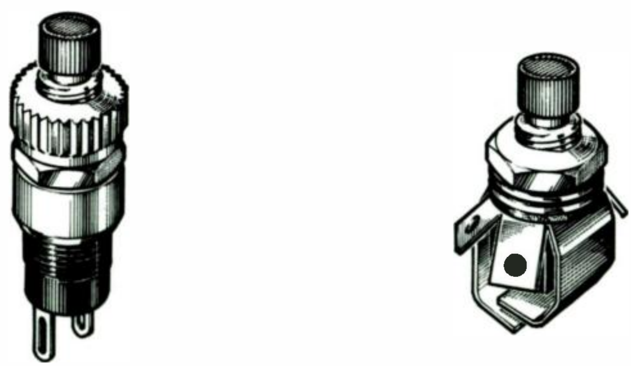
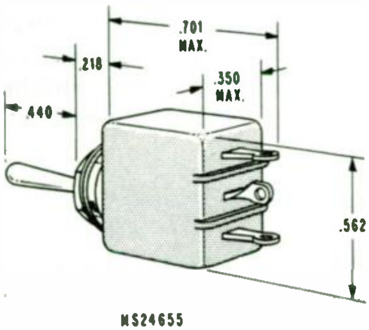
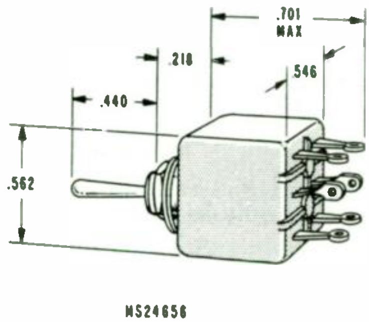


Figure 3 - Push button switches.

A
TOGGLE SWITCHES





B
SLIDE SWITCH

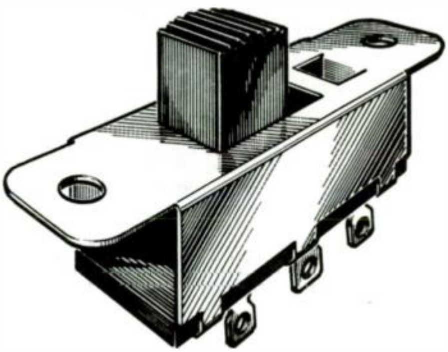


Figure 4 - Manually operated switches.

switches are activated by snapping the handle back and forth between two or three positions. Three position, toggle or *bat-handle* switches have a center-off position and they close a set (or sets) of contacts either side of center.

Slide switches operate from a square or rectangular button that slides back and forth in a rectangular channel (Fig. 4B). Slide switches may have several positions with a detent stop at each position. They are commonly used in test instruments or for controlling the record and play-back functions of tape recorders.

MULTIPOINT SWITCHES

Several independent switches can be grouped into a single assembly, thus forming a multipoint or multi-pole switch. The number of poles indicates the number of input terminals where current can enter the switch. The *throw* of a switch signifies the number of circuits each blade (or contact arm) can complete through the switch. The number of positions indicates the number of places where the rotary arm, or arms, can come to rest. Figure 1 is a schematic representation of a double-pole, single-throw and a double-pole, double-throw switch. Figure 4A shows one type of a SPDT toggle switch, and a DPDT switch. Figure 5 shows (schematically) a multipoint switch of the rotary type. It is a two-pole, three position switch with the switching mechanism mounted on an insulated disc. A single wafer of a rotary switch may have a number of poles, but two or three poles are most common.

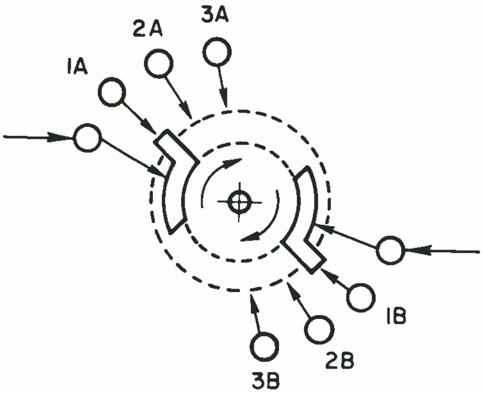


Figure 5 - A two pole, three position rotary switch.

MULTIDECK SWITCHES

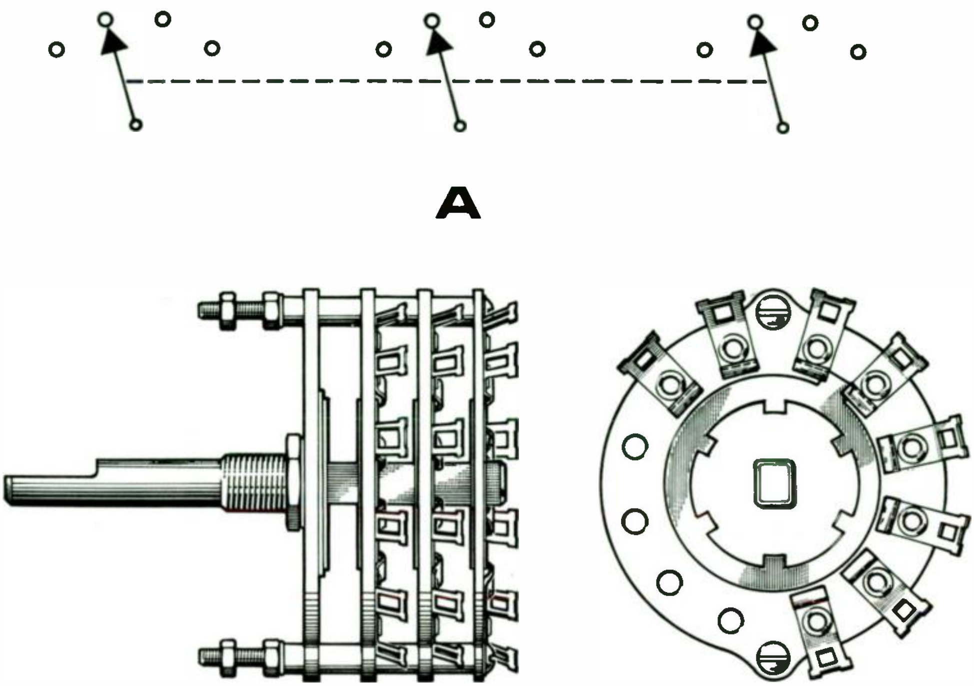
A rotary selector switch with a number of decks may perform the functions of a number of single deck switches. As the selector knob is rotated, contacts are opened from one circuit and closed to another. Some rotary switches have several decks or wafers and are called multi-deck, multi-wafer, or multi-layer switches. By adding wafers, the switch can be made to shift a large number of circuits as the selector switches do in TV tuners.

Figure 6A shows the schematic symbol of a three-deck, multi-position rotary switch. The dotted lines indicate that each one of the three switch arms on the three-deck switch shift from one contact position to another at the same time. The physical appearance of a three-deck switch is shown in Figure 6B.

A multi-deck switch with its associated wiring can appear to be impressive and complicated. In most cases, however, it is a combination of simple switching of circuits. One should always remember that it is just an assortment of independent switches with each section operating as an independent circuit. Thus, each switching function can be considered independently, to make trouble-shooting easier.

ELECTROMAGNETIC RELAYS

An electromagnetic relay is a device that is opened or closed with a switch. The switch is usually located in another circuit, thus allowing an electrical separation between the two circuits.



A

B

Figure 6 - A three deck, multi-position rotary switch.

Relays have a coil of copper wire wound on a steel core. The magnetic lines of force that are produced when current flows in the coil, pull in the armature of the relay. When the armature is flat against the face of the pole, it will have moved the center leaf of the switch from contact 1 to contact 3 (Fig. 7). There is no electrical connection between the current that flows in the coil through terminals 4 and 5, and the current that flows through the switch terminals 1, 2, and 3.

The current applied to the relay coil is usually controlled by either a mechanical "on/off" switch, or by a vacuum tube or transistor used as a switch. With the relay coil in the plate circuit of the vacuum tube, the coil will become energized whenever plate current flows. A similar action will occur when a relay is in the collector circuit of a transistor. The impedance of the relay coil must be appropriate for the circuit in which it is being used, which is one of the reasons for the wide variety of relays that are available.

Another reason for the wide variety of relay designs is the different switch forms that are available. The relay

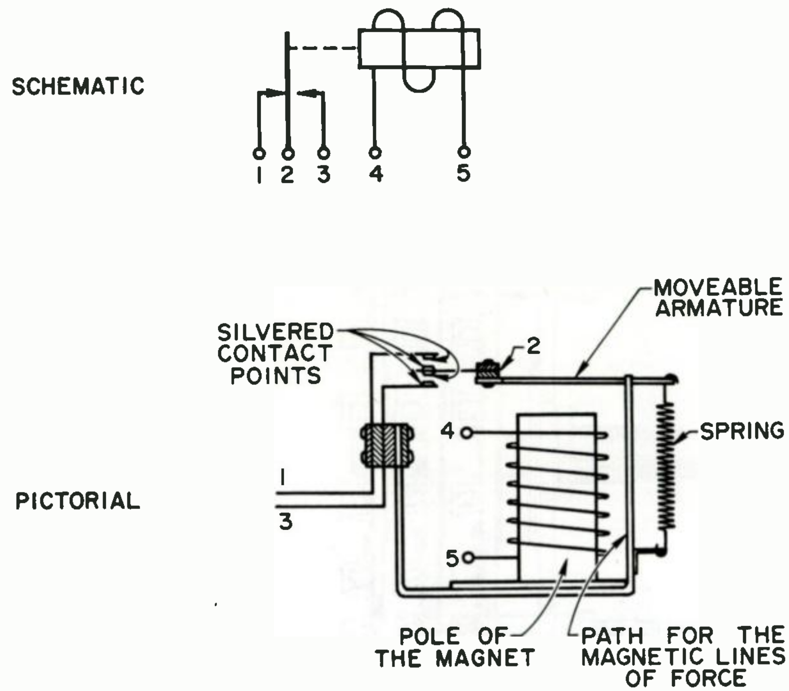


Figure 7 - An electromagnetic relay.

coils are wound for different currents and voltages, while the contacts are designed for different current carrying capacities. A relay coil that is designed to operate on DC is different than a coil designed for operation on AC. The magnetic field produced by a direct current flow is constant and maintains a uniform attraction of the movable armature against the pole face.

The operating principle of AC relay coils is fundamentally the same as the operation of DC relay coils except for one important difference. When AC is applied to an electromagnet, the current passes through zero, twice every cycle, permitting the magnetic field to collapse to zero. When the current nears zero, the armature tends to open each time, causing the contacts to chatter. To remedy this chattering, a shading coil is used on the pole piece of the magnet. A shading coil is a ring-like copper band or metal stamping that is placed around part of the pole face of the electromagnet. It acts like a secondary with a shorted turn around the core of a transformer. Since this shorted turn on a transformer, or the one turn of the shading coil, offers almost no resistance to current flow (caused by induced voltage) it will conduct an almost unlimited amount of current. This current in the shading coil occurs later (lagging in phase) than that in the main coil. In fact, current in the shorted turn is maximum when the current in the main coil is zero. Therefore, it causes a magnetic field to be counter-induced in the pole piece when excitation current is zero, thus preventing the armature from dropping out and causing mechanical chatter.

The switching action shown on Figure 7 is similar to the action of a SPDT switch. When the armature is against the pole face, the relay is said to be *closed*. In this position, contact 2 is separated from contact 1 and now touches contact 3. The dotted line in the schematics of Figure 7 is not always shown; it represents the line along which mechanical motion occurs due to the magnetic field. Relays are generally non-repairable and are usually replaced when they become defective.

REED RELAYS

Reed relays are popular supporters of the trend toward miniaturization. They are small and have their switch contacts enclosed in a sealed glass tube to prevent dust and moisture from interfering with their operation. Consequently, the contacts are rated for millions of operations, which is an unusual rating for a mechanical device.

Reed relay's contacts cannot carry heavy currents as they are small in size, although, in some cases the contacts can carry several amperes. The relay shown in Figure 8A is a SPST relay, about two inches in length. The one shown in Figure 8B is a SPDT type with contacts that can carry up to one-half ampere. All reed relays are energized by DC current.

CIRCUIT BREAKERS

A circuit breaker is designed to break the circuit and stop the current flow when the current exceeds a predetermined value. It is commonly used in place of a fuse and may sometimes eliminate the need for a switch. A circuit breaker differs from a fuse as it "trips" to break the circuit; it may be reset, while a fuse melts and must be replaced.

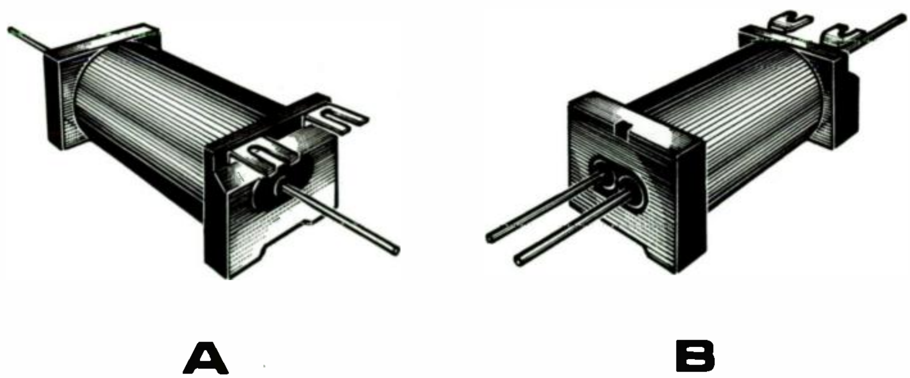


Figure 8 - Reed relays.

Several types of circuit breakers are commonly used, with the larger one being the magnetic type. When excessive current flows through the circuit of the electromagnet, it becomes strong enough to move a small armature which in turn trips the hold-in catch and opens the breaker. Another type is the thermal overload switch or breaker. This type consists of a bimetallic strip which, when it becomes overheated from excessive current, bends away from a catch on the switch lever and allows the switch to trip open.

Some circuit breakers must be reset by hand, while others reset automatically. If the overload condition still exists when the circuit breaker is reset, it will trip again to prevent damage to the circuit. Figure 9 shows a push-to-reset circuit breaker. Some TV receivers have this type of circuit breaker mounted at the rear with the reset button protruding conveniently through the back cover.

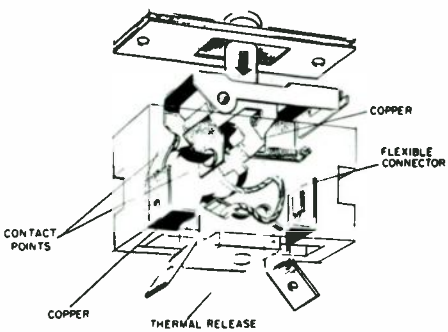


Figure 9 - Push-to-Reset circuit breaker.

SWITCH APPLICATIONS

Earphone Circuit

Some radio or TV sets have provisions for an earphone, which is a switch jack that automatically deactivates the speaker when the earphone plug is inserted. Figure 10 shows one type of circuit for this application. The phone jack is like a SPDT (single-pole, double throw) switch. Sometimes a low-valued resistor is inserted in series with the earphone to reduce the audio power to the earphone.

Switching in an AM/FM Radio

Figures 11, 12 and 13 illustrate the switching in an AM/FM radio. Three switch positions are used; one each for AM, FM and FM-AFC operation. A two-deck rotary switch with four independent groups of contacts is used. The switch unit is identified as SW1 to distinguish it from other switches in the set. Individual groups of contacts are identified according to which deck they are on (front or rear) and which section of the deck (1 or 2). Each group of contacts is assigned a particular function. The various functions of SW1's contact groups are:

Section 1 front:
grounds the automatic frequency control (AFC) bus to remove the effects of the AFC control voltage on the tuning except in the FM-AFC position

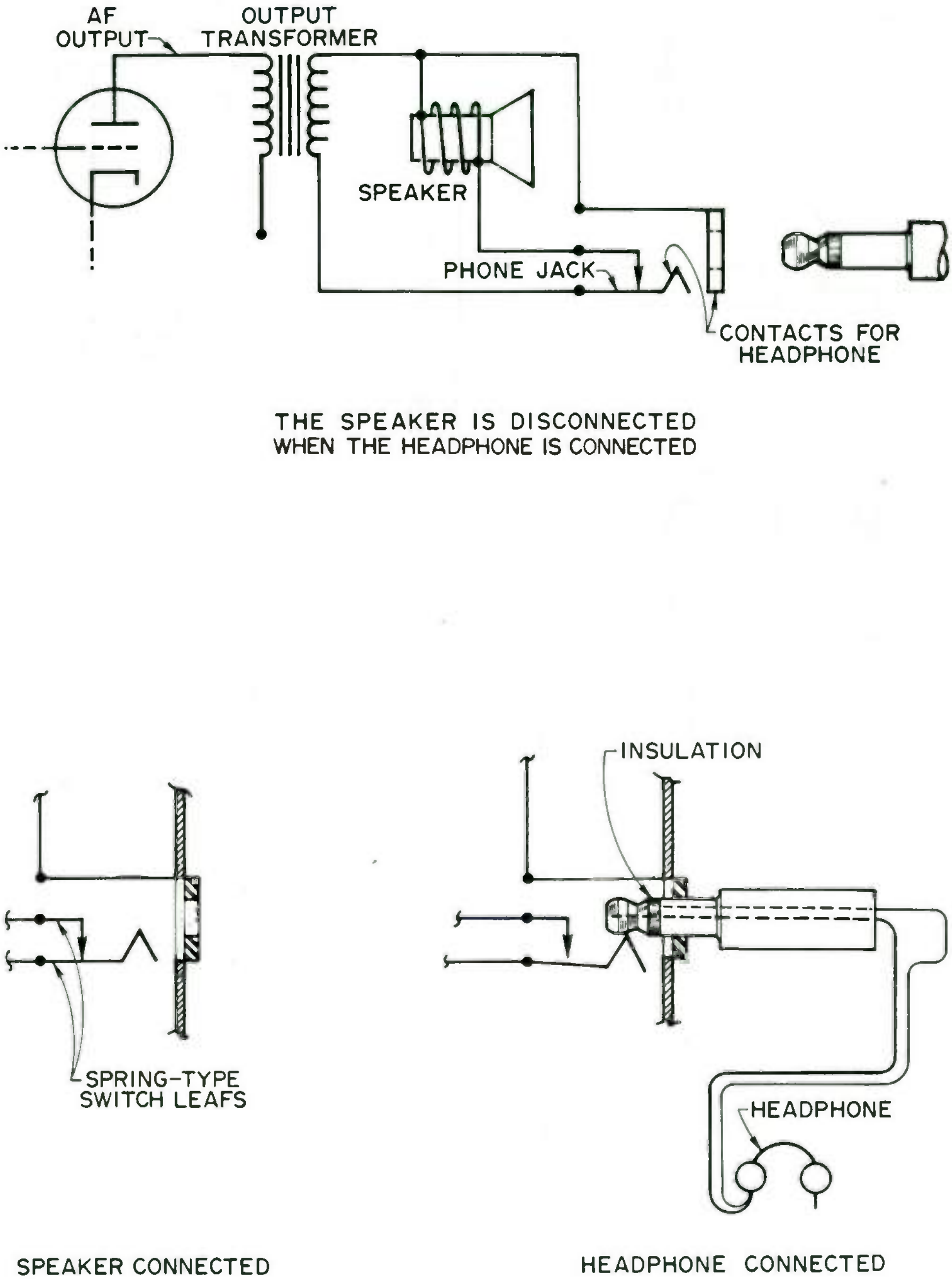


Figure 10 - An earphone circuit for a radio or a TV receiver.

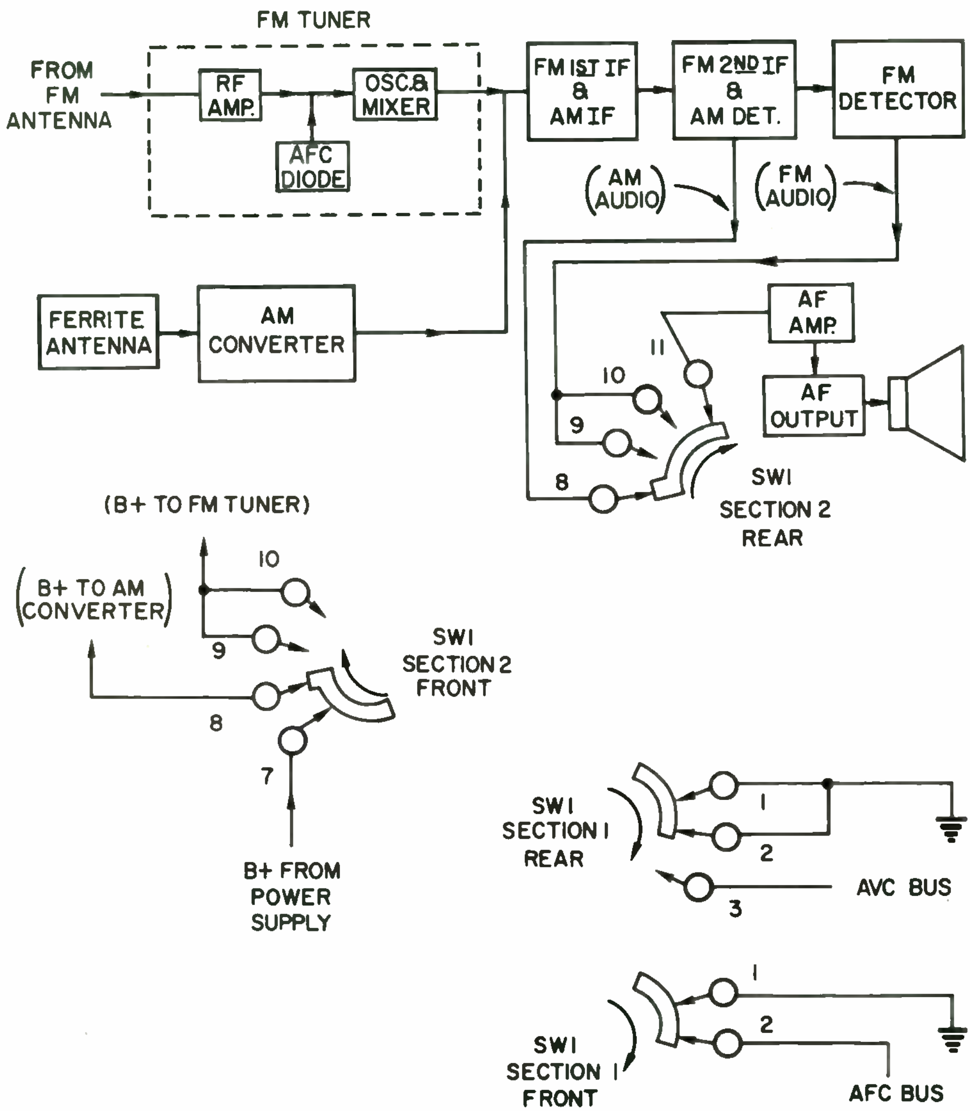


Figure 11 - AM/FM tube radio, in the AM position.

Section 2 front:
supplies B+ voltage to the AM RF and converter stages for AM operation;

or

it supplies B+ to the FM tuner during FM operation.

Section 1 rear:
grounds the automatic volume control (AVC) bus in the FM and FM-AFC positions to prevent a reduction of gain during FM operation. The ground is removed during AM operation allowing the AVC to function.

Section 2 rear:
switches the input of the

audio stage between the AM detector and the FM detector for AM or FM operation.

Figure 11 illustrates the switch (SW1) positioned for AM operation. Power (B+) is supplied to the AM converter stage through terminals 7 and 8 (section 2 front). Audio from the AM detector is routed to the AF amp through pins 8 and 11 (section 2 rear).

The AVC bus is removed from ground (section 1 rear) and the AVC is active. Section 1 front is not associated with AM operation.

Figure 12 shows SW1 rotated one position clockwise from Figure 11 for FM operation. Power (B+) is supplied to the FM tuner, through contacts 7 and 9, section 2 front. Pin 8 is opened, removing B+ from the AM RF and converter stages. The input of the AF amp is now connected to the output of the FM detector through lugs 9 and 11, section 2 rear. The AVC bus is grounded through terminals 1, 2, and 3, section 1 rear and the AVC is inactive. A ground path exists for the AFC bus through pins 1 and 2 of section 1 front and the AFC is still inactive.

In Figure 13, SW1 is shown in the FM-AFC position. Power (B+) is now

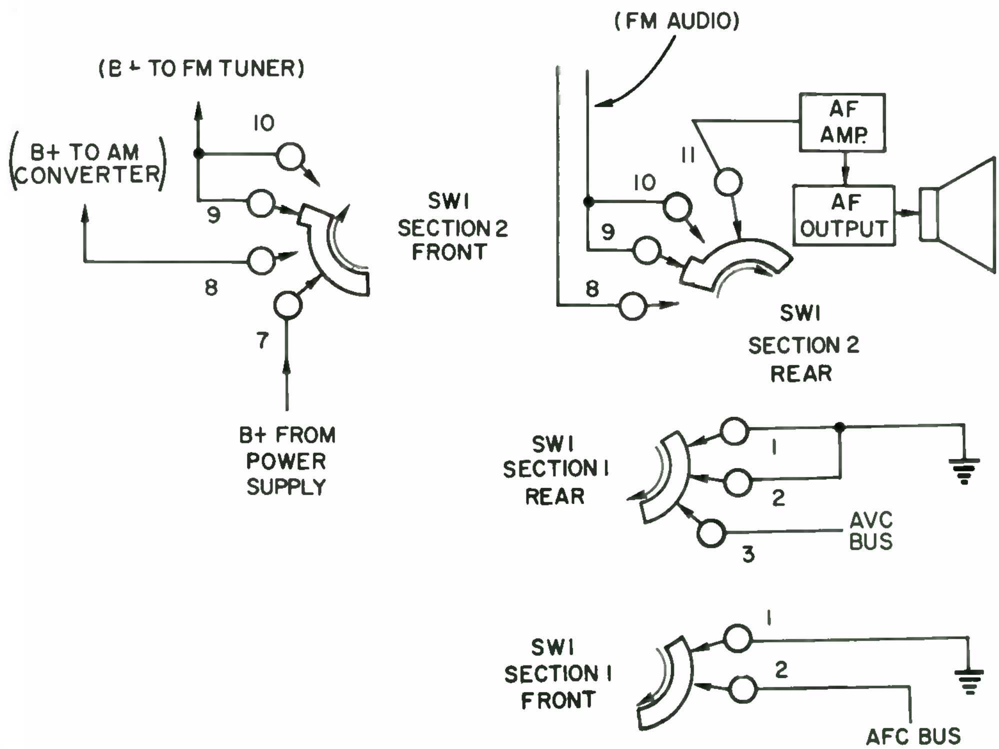


Figure 12 - AM/FM radio, in the FM position.

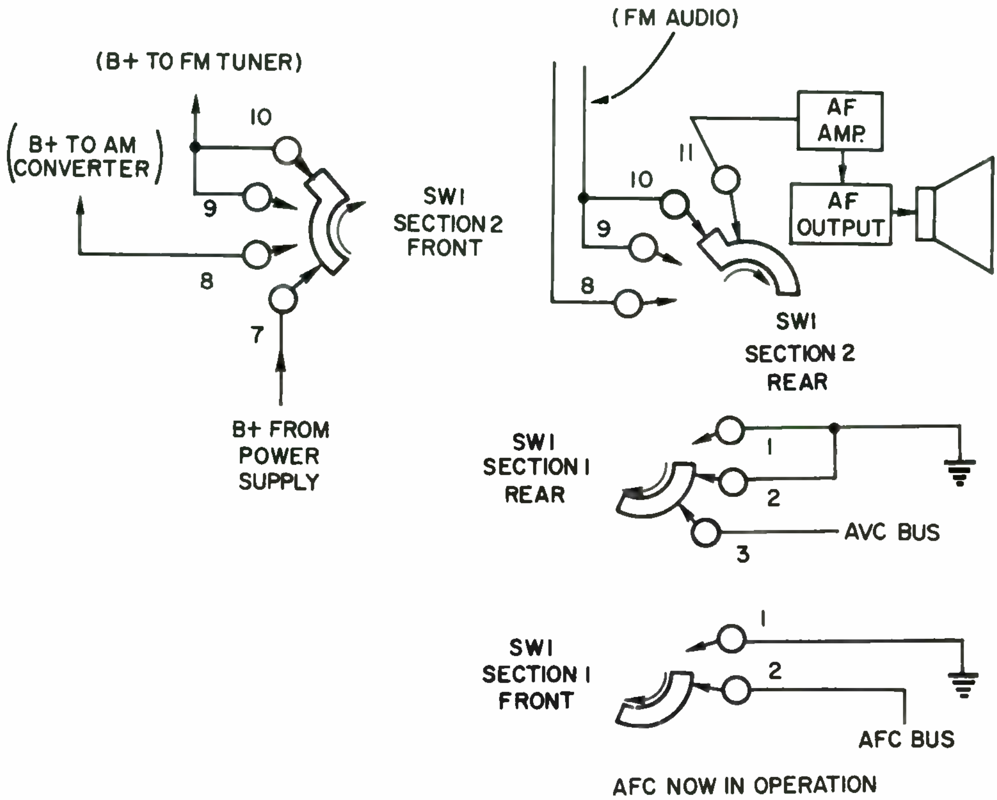


Figure 13 - AM/FM radio, in the FM position with AFC.

supplied to the FM tuner through switch terminals 7 and 10, section 2 front. The audio path between the FM detector and the AF amp is completed through terminals 10 and 11, section 2 rear. The AFC bus is removed from ground (section 1 front) and the AFC is in operation.

Note: AFC (automatic frequency control) is a provision whereby a control voltage is supplied to the FM oscillator to compensate for frequency drift.

Phono-Radio Combination

A tube-type phono-radio combination in block diagram form is shown in Figure 14. The selector switch is shown in the "Phono" operating position. The right audio signal from the stereo cartridge is connected (through the switch) to the right channel audio section. The left audio channel is similarly connected to the left channel audio section. A negative feedback loop is included in each channel to reduce distortion.

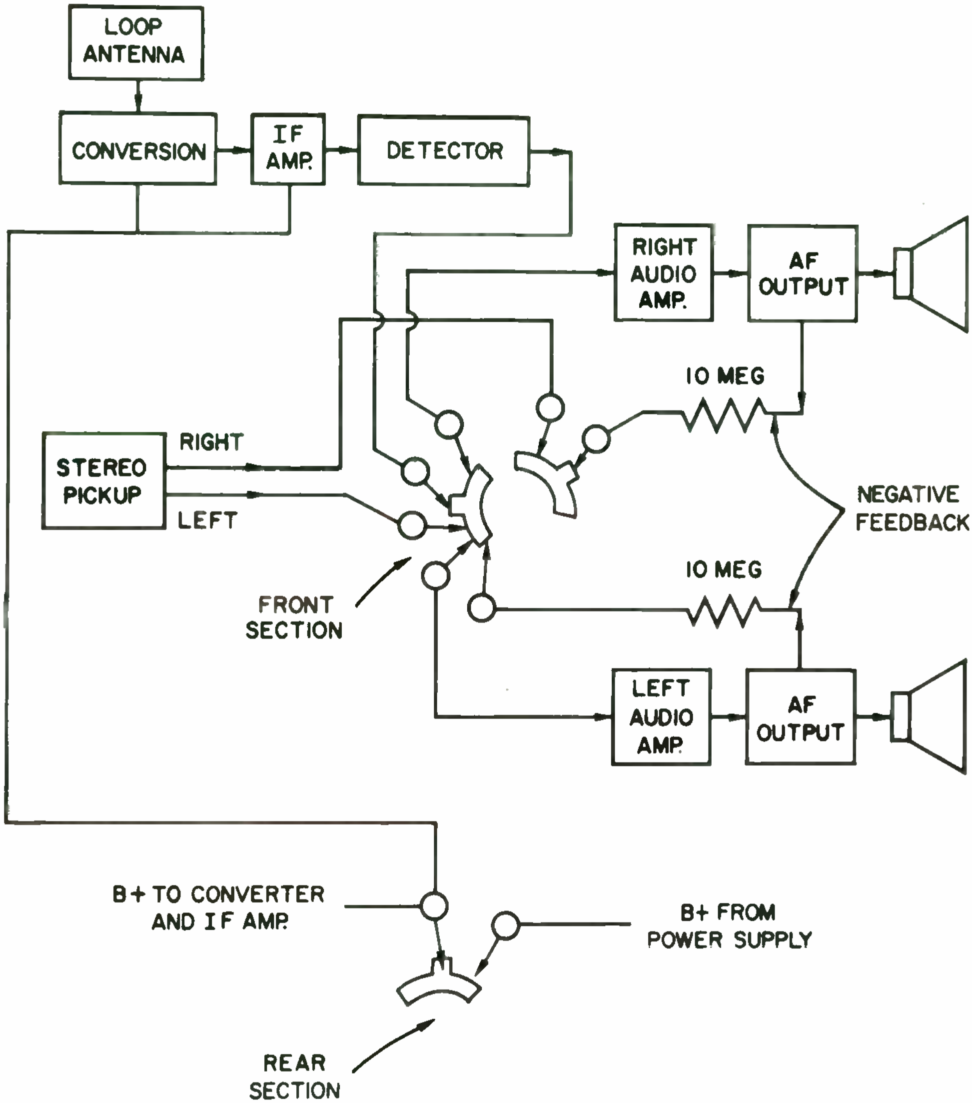


Figure 14 -Phono-radio combination in the phono position.

There is no audio at the output of the detector stage because the IF amplifier and converter stages have no voltage supplied to them. Consequently they cannot produce a signal for the detector to rectify. The AVC connections are not shown in this figure because they are not switched in this receiver.

Figure 15 shows the selector switch in the radio position. The pickup is no longer connected to the audio amplifiers; instead the detector stage feeds

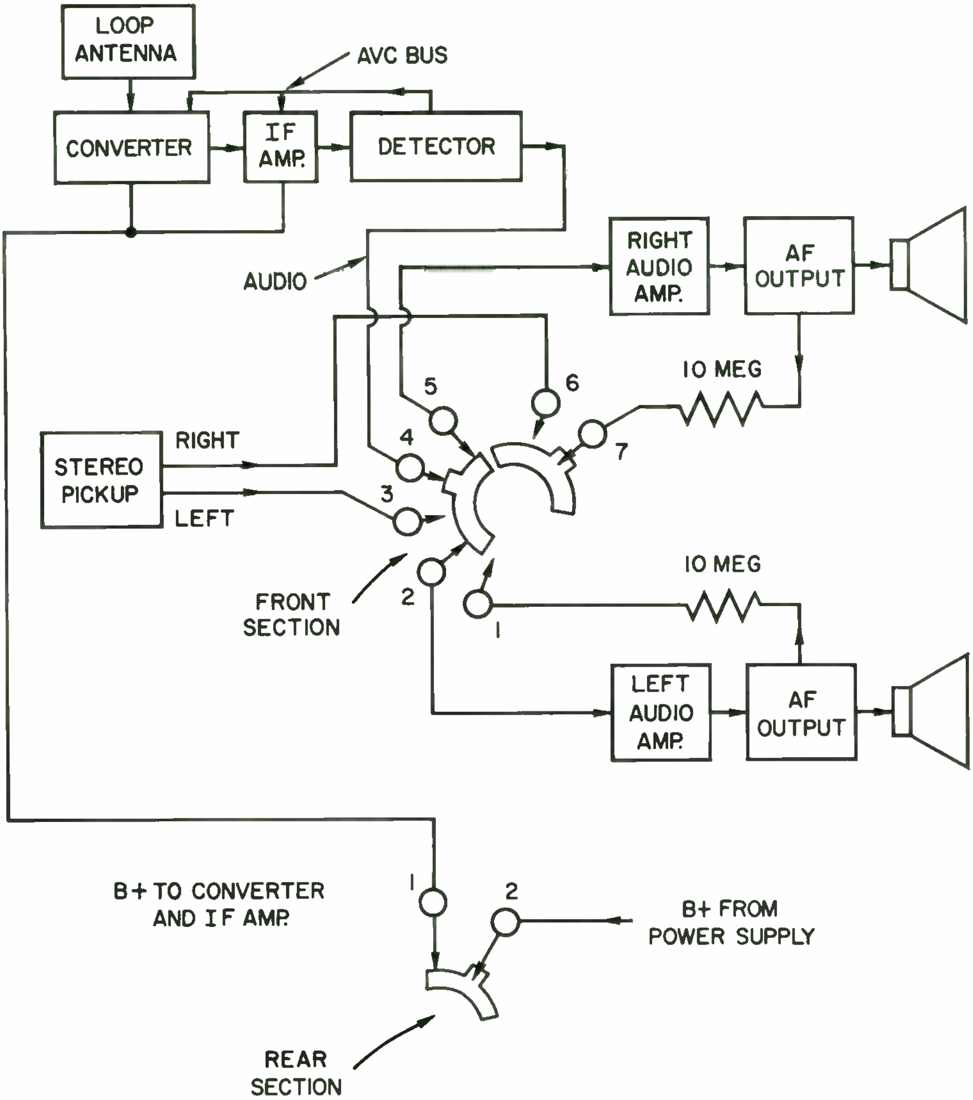


Figure 15 - Phono/Radio combination in the radio position.

both the right and left audio amplifiers. The negative feedback connections of each amplifier circuit have been opened by the switch and the absence of this negative feedback increases the gain of the audio section. The power supply circuit is completed to the converter and the IF amplifier, permitting these two stages to operate.

As you trace the signal through the set from the loop antenna to the speakers, observe that it passes in sequence through the converter stage, the IF amplifier, the detector, the switch, the audio amplifiers and finally through the output amplifiers to the speakers. The DC control voltage that appears on the AVC bus is obtained by filtering the pulsating DC output from the detector with a resistor-capacitor combination to remove the AF variation. The result is a negative DC voltage that increases with signals from strong stations and decreases for weak stations. This voltage controls the gain of both the converter and the IF amplifier so that strong signals are amplified less than weak ones to maintain a uniform sound level. AVC also permits tuning from strong stations to weak stations without having to adjust the volume control.

AM/FM RADIO, TWO-POSITION SWITCH

Figure 16 shows in block form a 6 tube AM/FM radio with the selector switch in the FM position. The lower section of the switch supplies B+ to the plate circuits of the RF amplifier and the FM converter. A twin triode tube is used for these two stages.

The FM antenna responds to many FM stations but the tuned circuit at the input of the RF amplifier selects only the signal from one station. The RF stage amplifies this selected signal and supplies it to the converter stage. At the converter stage, it is heterodyned to produce a 10.7 MHz IF signal. The IF signal is amplified through two IF amplifiers and applied to a ratio detector. The ratio detector is a commonly used FM detector that uses two semiconductor diodes. The AF output of the ratio detector is switched to the AF amplifier which feeds the AF output stage. The output stage then supplies the necessary drive to the speakers.

Audio from the output of the ratio detector is rectified first and then filtered and applied to an AFC diode in the oscillator portion of the FM converter. A small amount of AVC voltage is developed by the tube that is used as the FM IF amplifier, but it does not appreciably affect the gain during FM reception. The AM section is disabled during FM reception by removing B+ from the AM converter.

Figure 17 shows the same receiver switched for AM operation. The lower portion of the switch feeds the positive voltage from the power supply to the AM converter stage. Audio from the AM detector is connected to the AF amplifier through the upper portion of the switch. The FM RF amplifier and FM converter are inoperative because the plate supplies are interrupted. Thus, there is no audio at the output of the FM detector to interfere in any way with the AM operation.

The loop antenna supplies the incoming station signals to the AM converter which converts the one selected signal to a 455 kHz IF signal. This signal is fed to the IF amplifier which in turn supplies the AM

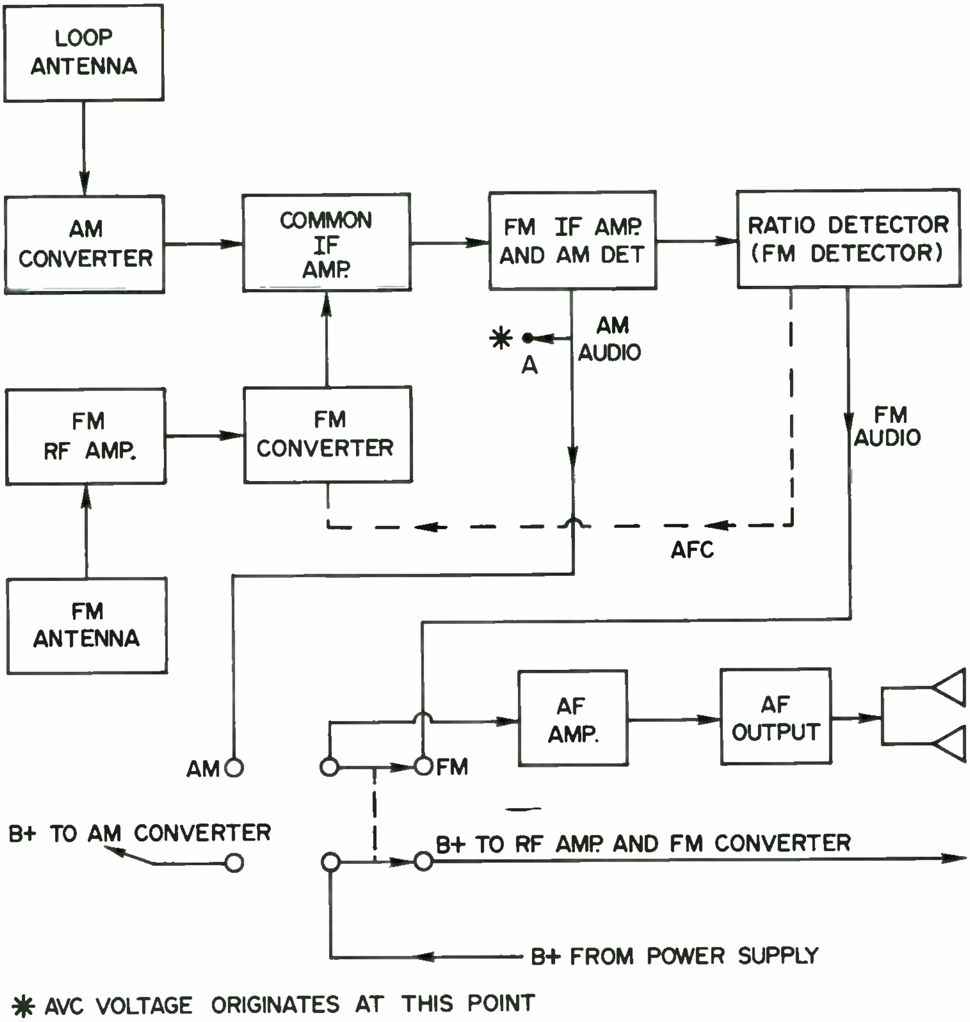


Figure 16 - AM/FM tube radio, with a two-position switch in the FM position.

detector stage. An AF signal at the output of the AM detector is fed to the AF amplifier. This signal is filtered (Fig. 16, Point A) in order to produce AVC voltage for the AM converter and the common IF amplifier. (AVC connections are not shown in the diagram). The audio stages function in a manner similar to that described for FM operation.

AM/FM Transistor Car Radio

A 9 transistor auto radio is shown in block form in Figure 18. The switch is shown in the FM position. Positive battery voltage is connected to the FM RF amplifier and the FM converter stages through the center section of the switch.

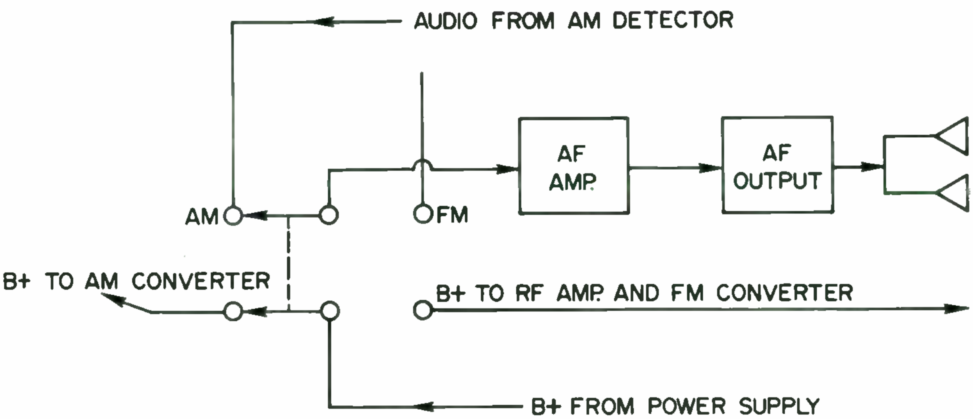


Figure 17 - AM/FM tube radio, two-position switch in the AM position.

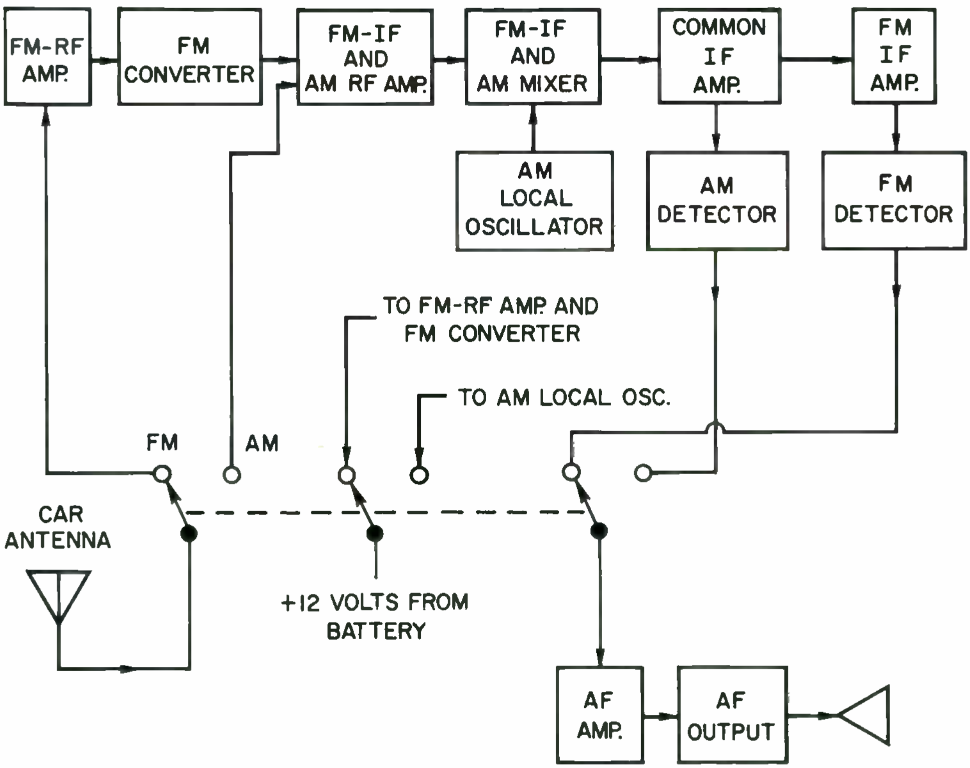


Figure 18 - AM/FM transistorized car radio.

The car antenna is coupled to the FM RF amplifier which in turn is coupled to the FM converter. The FM converter stage has an AFC diode that is controlled by a voltage derived from the FM detector stage. The connection between the two is not shown in Figure 18. A 10.7 MHz IF signal from the converter passes through four IF amplifiers and is then applied to the FM detector stage. Two semi-conductor diodes are used for FM detection, and the resulting AF is switched to the AF amplifier. The AF signal progresses through the AF stages and drives the speaker.

For AM operation (Fig. 18), the center switch section de-energizes the FM RF amplifier and FM converter and energizes the AM local oscillator. The left switch section switches the car antenna to the AM RF amplifier stage which supplies amplified RF to the AM mixer. The AM mixer also receives a signal from a separate oscillator. A 455 kHz mixer output signal is fed to the common IF amplifier and then to a diode AM detector stage. The resulting AF is supplied through the right-hand switch to the AF stages and to the speaker.

The center contacts that switch the battery voltages, are the only contacts that carry large amounts of current. As a result, these are the switch contacts that are apt to become defective after a period of use. The other two sections of the switch should have a long life because the contacts do not carry DC current. Arcing during disengagement of the switch (breaking the circuit) causes most damage to the switch contacts. Present day switches, however, have reasonable life due to improved design.

SEARCH TUNING

Radios with an automatic station seeking system are available for many cars. Momentarily depressing a spring returned push button switch, activates the signal seeking circuitry. The circuitry engages a motor (usually through a relay) which drives the radio's tuning mechanism. When a station of sufficient strength (for good listening) is encountered, the search (signal seeking) circuitry disengages the motor allowing the station to be received. If the program material is unacceptable to the listener, he simply presses the search button again and the next station on the dial is automatically tuned in.

The listener may repeat the operation until either he finds a program that suits him; or until every station within listening range has been sampled.

At the extreme end of the dial, the search system rapidly returns the tuning mechanism to the opposite end and begins all over in its search for stations.

The control circuitry (partially in block form) for a search tuning system is shown in Figure 19. The diagram shows a control bus originating at the IF or detector stage. The voltage on this bus is derived from the presence of a station signal and it is supplied to the input of the search control amp. This voltage at the input

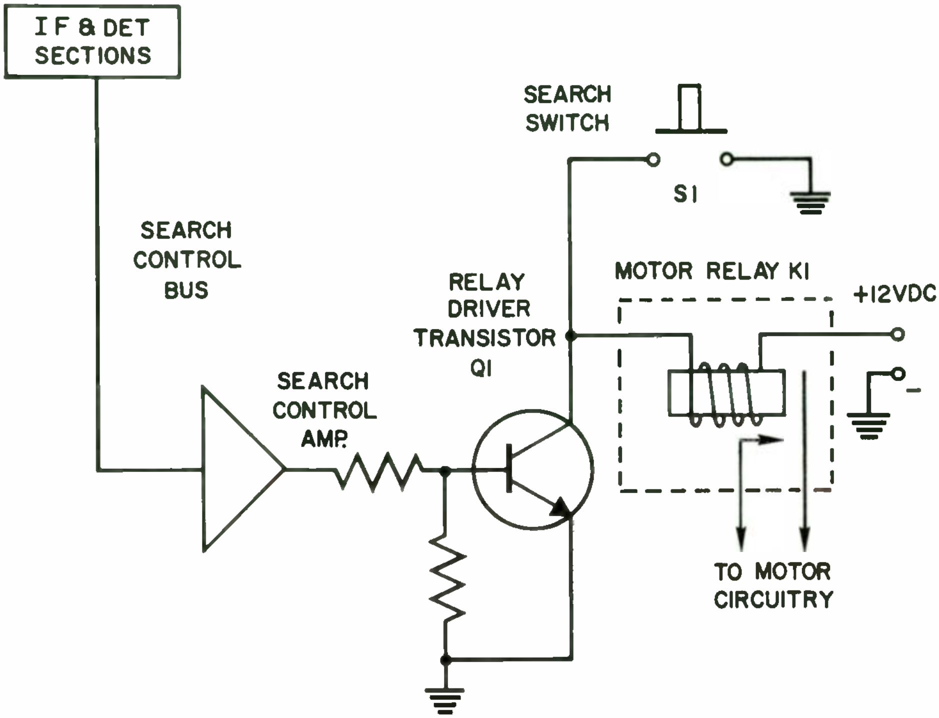


Figure 19 - Circuitry for search tuning.

of the search amp causes it not to supply drive to Q1. Transistor Q1 is therefore not conducting and Relay K1 is not energized. The motor contacts are open and the motor is off. The radio is "locked-in on" (receiving) a station.

Closing S1 (the search switch) bypasses Q1 and completes the current path through K1's field. The relay contacts close, completing the motor circuitry and the motor begins driving the tuning mechanism of the radio away from the station being received. Once off-station, the voltage on the control bus drops to zero and the search amp supplies drive current to Q1 (the relay driver transistor). Q1 keeps the motor relay closed, allowing the motor to continue tuning the radio. When the tuning locates a station, the voltage on the control bus again rises causing the search amp to cease supplying drive current to Q1. Transistor Q1 turns off, the relay contacts open and the drive motor stops. The radio remains on the selected station until the search button is once more depressed.

Search systems are very simple in their basic operation but they can be confusing when all the components are shown. A complete explanation is reserved for a later lesson devoted specifically to auto radios.

TELEVISION TUNERS

TV VHF Turret Tuners

Station selection of VHF channels 2 through 13 is accomplished in modern TV sets by switching from channel to channel. The tuned circuit for each channel is on a flat bar-like strip (Fig. 20) that is inserted in a drum shaped assembly, called a turret tuner (Figs. 21 & 22). Only one strip at a time makes contact with the appropriate electronic circuits. The RF amplifier, mixer, and local oscillator circuitry plus the switching assembly makes up the entire turret tuner. The tuned circuits used in a TV receiver are the RF amplifier, mixer, and local oscillator and they function just as they do in AM and FM receivers.

A TV receiver receives two signals from each TV station. The picture information is contained in an AM signal, while the second signal is FM and contains the sound information. A single local oscillator frequency is used to mix with both of these signals, and consequently two IF frequencies are produced in the mixer stage. One is called the video IF, and the other is called the sound IF. These IF frequencies are 4.5 MHz apart because the two signals transmitted by the TV station are 4.5 MHz apart. Both the video IF and the sound IF signals are amplified in the video IF amplifiers of the TV receiver. In older TV receivers, the video and sound IF signals were separated at the mixer output, but currently they are separated after both have been amplified by video IF amplifiers. In many cases the two

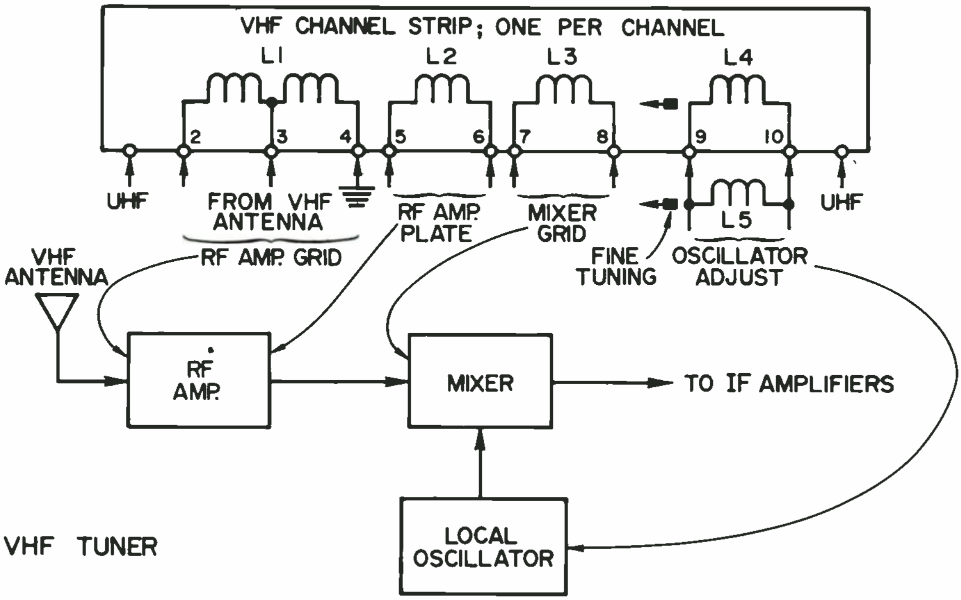
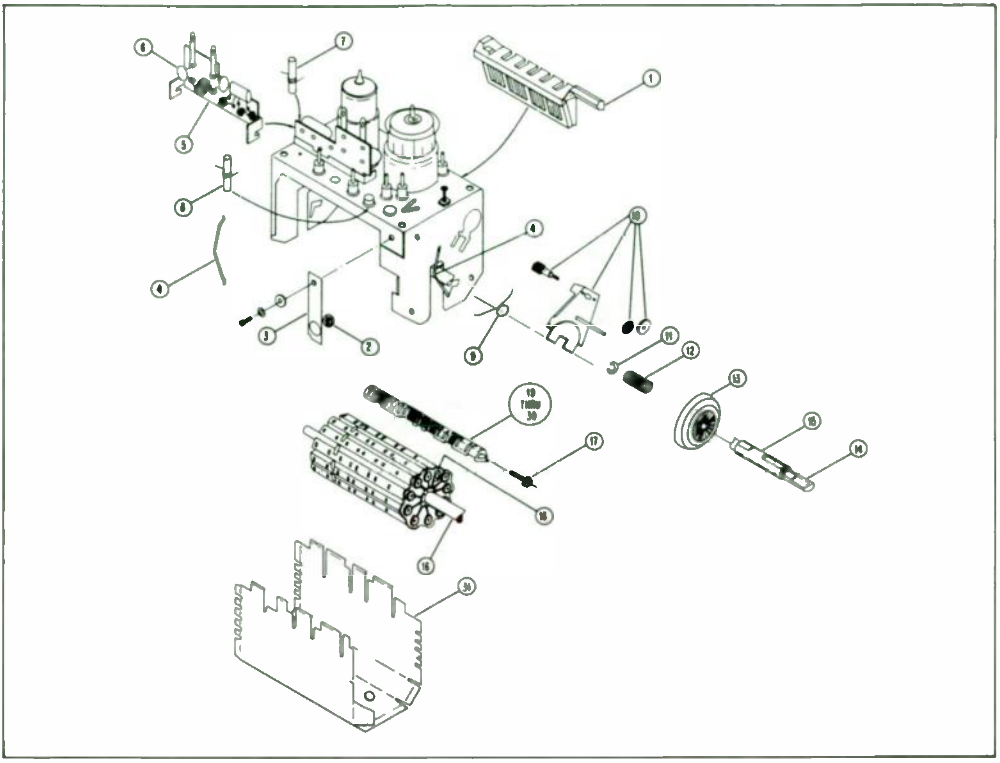


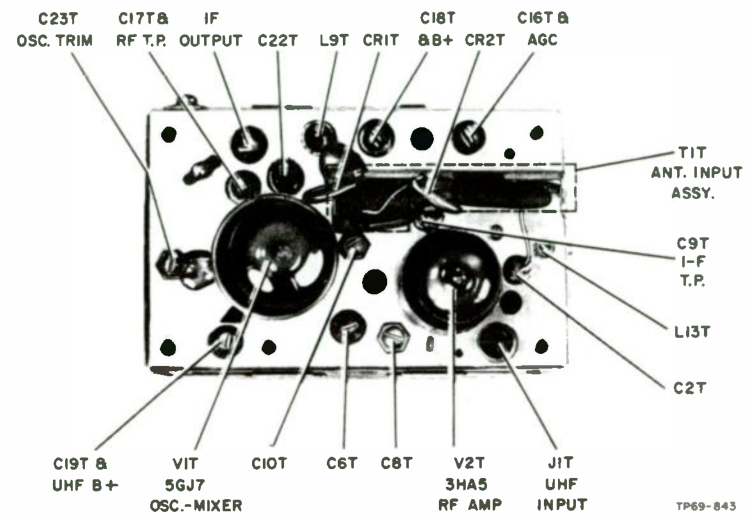
Figure 20 - Switching of TV VHF channel strip, UHF operation.



Exploded view of a VHF tuner.

SYMBOL	DESCRIPTION
	VHF Tuner, TT230 (complete)
1	Stator Assy.
2	Detent Ball
3	Spring, detent
4	Spring, drum retaining
5	Antenna Input Assy. (complete)
6	Capristor
7	Channel 1 Input Assy.
8	IF Coil Assy.
9	Spring, slide return
10	Preset Slide Assy.
11	Retaining Ring
12	Spring, cone return
13	Cone
14	Insulator, drum shaft
15	Shaft, fine tuning
16	Shaft and Coil Support Assy.
17	Slug/Clip Assy.
18	Channel 1 Strip Assy.
19	Channel 2 Coil Strip Assy.
20	Channel 3 Coil Strip Assy.
21	Channel 4 Coil Strip Assy.
22	Channel 5 Coil Strip Assy.
23	Channel 6 Coil Strip Assy.
24	Channel 7 Coil Strip Assy.
25	Channel 8 Coil Strip Assy.
26	Channel 9 Coil Strip Assy.
27	Channel 10 Coil Strip Assy.
28	Channel 11 Coil Strip Assy.
29	Channel 12 Coil Strip Assy.
30	Channel 13 Coil Strip Assy.
31	Cover, bottom

Figure 21 - Exploded view of a VHF tuner and the mechanical parts. Courtesy of Philco-Ford Corporation.



Component layout - Top view VHF tuner.

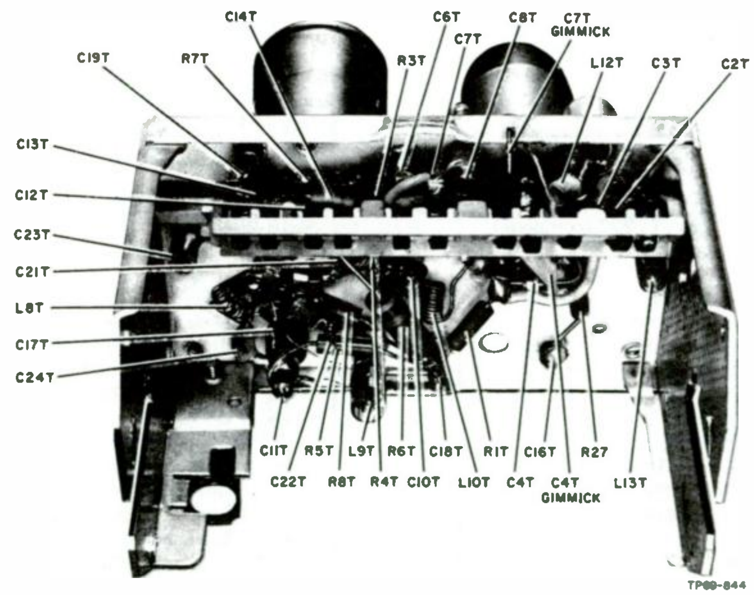


Figure 22 - Component layout - Bottom view VHF tuner.
Courtesy of Philco-Ford Corporation.

signals are separated after the video detector. In this case the video IF frequency serves as a local oscillator and beats with the sound IF to produce *another* sound IF frequency of 4.5 MHz. With this method, drifting of the local oscillator in the tuner does not affect the sound drastically, as it did in older receivers.

Tuners are not sealed against moisture or dust so contaminants can and do collect on the contacts and cause erratic receiver performance. Cleaning solvents that contain a lubricant are available in spray cans to both dissolve the residue that accumulates and to lubricate the contacts.

A strip is inserted at each channel position beginning with channel 2 and ending at channel 13. At each of these positions one complete tuner strip is connected to the VHF circuitry. Contact Nos. 2, 3, & 4 switch two coils into the grid circuit of the RF amplifier. The station signal from the VHF antenna enters at contact No. 3. The capacitance required in the RF amplifier grid circuit is primarily distributed capacitance contributed by the wiring and the components, but very little capacity is contributed by the channel strip itself. Contacts 5 and 6 connect inductor L2 into the plate circuit of the RF amplifier. Coil L3 is switched to the mixer grid circuit by contacts 7 and 8. (The use of tuned circuits at both the input and output of the RF amplifier gives the TV receiver superior selectivity.) The next pair of contacts, (No. 9 and 10) switch L4 into the local oscillator stage. Coil L4 is in parallel with coil L5 which is connected to the fine tuning control of the TV. Coil L4 is made variable as a service adjustment to set the range of the fine tuning control. After an extended period of use there will probably be uneven aging of the components in the local oscillator stage. This usually requires a readjustment of coil L4. In that event, the tuning slugs in each of the oscillator coils can be readjusted to insure that the best picture and sound occurs on each channel when the fine tuning control is set to the midpoint of its range. The first and last switch contacts that appear on the VHF strip are used only for UHF operation, if the TV is to be so equipped.

TV Incremental Tuners

Stacked wafer switches are also used in TV tuners. Figure 23 shows a VHF tuner schematic using wafer type switches. Each position of the switch can be considered as though the contact arm was being connected to a tap on an inductor. Each channel position adds a small amount of inductance, perhaps half a turn of a coil to the inductance, originally connected for channel 13. Channel 11 requires additional inductance to that used for channel 12, etc. This method of channel selection is frequently referred to as incremental tuning.

When switching from channel 7 to channel 6, a relatively large amount of inductance is added because channel 6 is appreciably lower in frequency than channel 7. Channel 7 extends from 174 to 180 MHz, whereas channel 6 is much lower in frequency, extending from 82 to 88 MHz. Channel 7 is the lowest channel in the *high* frequency portion of the VHF band, and channel

VHF TUNER TT210A

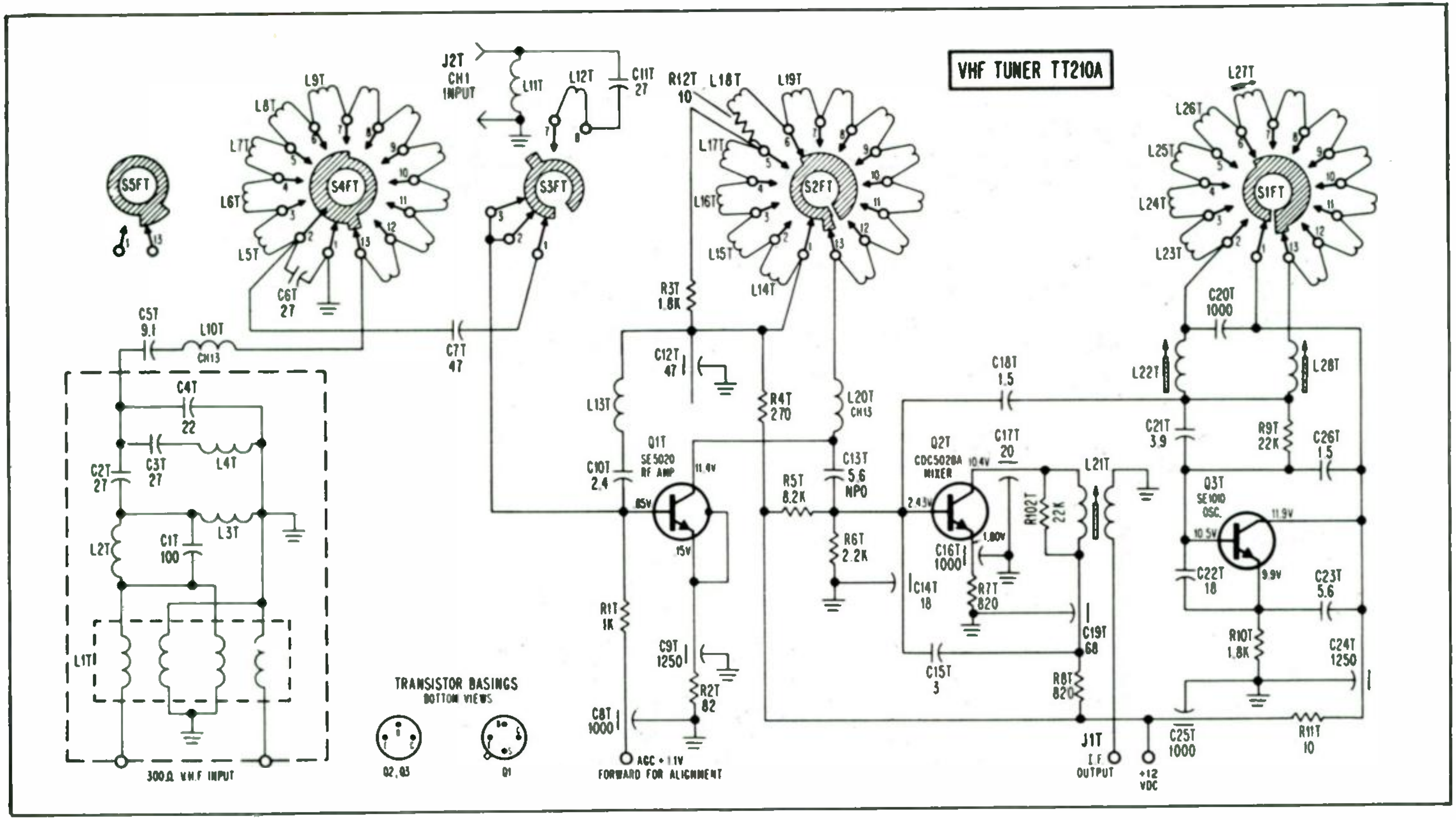


Figure 23 - Schematic diagram of a VHF tuner. Courtesy of Philco-Ford Corporation.

6 is the highest channel in the *low* frequency portion of the VHF band.

All three wafers are ganged to a common shaft and are switched simultaneously. When the switch is in position 1, the VHF tuner is disconnected. This permits the UHF tuner signal that is applied at J2T CH1 INPUT (in the upper left corner of Figure 23), to be connected to the base of transistor Q1T. The UHF tuner is a separate tuner, and is not shown on Figure 23. UHF tuners are the continuous tuner type, permitting any desired frequency to be selected.

In some TV receivers, the wafer switches are relatively accessible for inspection and troubleshooting. They may be easily cleaned, using one of the spray type cleaners containing a lubricant. Most servicemen do not attempt to do major repairs on TV tuners; instead the whole tuner assembly is exchanged for a new or rebuilt unit. This is a wise practice because tuners are constructed so compactly that extensive and time-consuming disassembly is required before tuner parts can be replaced.

TV UHF TUNERS

The band of frequencies between 470 MHz and 890 MHz have been allocated by the FCC for UHF television broadcasting. Each station broadcasting in the UHF band is assigned a 6 MHz channel just like those in the VHF range.

UHF tuning is done with a separate unit usually attached to and wired into the VHF tuner. Early UHF tuners were of the continuous type and stations were dialed in like AM radios. The trend is now toward either a series of push buttons (one each for each channel being selected) or a rotary switch with a position alloted for each UHF station that can be received in your locality.

INSTANT-ON TV

Tube filaments require almost a minute for their temperature to rise to operating temperature. On the other hand, solid state devices do not have filaments and begin operating the instant the On-Off switch is snapped to "On." Figure 24 shows a method used in current instant-on TV sets containing vacuum tubes. A solid state diode is placed across the power switch. When the power switch is in the "OFF" position, the rectifier completes the circuit to the tube filaments. The rectifier conducts on alternate half-cycles of the AC power supply and supplies sufficient current to the tube filaments to keep them warm. When the switch is turned to the "ON" position, the rectifier is by-passed and the filaments are supplied with full operating current. Because the filaments are already warm, electron emission from the tube cathodes is almost instantaneous and the tubes begin to operate in a few seconds.

In Figure 25, a different switch is used with a provision for removing the instant on (standby) feature, by switching to "Off." In the standby position, only the picture tube filament requires heater current because

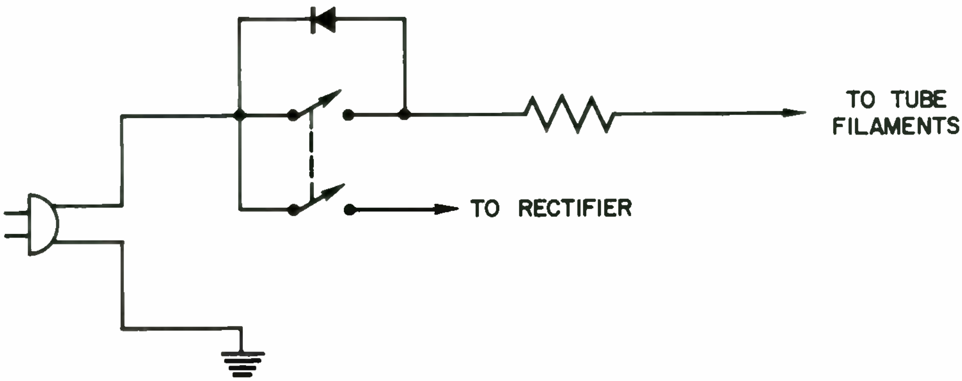


Figure 24 - Instant-on in TV's.

the balance of the set is transistorized. In the Off position, the rectifier is not producing DC because the rectifier circuit is incomplete. In the On position, the dropping resistor R in the picture tube's filament circuit is by-passed by a section of the switch.

Item CB is a circuit breaker that automatically opens the circuit when the primary current is excessive. The primary current will be excessive, of course, whenever the secondary current is abnormally high due to a defect in the circuitry.

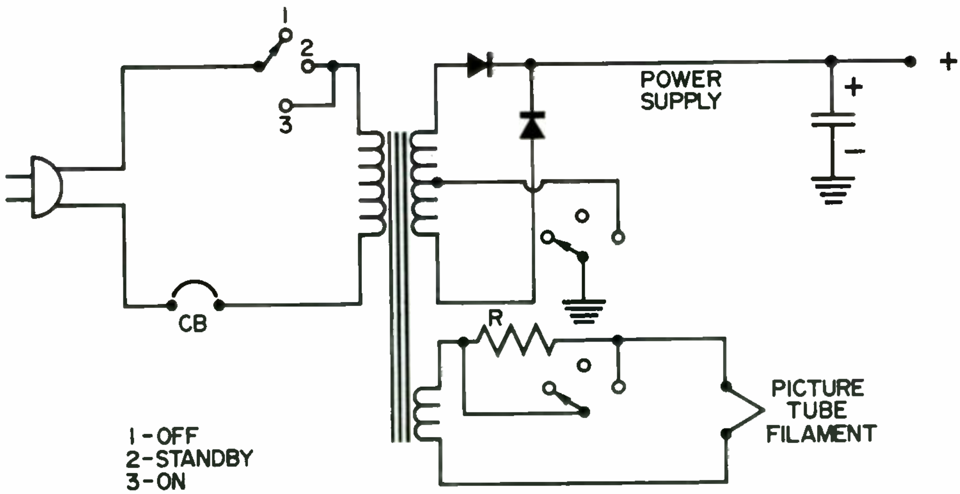


Figure 25 - Instant-on in TV's.

SUMMARY

It can be safely said that all electronic devices use switches. They are necessary and effective devices for changing the actions of electronic circuits. Rotary switches are usually multi-point switches that select the different modes of operation of radio and TV receivers.

To minimize arcing which is detrimental to the service life of a switch's contacts, snap action is built into switches. This results in a rapid change from one position to another.

Relays are also useful devices; they convert electrical action into switching action. Relays are used less frequently in radio and TV receivers than regular mechanical switches.

TEST

Lesson Number 45

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 52-045-1.

1. Switches are
   A. electrostatic devices.
   B. electromagnetic devices.
   C. mechanical devices.
   D. solid state devices.

2. When the term DP is applied to switches it means
   A. diode pair.
   B. double pole.
   C. dual parallel.
   D. divide position.

3. The term DT when applied to switches means
   A. double terminal.
   B. dual transistor.
   C. double throw.
   D. detent torque.

4. The rating VA when applied to switches means
   A. volts AC.
   B. volume of AC.
   C. volt-amps.
   D. variable amps.

5. The detent mechanism and the resulting detent action of a switch assures that the contacts at any position
   - A. cannot be engaged.
   - B. are always clean.
   - C. cannot arc.
   - D. engage and remain engaged.

6. The snap-action designed into switches
   - A. produces a strong arc.
   - B. reduces the duration of the arc.
   - C. has no effect on the arc.
   - D. slows the switching action.

7. A circuit breaker
   - A. has a built-in capacitor.
   - B. is another name for a reed relay.
   - C. must be replaced after it operates.
   - D. opens a circuit when it operates.

8. Switches are manufactured for ________ operation.
   - A. rotary
   - B. toggle or slide
   - C. push button
   - D. all of the above

9. Relays are ________ devices.
   - A. electrostatic
   - B. electromagnetic
   - C. mechanical
   - D. solid state

10. Multideck rotary switches are particularly useful for
    - A. very simple switching applications.
    - B. switching a large number of contacts simultaneously.
    - C. controlling relays.
    - D. none of the above.

Notes

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HONOR YOUR EMPLOYER

The best way to "Honor your Employer" is to always do a first-class job. Never forget the little details that make the difference between a good and a fair job.

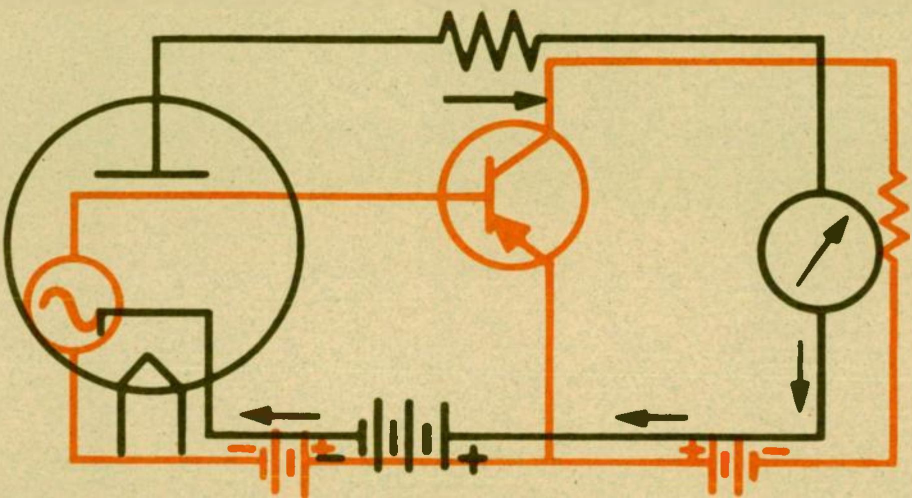
See to it that you are always clean and neat. Make certain you check every service procedure before you leave the job.

If you honor your employer by following these rules, you will become more successful in your position and respected by your fellow workers.

S. T. Christensen

LESSON NO. 46

PRINTED CIRCUITS



RADIO and TELEVISION SERVICE and REPAIR

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CONTENTS

PRINTED CIRCUITS

INTRODUCTION

In the 1940's volume manufacturers of electronic equipment began extensive research into cost-saving methods. First among the developments considered was a replacement for the massive amounts of wiring and soldering. A substitute was necessary because of the growing complexity in home entertainment, industrial, and computer electronic products.

It was during the early 1950's that printed circuitry first began to appear in electronic products. Printed circuitry consists of foil back sheets of insulating material such as fiber board, plastic, or fiber glass. In Figure 1, sheets of copper foil were bonded to the surfaces of these composition boards to serve as the conductive paths between components. The board material provides both insulation and rigidity. Two kinds of circuit boards are used; one has foil on both sides of the board material, while the other has foil on one surface only.

Component leads and wires are connected to the circuit board using holes drilled through the circuit boards. The wires and leads are then soldered to the foil usually by an automatic process.

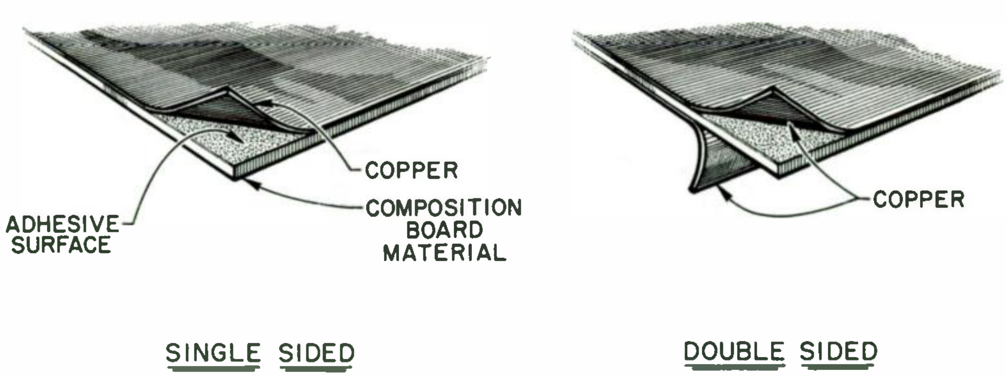


Figure 1 - Single and double sided circuit board material.

Automation has been widely adapted to electronic circuit processing. Even the installation of components can be done by machines.

CIRCUIT MATERIAL

The amount of copper on a circuit board is generally not specified in thickness. It is usually indicated by weight for a given area. The measuring standard in the electronics industry for copper foil boards is ounces of copper per square foot. One ounce copper-clad board material will contain one ounce of copper in a section measuring one foot by one foot. Two, three, and four ounce copper-clad boards are available for use where application requires more rugged material.

Circuit boards of the required size are cut from sheets of board material and dressed to the required tolerance with precision equipment. Holes to receive component leads may be drilled at this stage or, when the foil circuits are formed.

CIRCUIT DRILLING

Drilling is done with a special high speed circuit drill. Several boards are

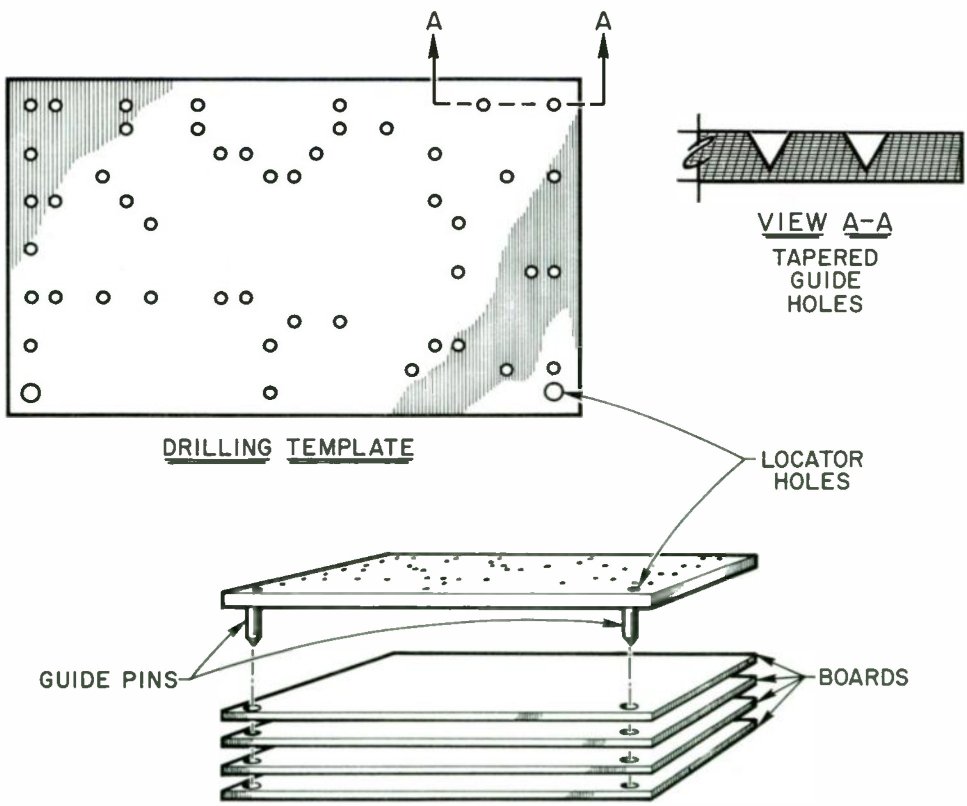


Figure 2 - A circuit board drilling template.

drilled simultaneously by stacking them on a fixture. Hole locations are established in one of a number of different ways.

Figure 2 shows a template used for drilling circuit boards. The top view shows a series of tapered holes used to locate the spots to be drilled. Notice that two locator holes are punched or drilled in each board. Several boards are then stacked onto the guide pins of the template. The two locator pins in the template protrude through the boards to locate them properly and to keep the boards from shifting during the drilling operation.

Figure 3 illustrates the head and table surface of a high speed circuit drill. Circuit drills operate from a foot pedal leaving the hands free to position the work. The template with its load of boards is positioned on the drill table, template side up. A tapered locator hole in the template is positioned under the stylus and the foot pedal is depressed. In Figure 4 the stylus extends from the head into the tapered hole in the template holding the assembly. Once the stylus has reached the extent of its travel, it trips the drilling mechanism which travels upward, rapidly drilling a hole through the stack. Releasing the foot pedal causes the drill and stylus to retract, allowing the operator to position the stack for the next hole.

A series of lines and arrows, painted or inked onto the template's surface, guides the operator to each successive hole. This method of drilling is called semi-automatic and is used by small volume manufacturers.

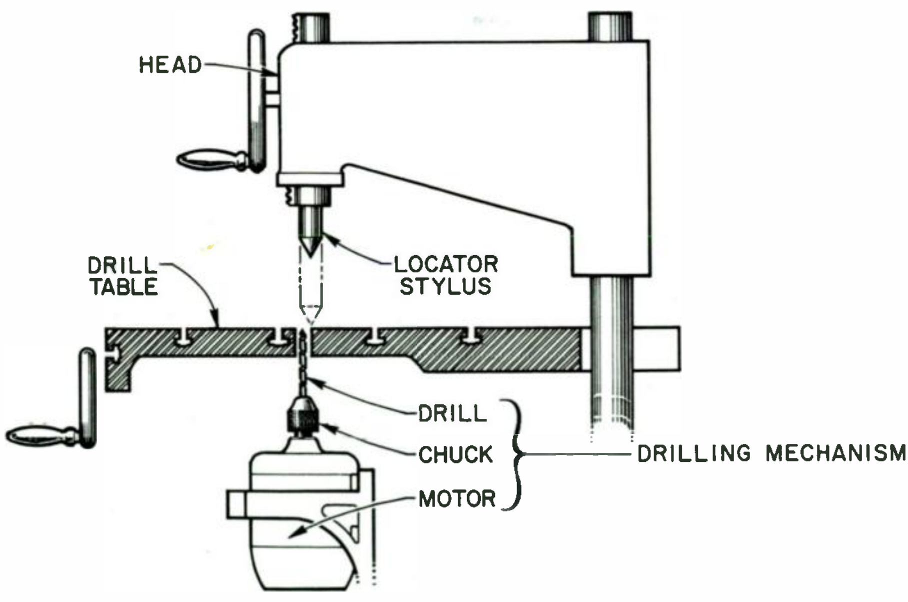


Figure 3 - Head portion of a special high speed circuit drill.

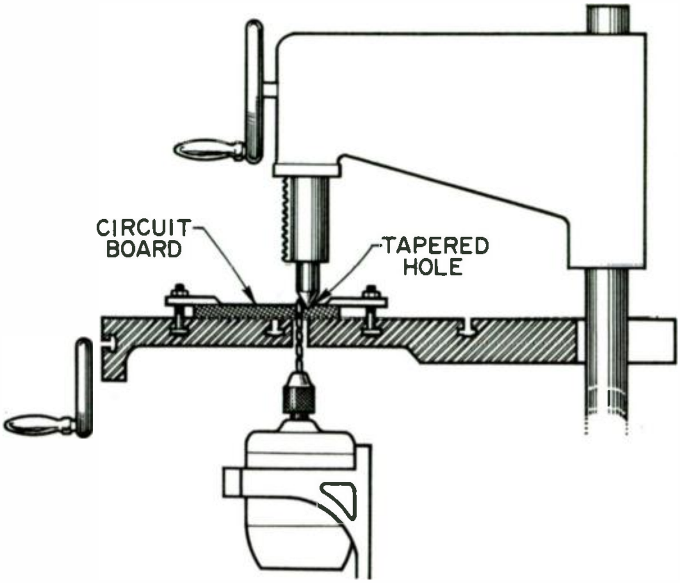


Figure 4 - View of a circuit drill showing the stylus seated into the locator hole of the template.

Large volume manufacturers use a fully automatic drilling process. Boards are stacked onto a holding fixture and secured to an indexing table. The table's position is controlled by a computer, a prepunched tape, a magnetic tape, or some other prepared program. Automatic systems can easily drill several hundred thousand holes per hour through many thicknesses of boards.

CIRCUIT ETCHING

The accepted way of preparing the pattern of circuitry in copper foil is to etch away all the copper on the surface except that which is required to complete the electrical paths between components. The etching solution may be a bath into which the boards are repeatedly dipped or a fine spray directed onto the board's surface. Spray etching is now the accepted method for speed and good line resolution.

Several methods are used to prevent the etching solution from removing copper in areas where copper is needed to complete the continuity between components. A common method is to coat the areas where the copper is to be left with a resist compound. *Resist* is a thick ink-like substance that prevents the corrosive action of the etching solution. It is deposited onto the board's surface through the open areas in a fabric screen by a process called *silk screening*. The silk screened circuit board as shown in Figure 5 illustrates how the circuit flow lines will interconnect between components.

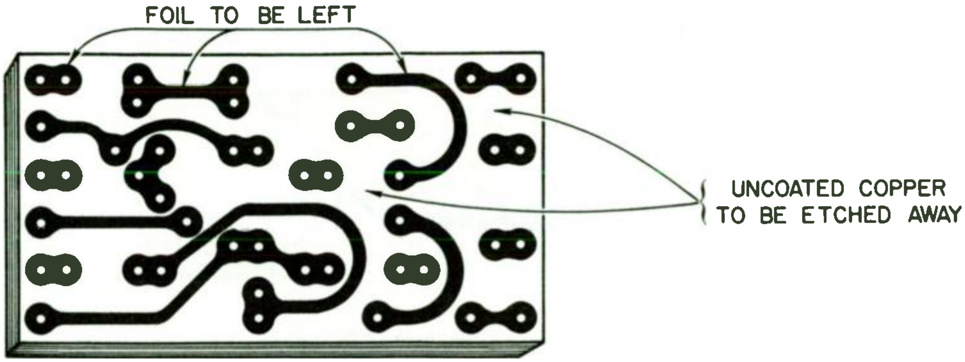


Figure 5 - A screened circuit board ready for etching.

Another method of producing circuit flow lines is by coating the surface with a light sensitive chemical and then exposing it to a high intensity light through a photo negative. A difference in chemical composition occurs between the areas to be removed and those to be left behind as circuit flow lines.

In some other processes, the resist is baked in a high temperature oven prior to etching. In others it needs only to be exposed to air. The drying process is dependent upon the type of resist used. Unwanted copper is removed from a board's surface by one of three methods:

1. . . . repeatedly dipped into an etching solution until all exposed copper is removed.
2. . . . passed from bath to bath by means of a conveyor system until the copper is removed.
3. . . . placed in an enclosed vessel in which fine sprays of etching solution (directed onto the board's surface) remove exposed copper.

The etching solution used may be an alkali, acid, or other corrosive chemical. Ferric chloride was one of the earliest etchants used and is still quite popular. When ferric chloride contacts copper, the iron in the solution is replaced with copper. Other etchants act in a similar manner to absorb exposed copper.

After the etching process has been completed the boards are subjected to a neutralizing bath which prevents further corrosive action from etchants trapped on their surfaces. A chemical wash follows this process to remove surface residue. Following the wash, the boards may receive a solder soluble coating for protection or they may be dried.

For improved solderability, additional metal is sometimes deposited onto the surface of the remaining

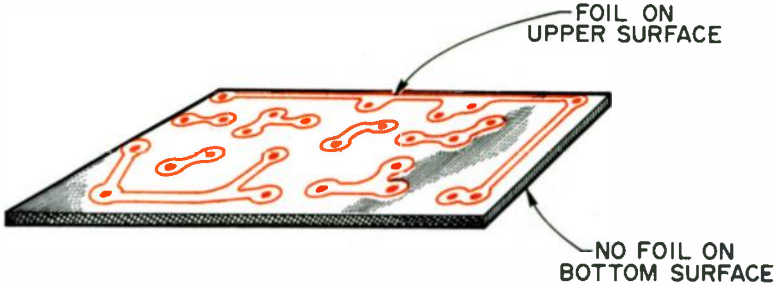


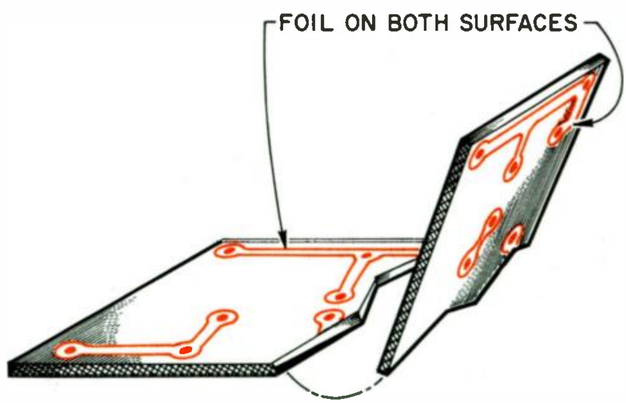
Figure 6 - A single sided etched PC board.

copper. This deposit may be solder, tin, or gold. The circuit board is now ready to receive it's components.

TYPES OF PRINTED CIRCUITRY

There are two types of printed circuitry commonly used in electronic products. One has foil runs on only one surface of the board, and is called *single sided circuitry* (Fig. 6). Another has runs of foil on both surfaces and is called *double sided circuitry* (Fig. 7).

Double sided circuitry has some means of connecting a run of foil on one side of the board to foil on the opposite surface. Figure 8A illustrates a tubular eyelet that has been inserted into a hole to interconnect foil from opposite surfaces. The ends are rolled



(BOARD SHOWN BROKEN FOR CLARITY)

Figure 7 - A double sided etched PC board.

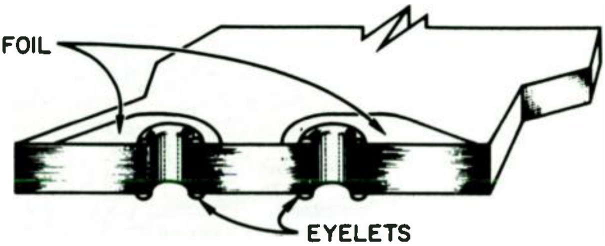


Figure 8A - Eyelets inserted through double sided circuitry to interconnect foil between sides.

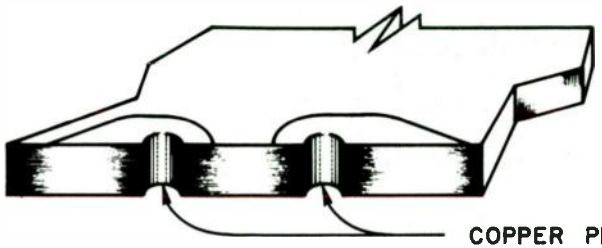


Figure 8B - Copper plated through the holes interconnects foil from opposite sides.

over on each side to contact the foil. This operation is performed with a special eyeleting machine.

Figure 8B shows a *plate through process* used to interconnect foil. Copper is plated onto the inside walls of a hole and onto the foil on each surface.

COMPONENT PREPARATION AND INSERTION

2 Components are inserted into circuit boards by hand or with a special machine. Frequently, standard components are assembled to the board by a machine while a few non-standard items are installed by hand.

The insertion head of a component assembly machine vaguely resembles the head portion of a sewing machine. Instead of driving a threaded needle through cloth, insertion machines push component leads through holes in circuit boards.

In some insertion machines, components are fed loose from a hopper. However, as shown in Figure 9, insertion machines are generally supplied with components attached to a strip of material formed into a roll. The roll is placed on a spindle from which the components are supplied sequentially to the machine. Many components are available with precut and formed leads while others must be cut and formed. Most insertion

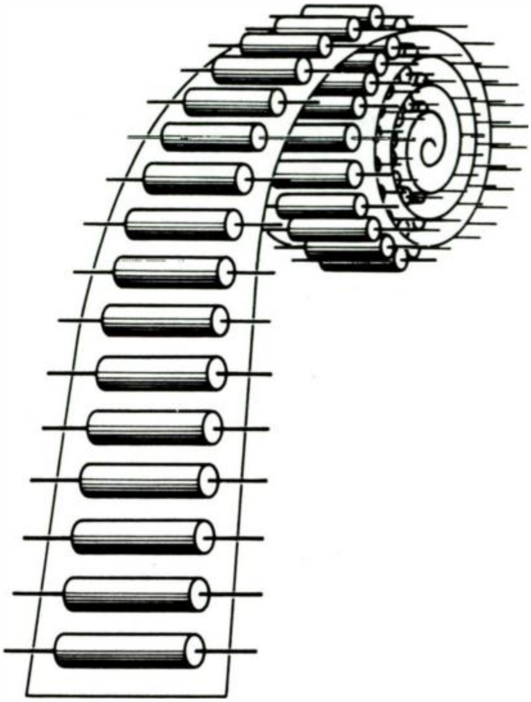


Figure 9 - Roll of components ready for loading into an insertion machine.

machines can cut and form leads as well as insert the components. Where hand insertion methods are used, such as by small volume manufacturers, simple component preparation machines may be used to speed up handling.

PC COMPONENTS

A whole new family of components was developed with the adoption of printed circuitry. These components had their leads sized and spaced to a standard dimensioning system. This simplified both circuit board layout and component assembly.

One of the earliest developments was a series of components with leads projecting from only one side or end. Figure 10 shows several capacitors with this form. Presently, most categories of parts are available with this style of construction. Even switches, potentiometers, trimmers, and transformers have been revised for ease of insertion (Figs. 11, 12, and 13).

Resistors, as a rule, have remained as axial lead components with the exception of some power and special purpose types. Power resistors with lead locations suitable for printed circuit use are shown in Figure 14.

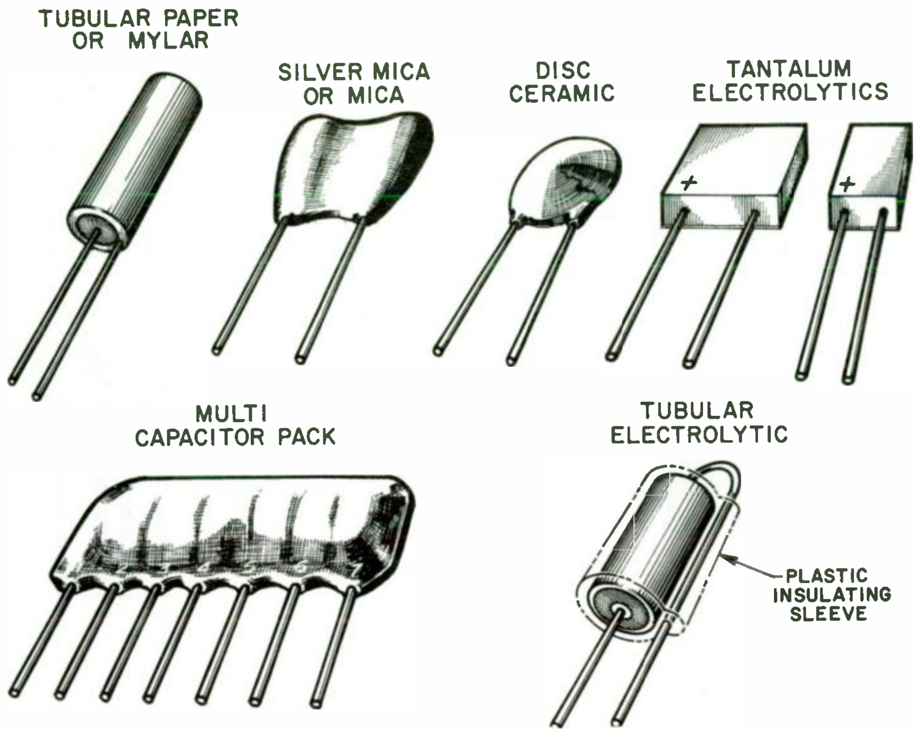


Figure 10 - Capacitors especially developed for printed circuitry.

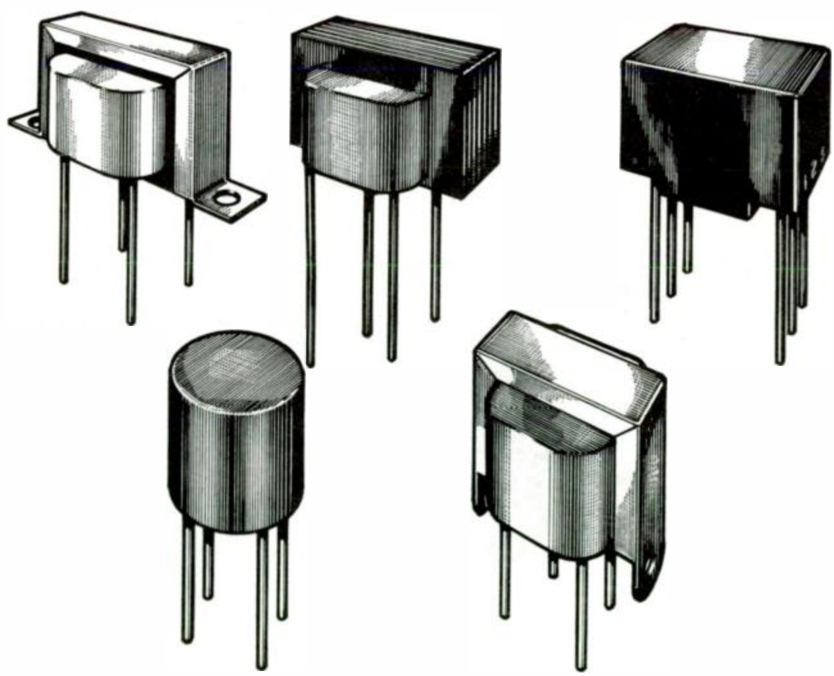


Figure 11 - Transformers especially developed for printed circuitry.

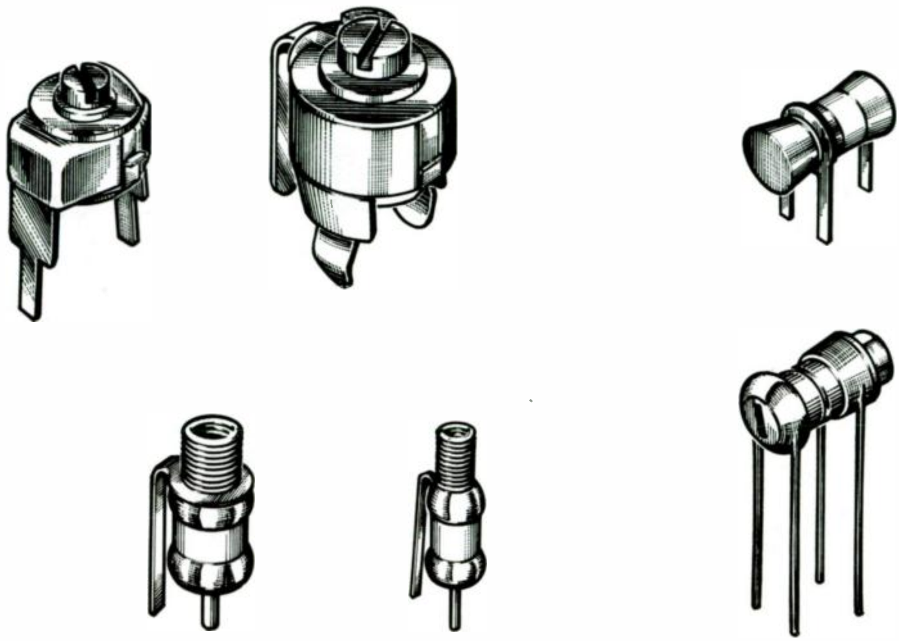


Figure 12 - Trimmer capacitors for printed circuitry.

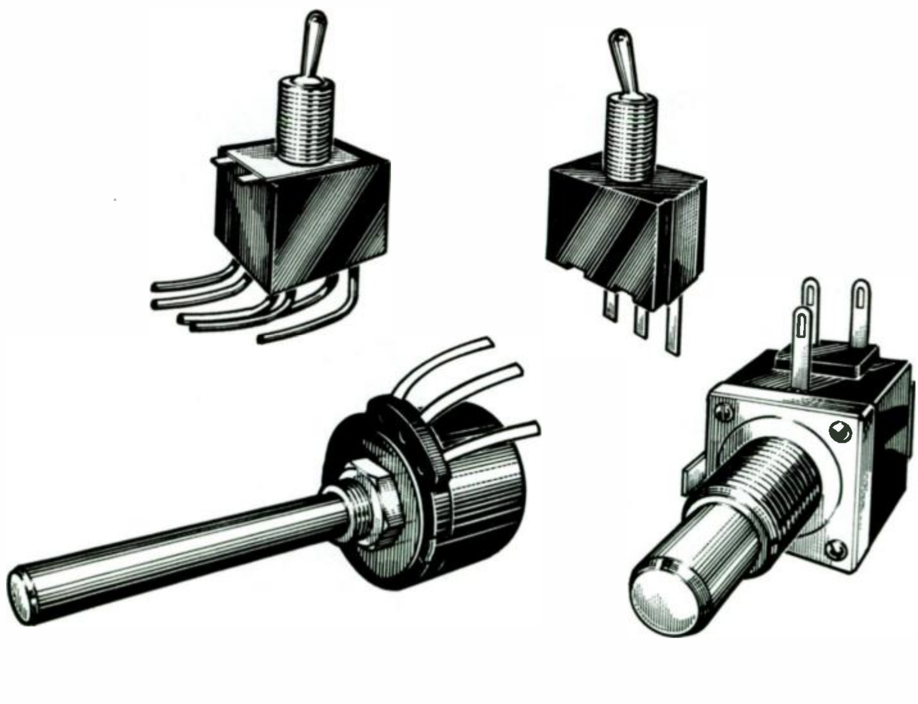


Figure 13 - Switches and potentiometers for printed circuitry.

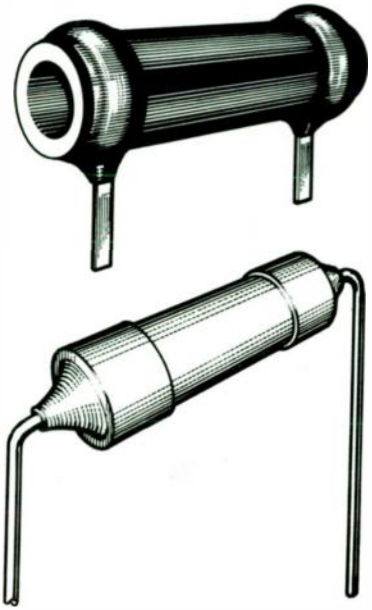


Figure 14 - Power resistors suitable for printed circuitry.

One of the latest developments in printed circuit components is the integrated circuit pack. Several of these are shown in Figure 15. Each IC pack replaces numerous components and can perform a complex function or many functions (Fig. 16). Their dimensions are rigidly controlled for PC board use.

Electronics is a swiftly changing field. You will constantly encounter new style and size parts as manufacturers incorporate them into their products. Publications devoted to the trade will introduce you to new products as they are being marketed and will contain service hints and suggestions. It is wise to subscribe to one or more good service magazines.

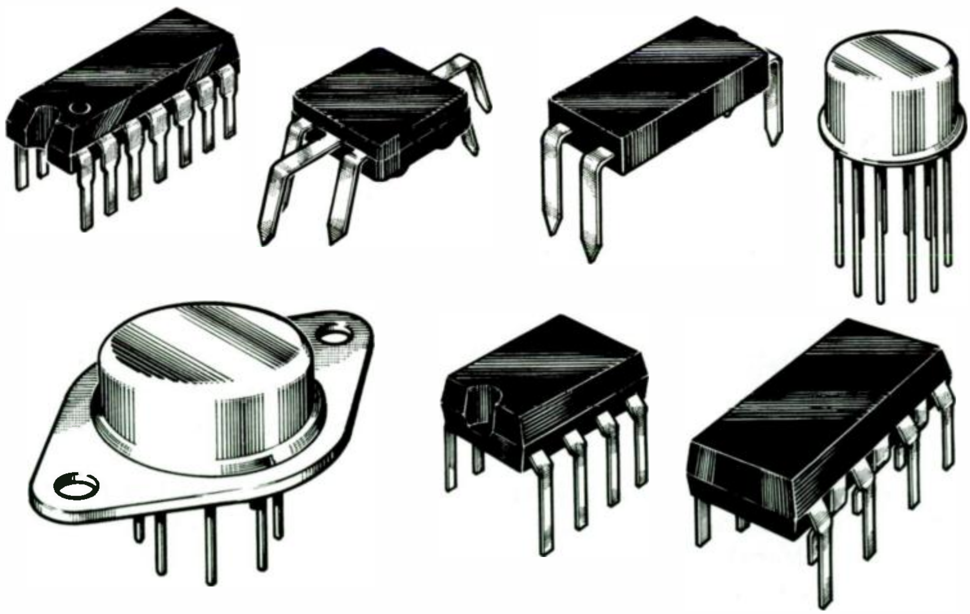


Figure 15 - Integrated circuit packs.

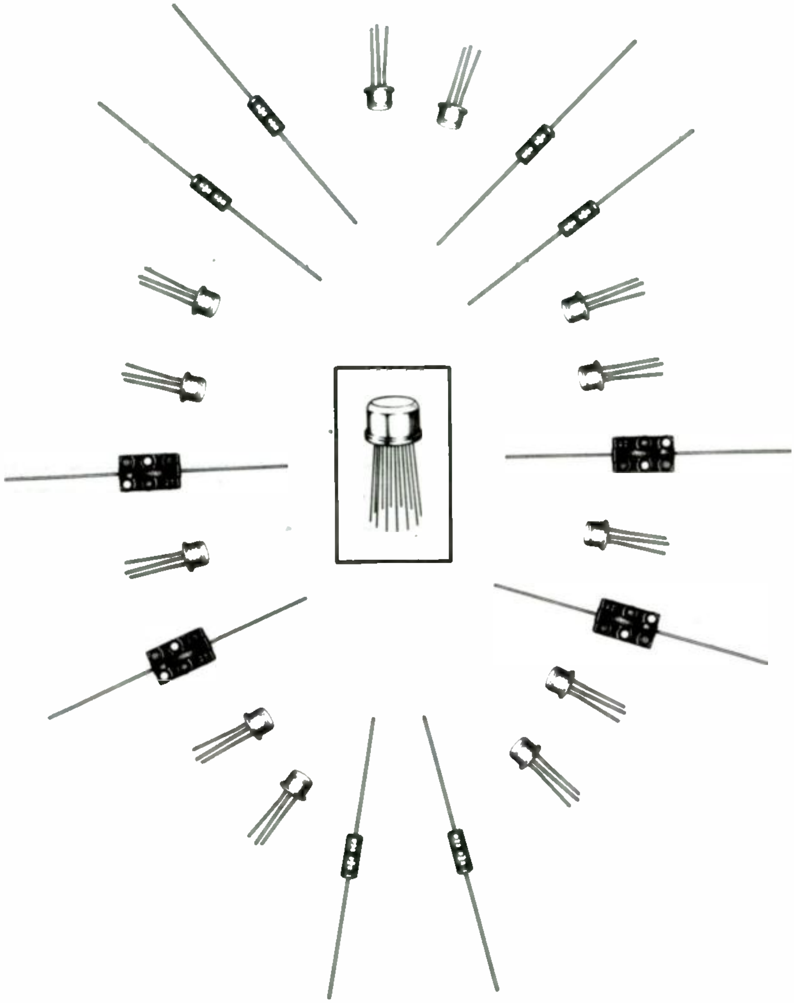


Figure 16 - An IC pack surrounded by the components it replaces.

PRINTED CIRCUIT SOLDERING

Once the components and wires have been inserted into a circuit board, they must be soldered into place. Nearly all manufacturers use some kind of automatic soldering process. Most common is a technique called *wave soldering*. This is done with a special machine that pumps molten solder from an electrically heated soldering pot over a dam-like restriction. A wave of molten solder builds up behind the dam and the circuit board is floated momentarily in this wave as it travels by on an overhead conveyor.

It is unlikely that you, as a service technician, will require this type of necessary to acquaint you with the basics of these techniques. Some students will undoubtedly find jobs in industry once they have completed their training.

As a service repair technician it will be important for you to know how to solder and unsolder components in printed circuitry. Good soldering is frequently the difference between a professional repair and a botched job.

Most important in repairing printed circuitry is a clean soldering iron. This assures good heat transfer to the work and prevents the transfer of foreign matter from the iron to the work.

A small tip, low-wattage soldering iron should be used when soldering on a printed circuit board. The size of the soldering iron is extremely important. The iron should have a small tip because of the relatively small width of the foil paths. The iron should produce adequate heat for the soldering operation, but the amount of heat applied should not be excessive. Excessive heat could cause the foil to lift from the printed circuit board surface. A soldering iron with a 30 to 40 watt capacity is considered adequate for printed circuit soldering.

Correct use of your iron will prevent damage to components and circuitry. Be careful that your iron does not contact insulation or part bodies when you apply heat to a connection. In addition to the unsightly mess that results, it can cause damage and more work for you.

To loosen or secure a soldered component, lay the tip of the iron firmly on the protruding part lead. Do not scuff the foil by drawing the iron back and forth across the connection. Once the part has been removed or is securely soldered, remove the iron promptly.

Prevent any movement of the component until the solder has cooled and congealed. Movement of the lead before the solder has solidified causes the solder to crack or crumble, a condition called a *cold solder joint.* Cold solder connections may hold for a time, but they are very unreliable and will probably fail later. You cannot honorably charge for rework that becomes necessary due to shoddy repair techniques.

PLUG-SOCKET ARRANGEMENTS

Some means must be used to connect signals and power in and out of circuitry. Many products have more than one circuit board with wiring between them. Also, controls and other remote components, such as speakers, must be connected to the foil circuits.

The simplest connections are wires soldered to the foil or to the terminals that connect to the foil. Wire-wrap connections are another means of interconnections.

The trend is now toward replaceable circuit boards called *modules.* To be easily replaceable, a system must be used that allows for quick disconnecting of the wiring from the boards.

External wiring into circuit boards occasionally terminates in a plug-

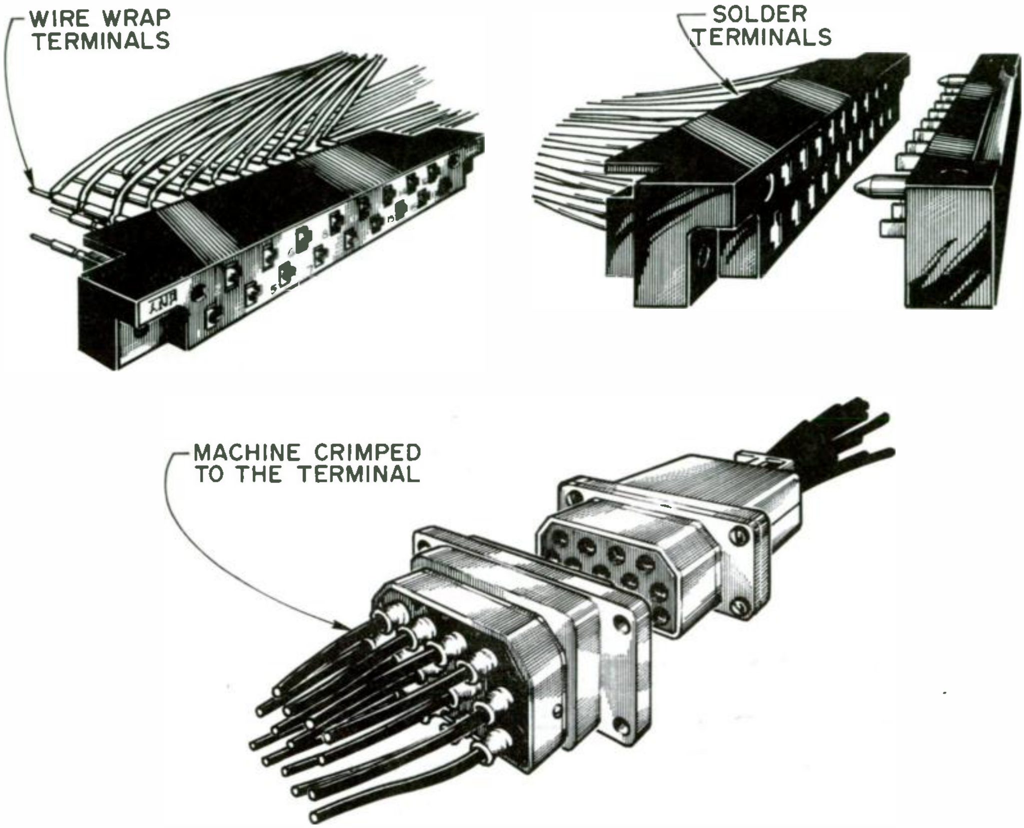


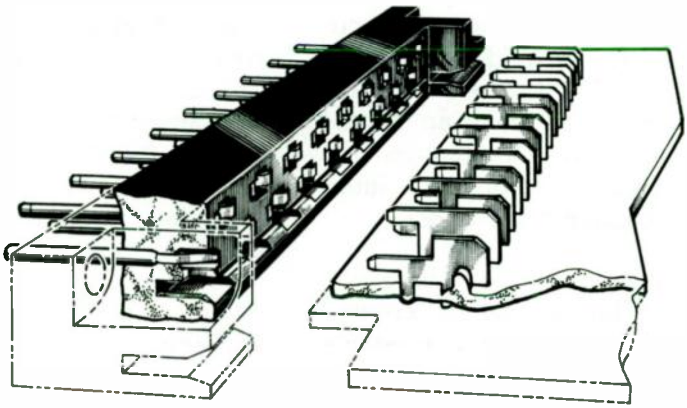
Figure 17 - Examples of plug-socket connectors.

socket arrangement. There are literally thousands of styles and sizes of plugs and sockets. They are grouped under the common category of connectors and are available in sizes to handle anywhere from a few wires to dozens of wires. The connectors shown in Figure 17 are only representative examples. You will notice that both solder and wire-wrap terminals have been included.

Figure 18 illustrates two types of circuit board connectors. The edge of the PC board can be prepared with soldered-in terminals that plug directly into a connector socket as illustrated in Figure 18A, or foil contact pads may be left near the edge of the board. These surfaces are plated with a durable metal and serve as the mating section to the socket connector shown in Figure 18B.

Terminal and connector arrangements vary widely. Styles are available to suit the needs of a majority of the equipment manufacturers. You will encounter numerous styles in your service work. The purpose of this section of the lesson is to acquaint you with their existence and basically what they look like.

A



B

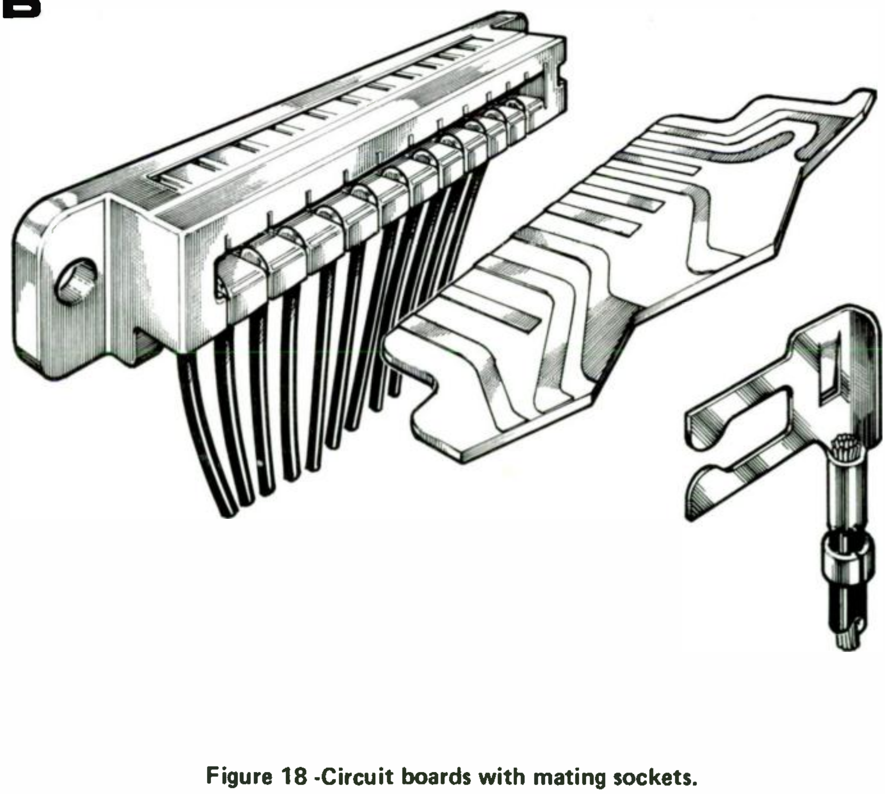


Figure 18 -Circuit boards with mating sockets.

SUMMARY

The advent of printed circuitry produced a drastic change in the electronics industry. Using printed circuits, components could be mounted to a small board, with the connecting paths between components an integral part of the board. This reduced the amount of time required to interconnect components in a chassis.

A printed circuit board consists of a composition board that is covered with a conductive material, generally copper. The conductive paths between components are formed through several methods. The excess copper material is then removed by a process called etching, leaving only the conductive interconnecting paths. Components may then be mounted to the circuit board by a soldering process.

The printed circuit board may be double or single sided. Double-sided boards are generally used when circuit crossover would occur on a single surface. On a double-sided circuit, holes are drilled through the board to connect specific foil runs from one side to a foil run on the other side. These interconnecting holes are then plated.

Care should be exercised when soldering a printed circuit board. A small tip, low-wattage soldering iron should be used when soldering a printed circuit board. Using excessive heat when soldering can cause the conductive foil to lift from the circuit board. This can produce opens or shorts in the circuitry and generate many troubleshooting problems.

TEST

Lesson Number 46

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 52-046-1.

1. Printed circuit board material consists of
   A. inked sheeting.
   —B. foil cover insulated sheeting.
   C. single-sided circuitry only.
   D. double-sided circuitry only.

2. Components are installed in printed circuitry
   A. only by hand.
   B. only by machine.
   —C. by hand and machinery.
   D. none of the above.

3. The amount of copper on a circuit board is measured in
   A. hundredths of an inch.
   —B. ounces per given area.
   C. millionths of an inch.
   D. thousandths of an inch.

4. Circuit drilling is performed by manufacturers with
   A. a special circuit drill.
   B. a standard drill press.
   C. a hand held drill.
   —D. none of the above.

5. Large volume manufacturers drill circuit boards
   - A. one at a time.
   - B. by hand.
   - C. automatically.
   - D. without fixtures.

6. Circuit flow lines are prepared by
   - A. printing them with a press.
   - B. bonding small strips to a board.
   - C. etching away unwanted copper.
   - D. burning away unwanted copper.

7. Printed circuit components usually
   - A. have leads projecting from one side only.
   - B. always have leads projecting from two sides.
   - C. always have leads projecting from three sides.
   - D. always have leads projecting from four sides.

8. Electronic component styles for printed circuitry
   - A. never change.
   - B. change constantly.
   - C. seldom change.
   - D. none of the above.

9. Printed circuitry should be soldered
   - A. only with a hot-massive iron.
   - B. with a small tip, low-wattage iron.
   - C. only with sophisticated special equipment.
   - D. with flame heat only.

10. The trend now in connecting to circuit boards is through
   - A. wired connection.
   - B. connectors.
   - C. wire-wrapped connections.
   - D. riveted connections.

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SERVICE WORK...

At first glance standard repair procedure seems to be. . .repairing, collecting and giving your customer a receipted bill. This is *not correct*.

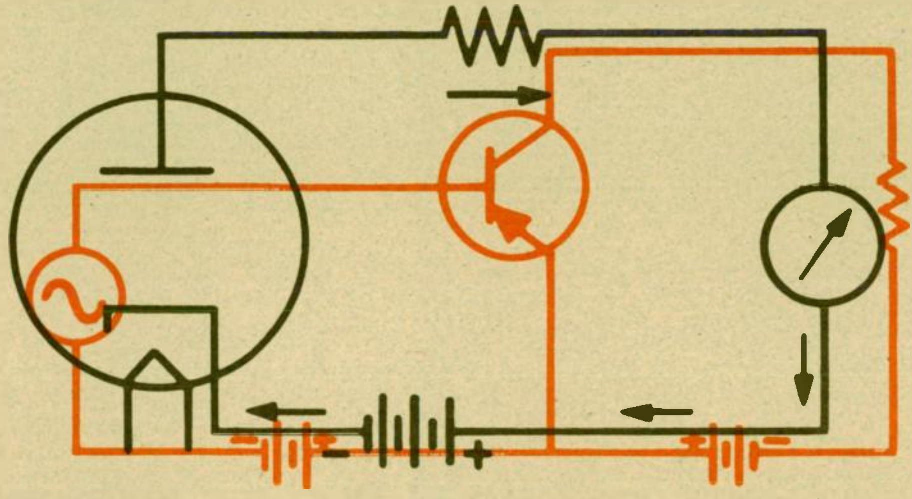
There are other steps you must take. . .steps which are important to your success!

1. Create a feeling of confidence in your customer.
2. Follow the "Golden Rule" in your service work.
3. Take an interest in your customer. Let him know you are interested and anxious to give the best service.

Make it your business to follow these steps, and you will be guaranteeing future business.

S. T. Christensen

CIRCUIT DIAGRAMS FOR SERVICING



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-047
412

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
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CONTENTS

CIRCUIT DIAGRAMS FOR SERVICING

INTRODUCTION

Not many years ago, when the electronic field and its products were limited, it was not unusual for the technician to become familiar with nearly all the equipment he was required to service. Each piece of equipment was similar to that of other manufacturers, in addition to being uncomplicated. It was not unusual for a technician to repair equipment with only an occasional reference to service literature.

Today, however, this practice is no longer possible. Even a mere listing of electronic equipment today would fill volumes. It is impossible for any one person to be thoroughly familiar with all the various types of electronic equipment in present use; but with a good general background of electronic principles and circuit theory, a little study will enable the technician to rapidly familiarize himself with any specific equipment.

BLOCK DIAGRAMS

Several categories of service literature are available to service technicians. Probably the most useful form of information for a specific unit is the simple block diagram. The block diagram consists of a series of interconnected squares or rectangles called "blocks." Each block represents a complete stage or circuit. If signals, waveforms and voltages are present, the block diagrams then become a flow diagram. Flow diagrams are invaluable as aids to understanding circuit functions. With flow diagrams, you can trace signal flow and see how a unit operates without being presented with extensive circuitry or symbolic notation. Properly used, a block-flow diagram can provide the serviceman with an almost instant understanding of how a piece of electronic equipment operates.

Figure 1 shows a very simple phonograph in block form. At first glance, the diagram seems to tell very little about the unit. However, a considerable amount of information can be found by further study of Figure 1. Since only one block is used to illustrate the amplifier, it is probably quite simple. The block may contain one or two tubes; or two to three transistors. The unit is powered from standard house current at 120 VAC. There is only one input to the

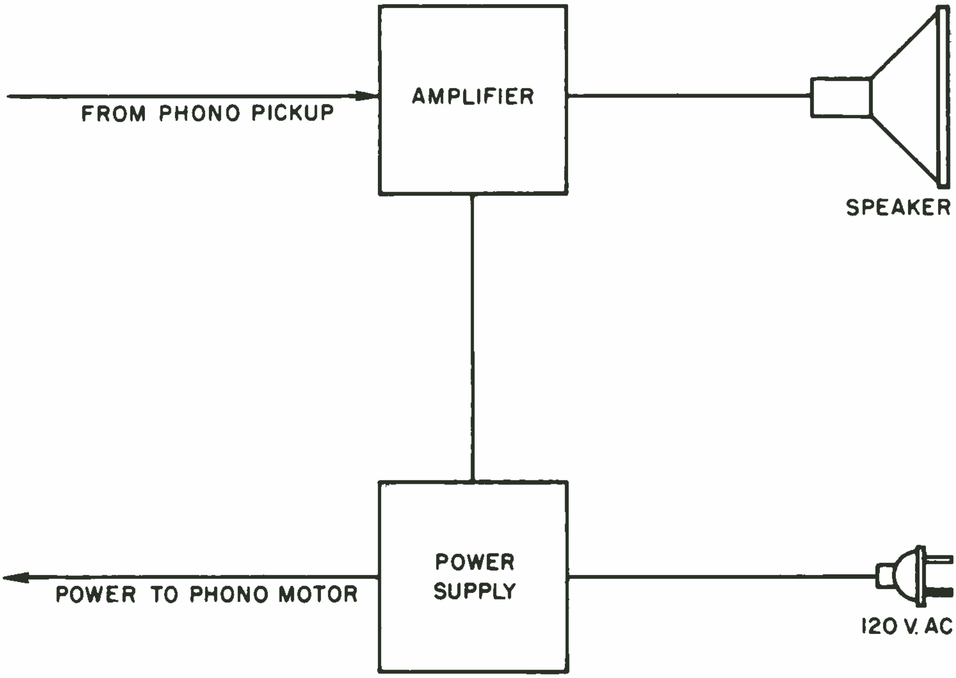


Figure 1 — Simple monaural phonograph.

amplifier; therefore, the unit is monaural or single channel and it has only one speaker.

The unit probably has a 120V AC operated motor, but there are exceptions. Some small phonos manufactured a few years ago had the motor winding connected in series with the tube filament or filaments. In this case the motor requirements were reduced by the amount of voltage dropped across the tubes.

The above information is an example of that which can be derived from a simple block diagram without having to resort to time consuming circuit tracing or analysis.

Compare Figure 2 with Figure 1 and note the similarities and differences between the two units illustrated. Figure 2 is similar in all respects to Figure 1 except that Figure 2 is a stereo unit rather than a monaural unit. This fact is evident from the right and left speakers and inputs.

This is the type of information that you will be able to obtain from simple block diagrams. Naturally, the more experienced and observant you are, the more information you will be able to derive.

In Figure 3 we have shown a more complex phonograph than either of

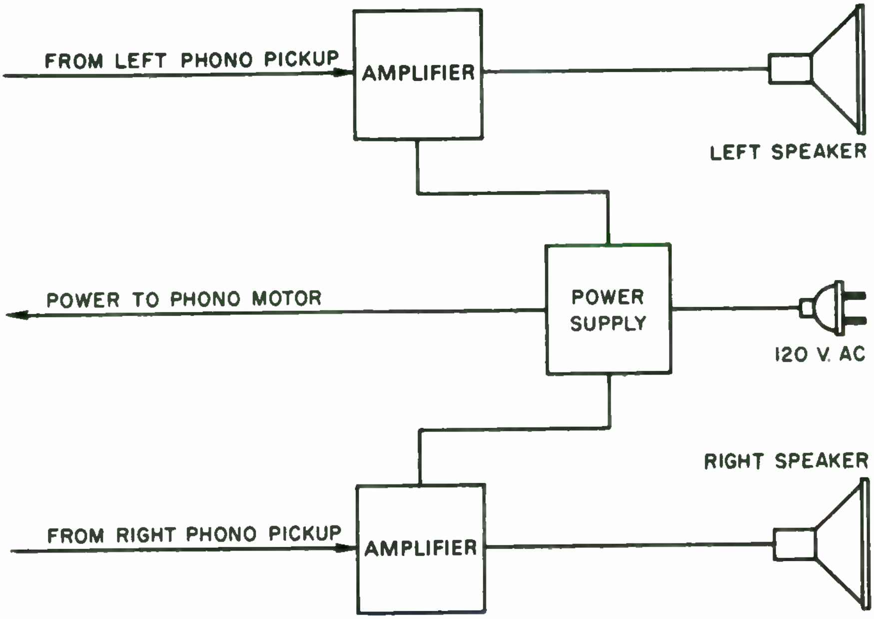


Figure 2 – Simple stereo phonograph.

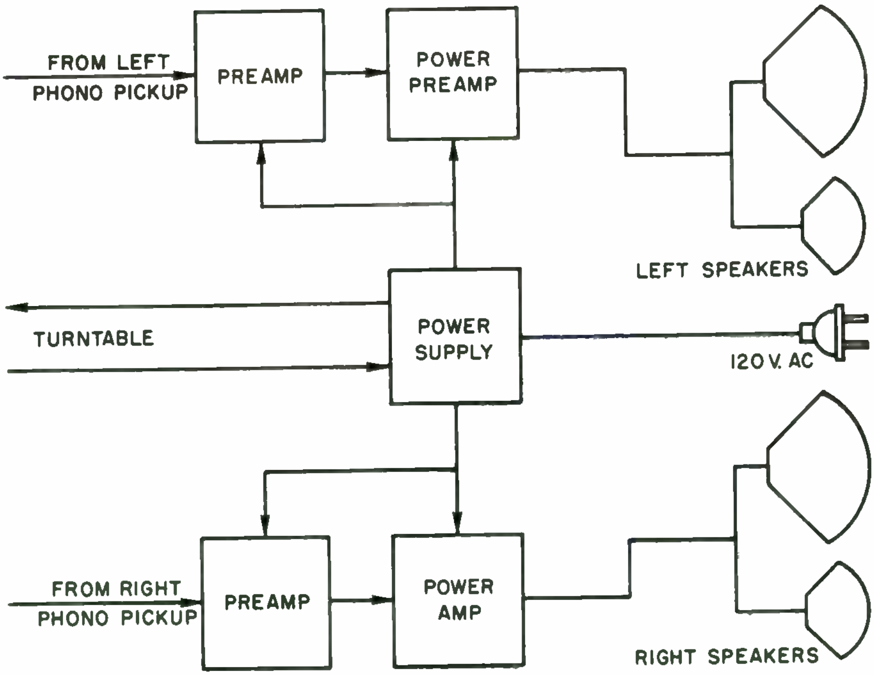


Figure 3 – Stereo Hi-Fi phonograph.

the preceding two. As in Figure 2, it has right and left inputs and outputs and is, therefore, a stereo unit. Several other facts or assumptions can be drawn by studying Figure 3.

Each channel (the left and the right) has two speakers. These two speakers are drawn with different size symbols, indicating that the speakers themselves differ in size. In all probability, the smaller of the two is a tweeter that reproduces only the high frequency sounds. The larger one would then be required to reproduce the low and mid-range sounds.

Assuming that the above is true, the unit must be a high fidelity set capable of reproducing all the sounds that are recorded on a good quality record. In this case, some optional circuitry is probably included, such as separate bass and treble controls and quite possibly an equalization network in each channel. Equalization assures constant reproduction of bass and treble regardless of loudness control setting.

The amplifier in each channel is illustrated with two blocks indicating the use of several amplifying devices to provide more than adequate gain. Gain is probably sufficient to handle signal currents from a good quality, low level phono cartridge. This is the kind of cartridge most likely used.

Two lines are shown interconnecting the power supply with the turntable. One line is illustrated with an arrow returning from the turntable. This could mean that the turntable includes a switch that automatically turns the whole unit off after the last record has played.

Some of the information discussed is only assumption but it can be easily verified by consulting more detailed drawings or schematics. You can never go wrong by making an assumption unless you fail to verify it. Never act on assumptions until you have determined them to be factual.

4 We will now study a block diagram of a table radio and attempt to determine what it contains. If the radio represented by the block diagram of Figure 5 were delivered to an experienced radio and TV serviceman, he would instantly identify it and visualize its operation. A block such as the one in the figure might appear in his mind.

He would quickly determine that it is a vacuum tube radio of a specific type; a type of which millions have been manufactured with little variation between units regardless of who made them.

This radio contains five vacuum tubes, two of which are multiple purpose. The frequency converter section contains a pentagrid converter tube that serves as both mixer and oscillator. The detector, AVC and first audio amp functions, are performed by a duo-diode-triode tube.

The experienced technician would know that the unit contained no power transformer. Its tube filaments were connected in series, and their series voltage drops totaled 120 volts.

Unit/quantity	Old term	Old abbrev.	New term	New abbrev.
Frequency	Cycles Per Second	cps	hertz	Hz
1 Thousand Cycles Per Sesond	Kilocycles Per Second	kc	Kilohertz	kHz
1 Million Cycles Per Second	Megacycles Per Second	Mc	Megahertz	MHz
1,000 Million Cycles Per Second	Gigacycles Per Second	Gc	Gigahertz	GHz

Figure 4 - Conversion chart for frequency in hertz.

The filament current requirement is 0.15 amps.

If the set were inoperative and the tubes did not light, he would probably not bother to consult a diagram. Most likely, he would replace the rectifier tube in the power supply. This particular tube has a high failure rate, so most frequently he would be right.

Suppose the set operated but a loud hum, squeal or the familiar put-put-put that resembles a motor boat were heard from the speaker. An experienced service technician would uncase the unit, make one or two quick tests, and then most likely replace the two section electrolytic filter capacitors. In ten minutes or less, the set would be fixed.

The block diagram in Figure 5 can also be interpreted as a simple flow diagram. Station signals intercepted by the loop antenna, progress toward the right. They are processed and modified by each stage until sound is reproduced in the speaker.

The frequency converter of our five tube "superhet" converts selected incoming signals to a 455-kHz signal which is further amplified by the IF amplifier stage. The amplified IF signal is presented to the detector AVC first audio stage where the audio is removed, amplified, and then fed to the audio output tube. The output stage (also called a power amp) amplifies these signals and produces a watt or more of sound power to drive the speaker. Pure DC power to operate the elements of the tubes in various stages is supplied by the rectifier-filter unit in the power supply.

NOTE: The National Bureau of Standards is now using the term hertz, abbreviated Hz, in all its publications.

The term is applied to a unit of frequency, one hertz being one cycle/sec. Figure 4 will give you a quick reference of a few applications of the term.

In spite of the take-over by transistors in small radios, there are still a lot of these "miracle fivers" (as they are called), five tube radios needing service. Many of them can be repaired with the assistance of only a block diagram for service literature.

Figure 6 is a block diagram that could represent one of several popular AM-FM receivers. As with previous block diagrams, much can be learned about the set without resorting to time consuming circuit analysis.

A block diagram of a black and white TV is shown in Figure 7. All the stages are labeled as to their function, with interconnections shown between stages. This block diagram is also a simple flow diagram of the set's operation.

Signals enter the tuner (shown at the upper left) where they are amplified, and converted to frequencies of 41.25 and 45.75 MHz. This broad band of frequencies contains all the information necessary to reproduce the picture and sound.

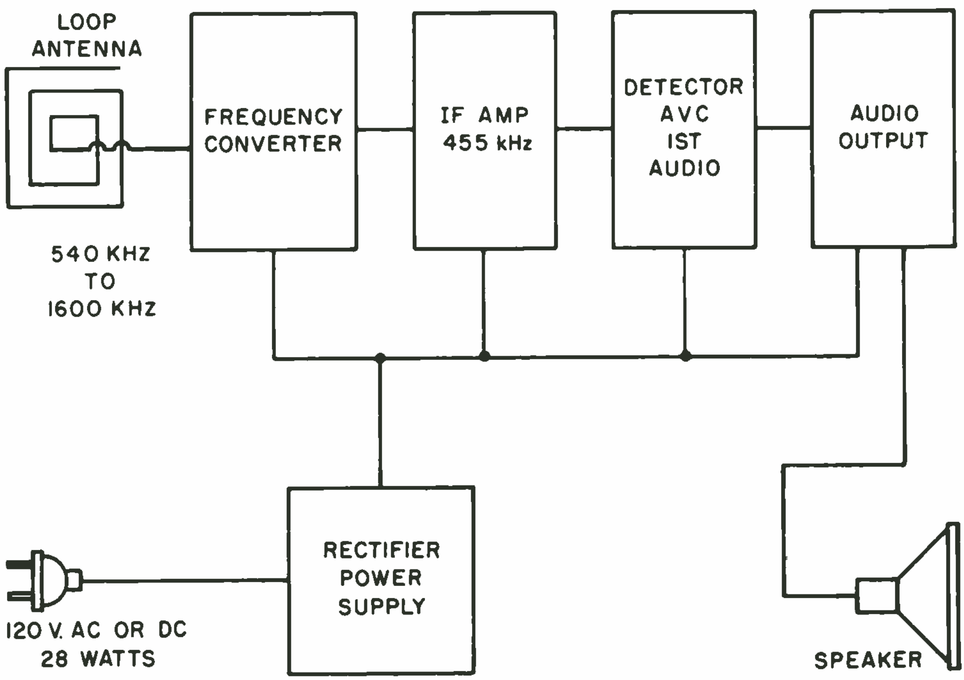


Figure 5 - Simple superheterodyne radio.

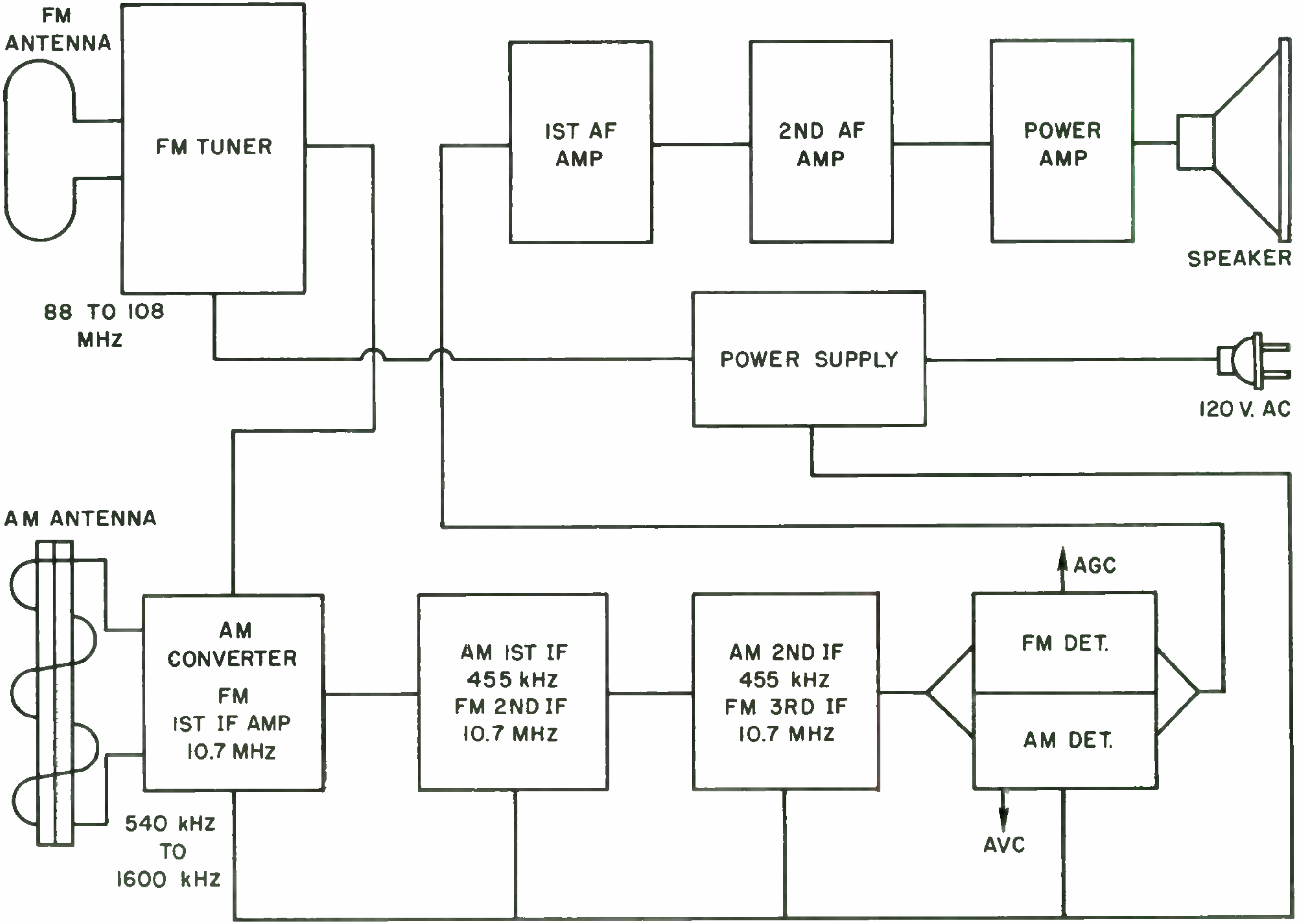


Figure 6 - An AM-FM receiver.

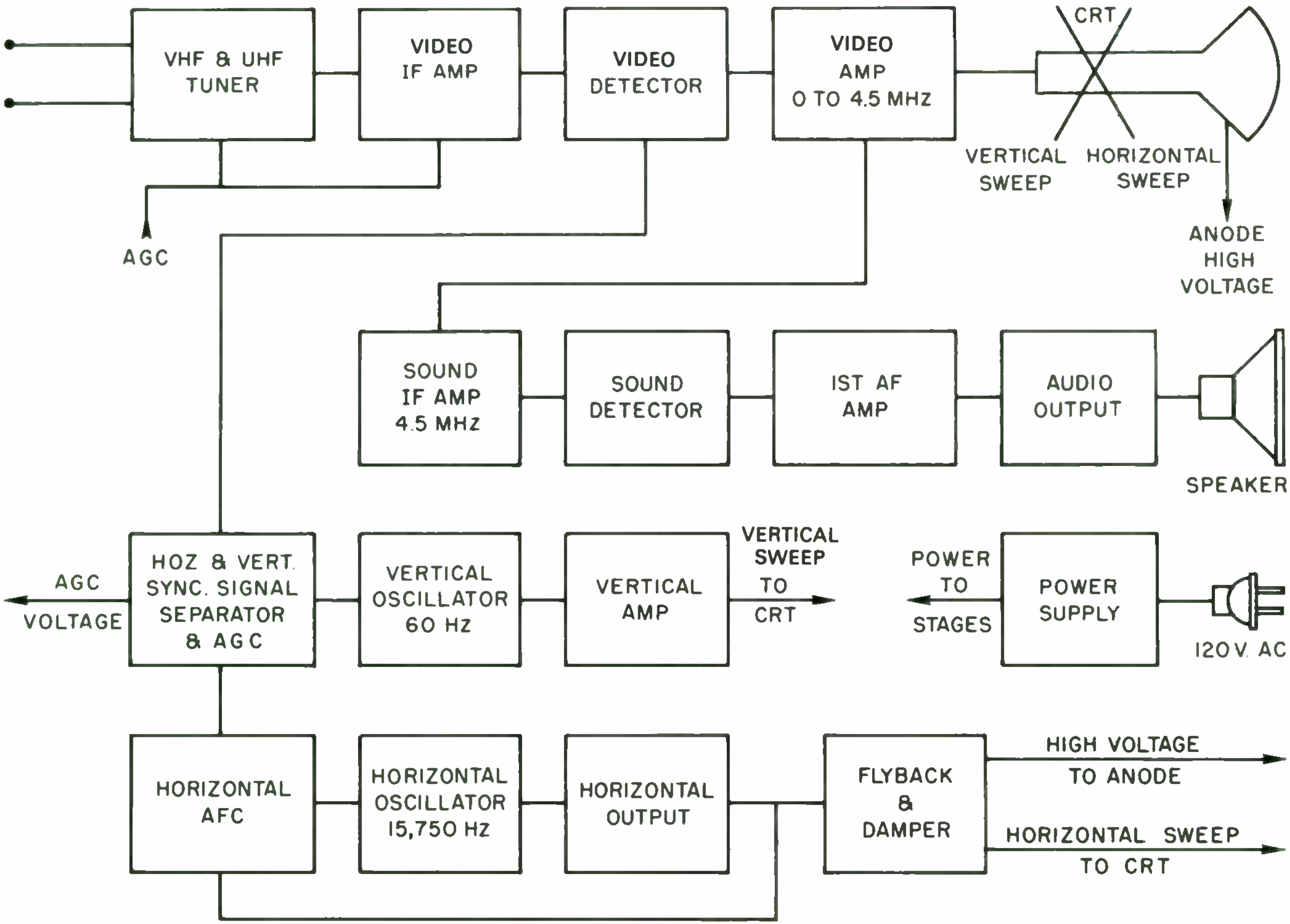


Figure 7 - Block of a television set.

The intermediate frequency from the tuner is amplified by two or more stages of IF amplification. From the last IF stage it is passed to the video detector where sound, sync, and picture information are removed. At this point, horizontal and vertical sync information is removed and routed to the sync separator. The video and sound portions are fed to the video amp. The sound carrier is tapped off and routed to the sound IF amplifier after a stage or two of amplification. The video portion proceeds onto the CRT.

Sound is processed in a fashion similar to that of FM receivers. The only basic difference is that the TV audio IF frequency is 4.5 MHz instead of the 10.7 MHz used in most FM broadcast receivers. The audio is detected, amplified, and routed to a speaker where the sounds are reproduced.

Horizontal and vertical sync signals are separated from each other in a sync separator and routed to their respective sweep circuit oscillators. They cause these oscillators to start and complete each cycle at the proper times so that each line and field of a picture will be in proper sequence.

Automatic gain control (AGC) voltage is developed in the sync separator and supplied to the tuner and video IF stages. This voltage assures a constant picture level on the CRT. It is derived from the amplitude of the sync pulses; an amplitude which varies with signal strength. The voltage developed is therefore proportional to signal strength and causes the gain of the stages it controls to vary. There will be less gain for strong signals and more gain for weak signals.

Although block diagrams are invaluable and present a simple, quick explanation of how equipment operates, other types of information are necessary in servicing. Additional information consists of component lists, component location drawing, mechanical assembly directions, alignment instructions and schematic drawings.

SCHEMATIC DRAWINGS

The main purpose of a schematic diagram is to establish the electrical operation of a particular system or circuit within a system. It is not drawn to scale, and it shows none of the actual construction details of the system (such as a physical location, layout of components, wire routing and other physical detail) not essential to understanding circuit operation.

Schematic drawings differ from block diagrams by presenting more detail concerning each circuit. Whereas, the block diagram deals with functional units of the system, the schematic diagram indicates each individual part which contributes to the functional operation of the circuit.

Schematic drawings consist of parts (shown symbolically) interconnected to form circuits. Each circuit performs a specific function and together they produce a result such as intercepting weak RF signals, amplifying and modifying them and producing entertainment by means of reproduced sound or sound and pictures.

A schematic drawing of a simple five tube AM radio is shown in Figure 8. This is the same radio seen as in the block diagram in Figure 5. Tubes in this particular line-up (Fig. 8) are all octal based, meaning that they have eight pins and a center key to prevent incorrect insertion. A set of tubes was developed and used for several years which were 7 pin miniature versions of these (Fig. 9). They are:

12BE6	Converter
12BA6	IF Amp
12AV6	Det-AVC-1st AF amp
50C5	Output
35W4	Rectifier

Because the AC power line connects directly to the circuitry in Figure 8, without benefit of a transformer for isolation, the metal chassis is not common to circuit ground. It is so isolated with a 220,000 ohm resistor. This prevents shock to the user should he touch the chassis when the line cord is inserted with the hot side to ground.

The power switch is inserted to interrupt the ground return side of the circuitry. The dashed line from the switch, indicates that a single shaft operates both the switch and the volume control.

Notice that the 35Z5 rectifier tube has a tapped filament. The section from pin 2 to pin 3 drops the voltage necessary to operate a pilot light. Pulsating DC from the cathode of the rectifier is applied to an RC filter through a 27 ohm resistor. The RC filter consists of a 1500 ohm resistor and two 50 Mfd. electrolytic filter capacitors. Current for the output tube does not flow through the 1500 ohm resistor. If it did, a considerable reduction in voltage would occur and there would be insufficient voltage to operate other circuits. Current through the output tube is usually greater than through all the remaining tubes.

Resistor and capacitor values are noted on the schematic and are easy to locate in these sets. If difficulty is encountered, service literature from manufacturers or service literature from publishers, contains a pictorial view of component locations. A list of nonstandard items such as coils and transformers is usually included and contains suggested replacements.

Troubleshooting methods vary among service men and depends largely upon the problem. Regardless of method, schematic drawings are invaluable as service aids. They help to locate the defective stage and then the defective part within the stage. They show points at which voltages may be read, signals injected or scope traces taken.

Let us troubleshoot the five tuber of Figure 8. We will assume that the

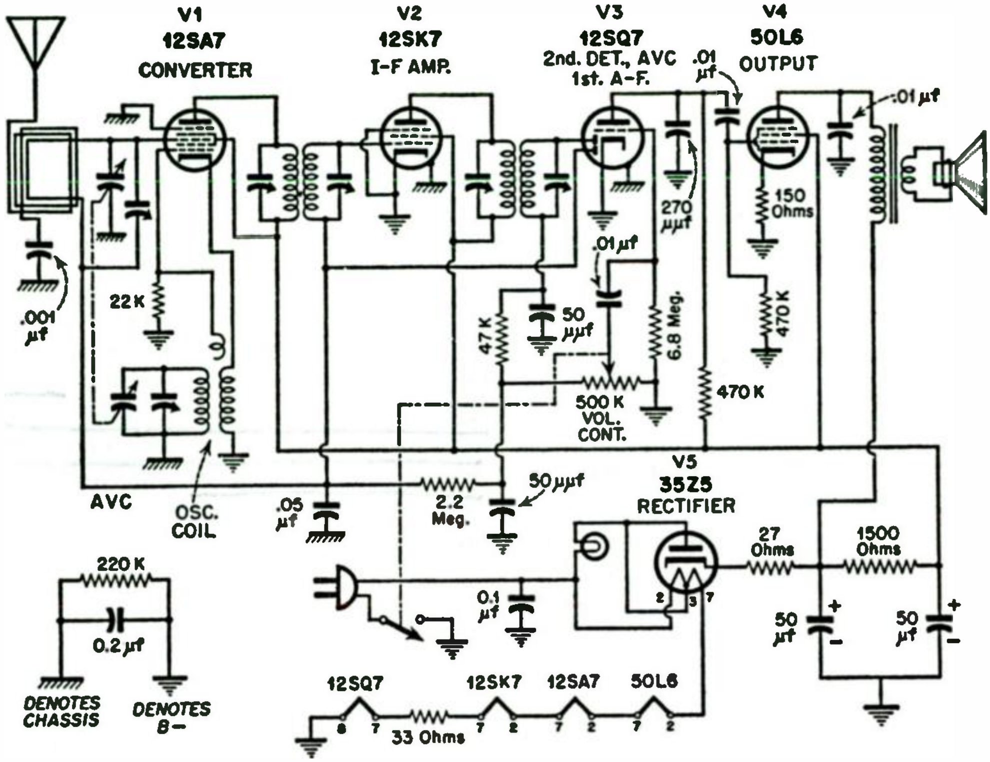


Figure 8 - Schematic of a five tube superhet radio.

set is inoperative but the tubes light. We may quickly determine if the voltages are correct by measuring at the cathode of the rectifier (35Z5) and then at the output of the filter. If all is in order, we can then measure the plate and screen voltages of all the tubes. Once these are verified we can resort to signal injection or circuit tracing.

An audio signal is injected into the grid of the *output* tube and should result in a tone from the speaker. If a tone is presented, we next inject the audio signal into the grid of the *first audio stage* and listen for a tone. The 400-Hz audio tone is available from the signal generator supplied with your course.

If no problem is found in the audio stages we then inject a 455-kHz modulated signal into the *grid* of the *IF amplifier.* This should produce a tone in the output. Next we move the generator lead to the signal *grid* of the *converter.* The 455-kHz signal should produce sound at the output but it may be garbled if the oscillator is working. Switch the generator to a modulated signal frequency that falls within the broadcast band; 1000 kHz is a good frequency with which to start. Dial this frequency with the set's tuning knob and listen for sound in the output. If you cannot tune in the 1000-kHz signal, perhaps the oscillator is not functioning. This can be verified by checking for the presence of a *negative* voltage at the oscillator grid of the converter. This point should measure several volts negative; if it does not, something is wrong in the oscillator stage. It could be the tube or any of the components.

Another way to signal trace an AM radio is to follow the signal through the set from the antenna. Regardless of which method you use; when you lose the signal you can be sure that the trouble is in that stage. By checking the components for shorts and opens, you should be able to locate the malfunctioning part.

SIMPLIFIED SCHEMATICS

In large or complex equipment, a complete schematic drawing may be too large for practical use. For this reason, many technical manuals present only partial or simplified schematics for individual circuits or units.

Simplified schematics normally omit parts and connections which are not essential to understanding circuit operation. In studying or troubleshooting equipment, the technician frequently must make his own simplified drawings. In these cases he should include only those items that contribute to the purpose of the drawing, but he should take care to include all such items. In using schematic drawings, many techniques for simplifying schematics will become apparent. Special attention should be paid to those techniques found useful by the individual — they can be extremely important tools in his work.

NOTES

An important part of many of the drawings and one that is often neglected, is the notes section. This section should always be studied first before any attempt is made to use the drawing for reference. It contains essential information relative to understanding the circuitry.

In Figure 9, the notes refer to components that are included or omitted in different models. In Figure 13 they are far more inclusive. In Figure 13, the note section indicates the position of the band switch, tolerances of components, units of measurement, and much additional information. Without this added information on a drawing, it would be confusing.

ASSOCIATING DIFFERENT DRAWINGS

The radio, illustrated schematically in Figure 8, is a wired unit with a metal chassis. Components are spread out and easy to locate. A later model five tube radio is shown in Figure 9. It has the later version 7 pin miniature tubes and contains a clock. Also, most of the components, including tube sockets, are soldered into a printed circuit board or panel (Fig. 10).

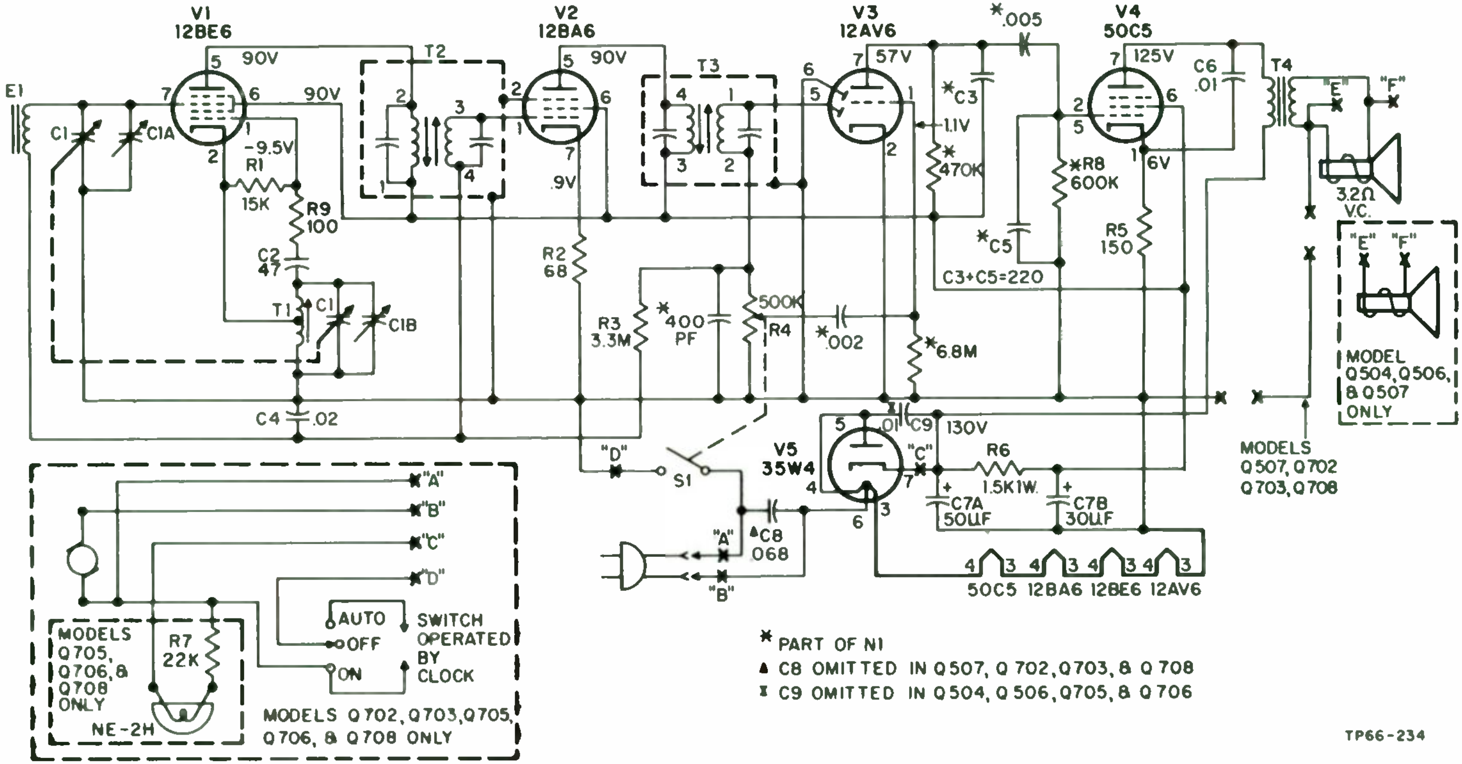


Figure 9-Schematic Diagram AM Models. Courtesy of Philco-Ford.

Specific components may be difficult to locate from the schematic. To aid in their location, the manufacturer provides a bottom view of the circuit panel (Fig. 10). In addition, the symbol for each part is stamped onto the circuit panel in ink or durable paint.

Parts lists are included separately along with their symbol designations and service part numbers to assist you in obtaining replacements (Fig. 11). Even a location code, similar to those used on road maps, is included to help you find a part. Do you see the scales at the top and left sides on each drawing in Figure 10? The circuitry has been separated vertically into areas A, B, and C. Across the top, horizontally from left to right, the panel has been separated into seven segments.

Referring to capacitor C2 on the schematic, we notice that it has a value of 47 pf. This information is repeated in the parts list (Fig. 11) and on the panel (Fig. 10). Opposite its symbolic notation (C2), in the part list, is the location code A6. By locating A in the vertical column at the left of Figure 10 and tracing across to the area under 6 on the top scale, we easily locate the component.

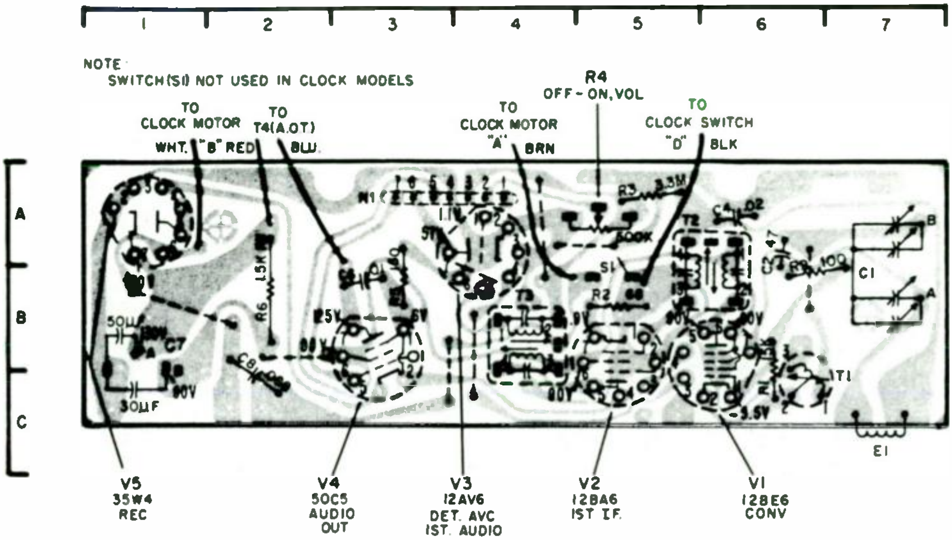
This is an excellent system for component location but unfortunately many manufacturers and publishers do not use it. Most, however, do have some kind of guide.

A system used by several manufacturers is shown with the aid of the schematic in Figure 13; the parts list, a section of which is shown in Figure 16 and component views of the circuit boards (Figs. 14A, B, and C). These diagrams, drawings and parts lists refer to a popular make AM-FM table radio.

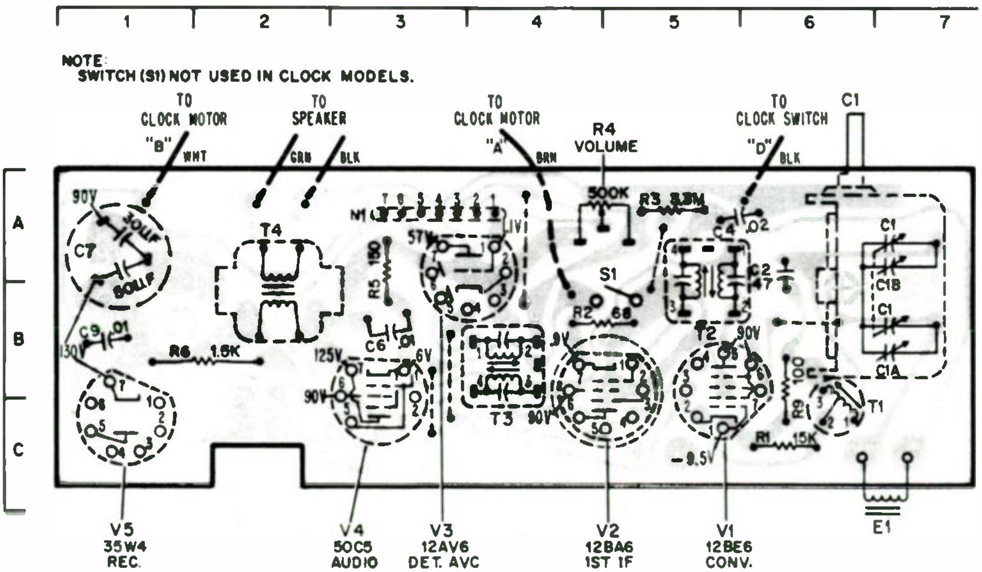
Referring to the schematic drawing of Figure 13, let us locate the PNP transistor that serves as the FM 1st IF and AM converter. Its designation on the schematic is TR4. Since it is in the IF section, we refer to a component view of IF circuit board (Fig. 14B). Components are listed in this Figure by designations located around the edges of the board. Transistor TR4's designation is located at the extreme upper right corner with an arrow pointing to the component.

Although this system is not as easy to use as the road map system, it does provide you with the information. A little perserverance may be required to locate a part.

The parts list in Figure 16, like the one in Figure 11, contains part numbers to assist you in ordering replacement parts. It also includes a description of most components which will usually enable a service man to obtain standard replacement components from his local supplier.



Bottom View - Perma Circuit Panel Top Components Models Q504, Q506, Q705 & Q706



Bottom View - Perma Circuit Panel Top Components Models Q507, Q702, Q703, & Q708

Figure 10-Circuit panels. Courtesy of Philco-Ford.

AM RADIO (TUBES)
MODELS Q504, Q506, Q705, & Q706
ELECTRICAL PARTS LIST

SYMBOL	LOCATION	DESCRIPTION	SERVICE PART NO.
		CAPACITORS	
C1	B7	Vari. tuning gang	31-2794-1
C2	A6	47 pf, osc. cplg.	30-1293-39
C4	A6	.02 mf, AVC	30-1294-27
C6	B3	.01 mf, output plate	30-1294-6
C7A-B	B1	50-30 mf/B+ filter	30-2585-18
C8	C2	.068 mf, AC line	**30-4696-13**
		ANTENNAS	
E1	C7	Magnecore A-M	76-12784-6
		NETWORKS	
N1	A3	Audio cplg.	30-6051-2
		RESISTORS	
R1	B6	15K, osc. grid	
R2	B5	68 ohms, IF cath.	
R3	A5	3.3 meg, AVC	
R4	A5	500K Vol. cont.	
		(Models Q504 & Q506)	33-5614-3
		(Models Q705 & Q706)	33-5614-4
R5	B3	150 ohms, output cath.	
R6	B2	1.5K, B+ filter	
R7	-	22K (neon bulb)	
R9	B6	100 ohms, osc. grid	
		SWITCHES	
SW1	B5	On/off pwr. (part of R4)	
		TRANSFORMERS	
T1	C6	Osc., AM	32-4756-3
T2	B5	1st IF	32-4834-7
T3	B4	2nd IF	42-4834-8
T4		Audio output (Part of speaker)	
		Perma-CKT panel	**27-10865-6**
		Socket, tubes, all except 50C5	27-6351-2
		Socket, tube 50C5	27-6309-3
		Speaker w/transf. for all models	36-1716-1
		Speaker (Models Q504 & Q506)	**36-1716-5**

AM RADIO (TUBES)
MODELS Q507, Q702, Q703, & Q708
ELECTRICAL PARTS LIST

SYMBOL	LOCATION	DESCRIPTION	SERVICE PART NO.
		CAPACITORS	
C1	B7	Vari. tuning gang	31-2794-1
C2	A6	47 pf, osc. cplg.	30-1293-39
C4	A5	.02 mf, AVC	30-1294-27
C6	B3	.01 mf, output plate	30-1294-6
C7A-B	A1	50-30 mf/ B+ filter	30-2585-18
C9	B1	.01 mf, rect.	30-1294-6
		ANTENNAS	
E1	C7	Magnecore A-M	76-12784-7
		NETWORKS	
N1	A3	Audio cplg.	30-6051-2
		RESISTORS	
R1	C6	15K, osc. grid	
R2	B4	68 ohms, IF cath.	
R3	A5	3.3 meg, AVC	
R4	A5	500K Vol. cont.	
		(Model Q507)	33-5614-3
		(Models Q702. Q703, & Q708)	33-5614-4
R5	B3	150 ohms, output cath.	
R6	B2	1.5K, B+ filter	
R7	-	22K (neon) Models Q705, Q706, & Q708	
R9	C6	100 ohms, osc. grid	
		SWITCHES	
SW1	B5	On/off pwr. (part of R4)	
		TRANSFORMERS	
T1	C6	Osc., AM	32-4756-6
T2	B5	1st IF	32-4834-7
T3	B4	2nd IF	42-4834-8
T4	A2	Audio output	32-10036-1
		Perma-CKT panel	27-11253-3
		Socket, tubes, all except 50C5	27-6351-2
		Socket, tube 50C5	27-6309-3
		Speaker (2 used in Model Q507)	**36-1716-5**

New parts not previously carried are shown in boldface type

Figure 11 — Manufacturers Parts Lists. Courtesy of Philco-Ford.

ORDER NO. RD-620 **MODEL RE-7259 or C**

PANASONIC® Service Manual

ISO

FM-AM 2-BAND TABLE RADIO

MODEL RE-7259 or C

SPECIFICATIONS

Frequency Range:	FM 87~108 MHz AM 525~1605 kHz
Intermediate Frequency:	FM 10.7 MHz AM 455 kHz
Transistors:	2SC429 FM RF Amplifier 2SC469 FM Oscillator 2SC185 FM Mixer 2SC920 FM 1st IF Amp. & AM Converter 2SC469 FM 2nd IF Amp. & AM 1st IF Amp. 2SC469 FM 3rd IF Amp. & AM 2nd IF Amp. 2SC183 1st AF Amplifier 2SB176 2nd AF Amplifier 2SB473} 2SB473} Power Amplifier (push-pull)
Diodes:	SC-15 FM AFC OA90/1N34A AM D. AGC 1S1211} 1S1211} Operation Compensator OA90/1N34A AM Detector & AGC OA90/1N34A} OA90/1N34A} FM Detector
Sensitivity:	FM 10μV for 30 dB Quieting AM 70μV/m for 50 mW Output
Power Output:	3 W Maximum
Power Source:	AC 110~120V 50-60 Hz
Power Consumption:	11W
Speaker:	6½" PM Dynamic Speaker, Imp. 16Ω
Cabinet Dimensions:	17⅜"(Wide) × 9⅜"(High) × 5⅞"(Deep)
Weight:	8 lb. 13 oz.

MATSUSHITA ELECTRIC CORP. OF AMERICA

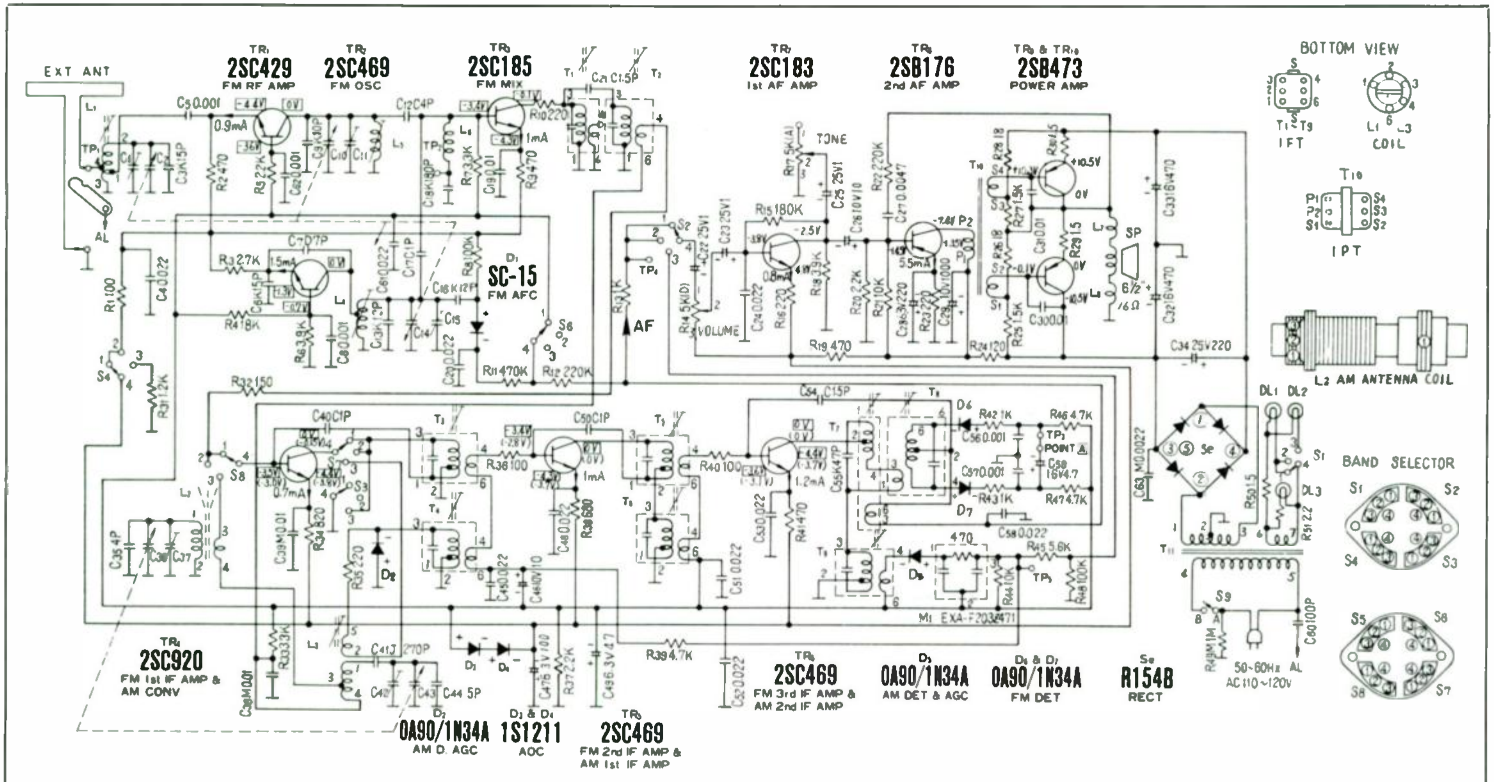
Pan-Am Bldg., 200 Park Ave., New York, N.Y. 10017

HAWAII/MATSUSHITA ELECTRIC OF HAWAII, INC., 205 Kalihi St., Honolulu, Hawaii 96819

CANADA/MATSUSHITA ELECTRIC OF CANADA, LTD., 40 RONSON DRIVE, REXDALE, ONTARIO

Figure 12-Cover page of Service Manual. Courtesy of Panasonic.

MODEL RE-7259 or C



Notes :

1. S1 ~ S8 Band selector switch in "FM" position
2. S9 Power source switch in "OFF" position
3. DC voltages measurements are taken with circuit tester (10KΩ/V) from chassis
   [ ] .....FM position ( ) .. ..AM position
4. Capital letters (M, K, D, J, C) in the circuit diagram show allowable tolerance of resistors and capacitors as follows
   C – ±0.25PF D = ±0.5PF J – ±5%, M – ±20%, K = ±10%
   • Tolerance of resistor is ±10% (K) if not otherwise indicated
   • Tolerance of capacitor is +100% (P) if not otherwise indicated – 0%
5. PF = pico farad – mmf
   μF – micro farad – mfd
6. All resistor values in ohms (K = 1000Ω)
7. All capacitor values in micro farads (P = mmf)

Figure 13-AM-FM radio schematic drawing. Courtesy of Panasonic.

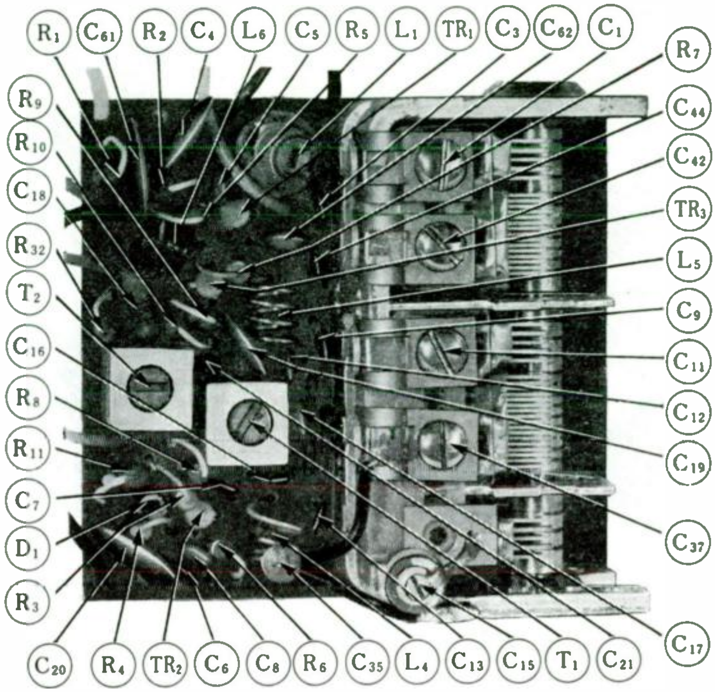


Figure 14A-Component View parts identification, FM RF section. Courtesy of Panasonic.

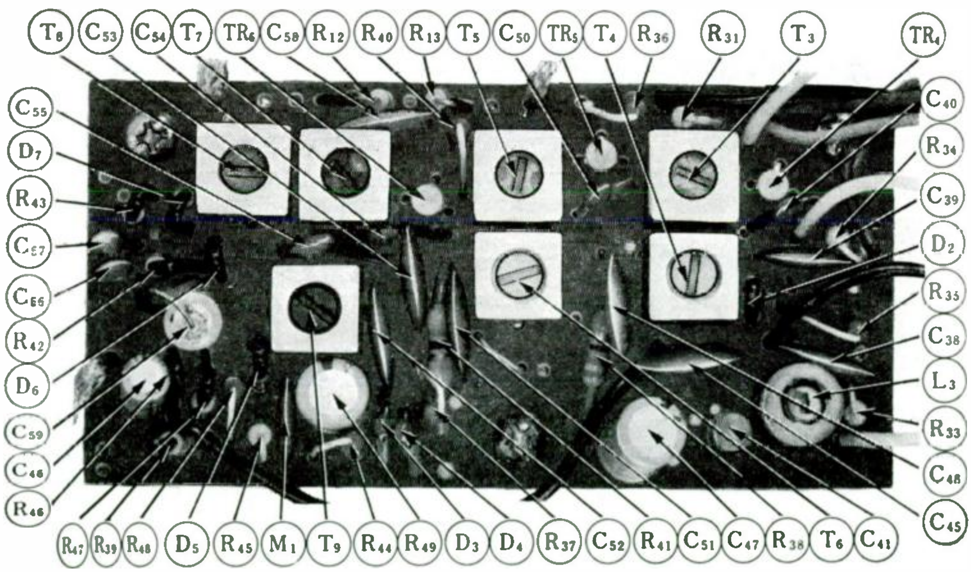


Figure 14B - Component View parts identification, IF section. Courtesy of Panasonic.

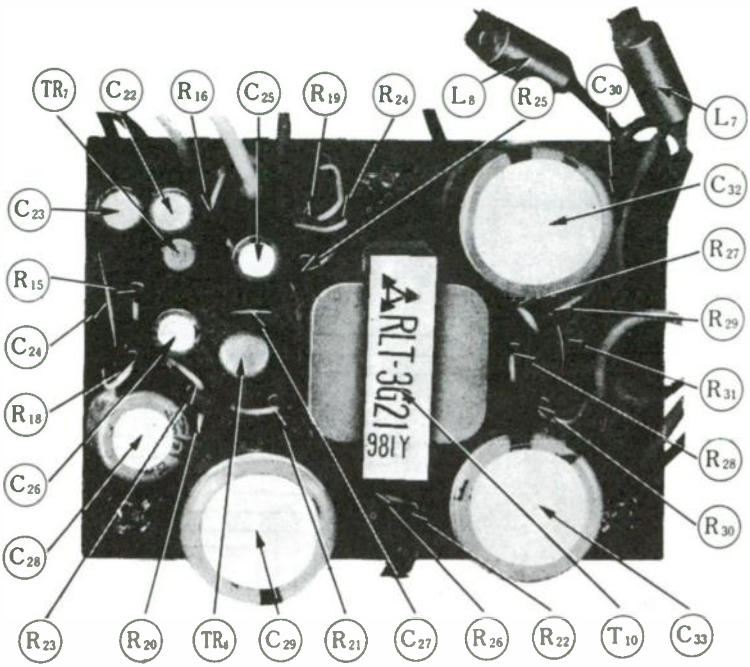


Figure 14C - Component view parts identification, Audio section.

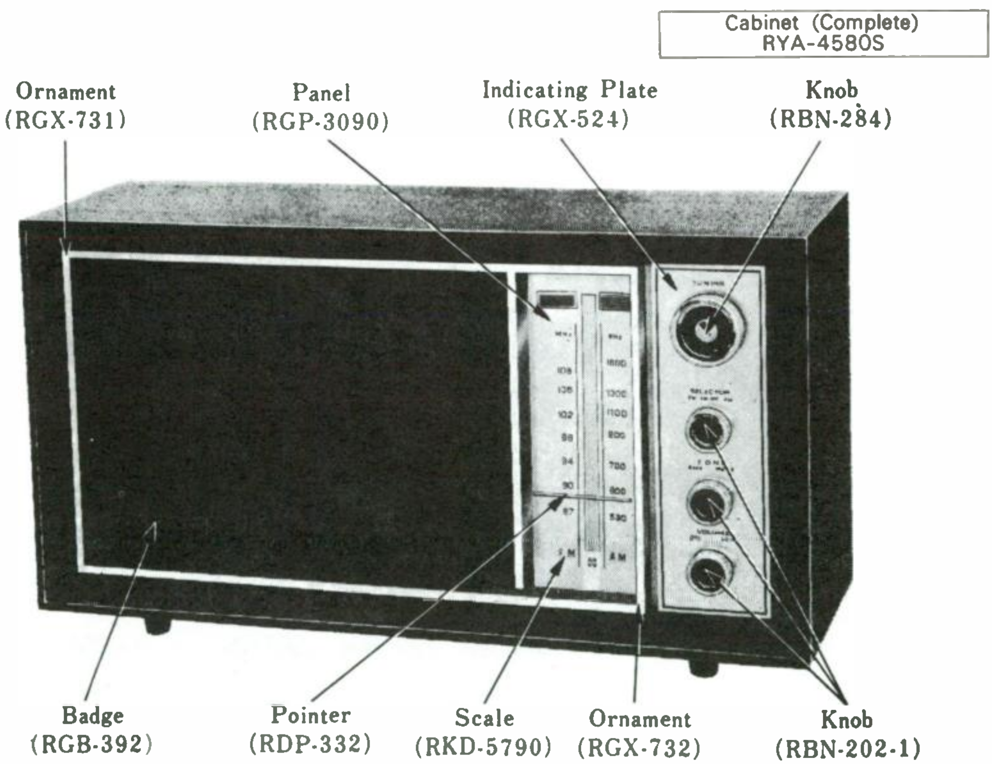


Figure 15-Cabinet component. Courtesy of Panasonic.

REPLACEMENT PARTS LIST

Ref. No.	Stock No.	Description
	TRANSISTORS AND DIODES	
TR_1	2SC429	FM RF Amplifier
TR_2	2SC469	FM Oscillator
TR_3	2SC185	FM Mixer
TR_4	2SC920	FM 1st IF Amp. & AM Converter
TR_5	2SC469	FM 2nd IF Amp. & AM 1st IF Amp.
TR_6	2SC469	FM 3rd IF Amp. & AM 2nd IF Amp.
TR_7	2SC183	1st AF Amplifier
TR_8	2SB176	2nd AF Amplifier
TR_9	2SB473	Power Amplifier (push-pull)
TR_{10}	2SB473	
D_1	SC-15	FM AFC
D_2	OA90 or 1N34A	FM D. AGC
D_3	1S1211	Operation Compensator
D_4	1S1211	
D_5	OA90 or 1N34A	AM Detector & AGC
D_6	OA90 or 1N34A	FM Detector
D_7	OA90 or 1N34A	
	RECTIFIER	
Se	R-154 B	Rectifier
	CAPACITORS	
C_2, C_{10}, C_{14}, C_{36}, C_{43}	ECV-5XR27812S	Tuning Gang. W/Trimmer (C_1, C_{11}, C_{15}, C_{37}, C_{42})
C_3	ECC-D05150KC	15mmf, 50WV, ±10%, Ceramic
C_4	ECK-E05223P	0.022mfd, 50WV, +100%, −0%, Ceramic
C_5	ECK-D05102P	0.001mfd, 50WV, +100%, −0%, Ceramic
C_6	ECC-D05150KC	15mmf, 50WV, ±10%, Ceramic
C_7	ECC-D05070DC	7mmf, 50WV, ±0.5mmf, Ceramic
C_8	ECK-D05102P	0.001mfd, 50WV, ±100%, −0%, Ceramic
C_9	ECC-D05100KC	10mmf, 50WV, ±10%, Ceramic
C_{12}	ECC-D05040C	4mmf, 50WV, ±0.25mmf, Ceramic
	RESISTORS	
R_1	ERD-14VK 101	100Ω, ¼Watt, ±10%, Carbon
R_2	ERD-14VK 471	470Ω, ¼Watt, ±10%, Carbon
R_3	ERD-14VK 272	2.7KΩ, ¼Watt, ±10%, Carbon
R_4	ERD-14VK 183	18KΩ, ¼Watt, ±10%, Carbon
R_5	ERD-14VK 222	2.2KΩ, ¼Watt, ±10%, Carbon
R_6	ERD-14VK 392	3.9KΩ, ¼Watt, ±10%, Carbon
R_7	ERD-14VK 332	3.3KΩ, ¼Watt, ±10%, Carbon
R_8	ERD-14VK 104	100KΩ, ¼Watt, ±10%, Carbon
R_9	ERD-14VK 471	470Ω, ¼Watt, ±10%, Carbon
R_{10}	ERD-14VK 221	220Ω, ¼Watt, ±10%, Carbon
	COILS AND TRANSFORMERS	
L_1	RLA-4P3	FM Antenna Coil
L_2	RLF-2D35	AM Antenna Coil
L_3	RLO-2P58	AM Oscillator Coil
L_4	RLO-4Y53	FM Oscillator Coil
L_5	RLD-4Y54	FM Collector Coil
L_6	RLQ-Y15G-5	FM Choke Coil

Notes:
1. * indicates parts for the complete cabinet which are included when the cabinet is ordered.
2. Stock numbers are indicated on most mechanical parts. Please use this number, therefore, when ordering parts.
3. ISO metric thread screws & parts which employ ISO metric thread screws are identified by ISO marking.

Figure 16-Manufacturers parts list. Courtesy of Panasonic.

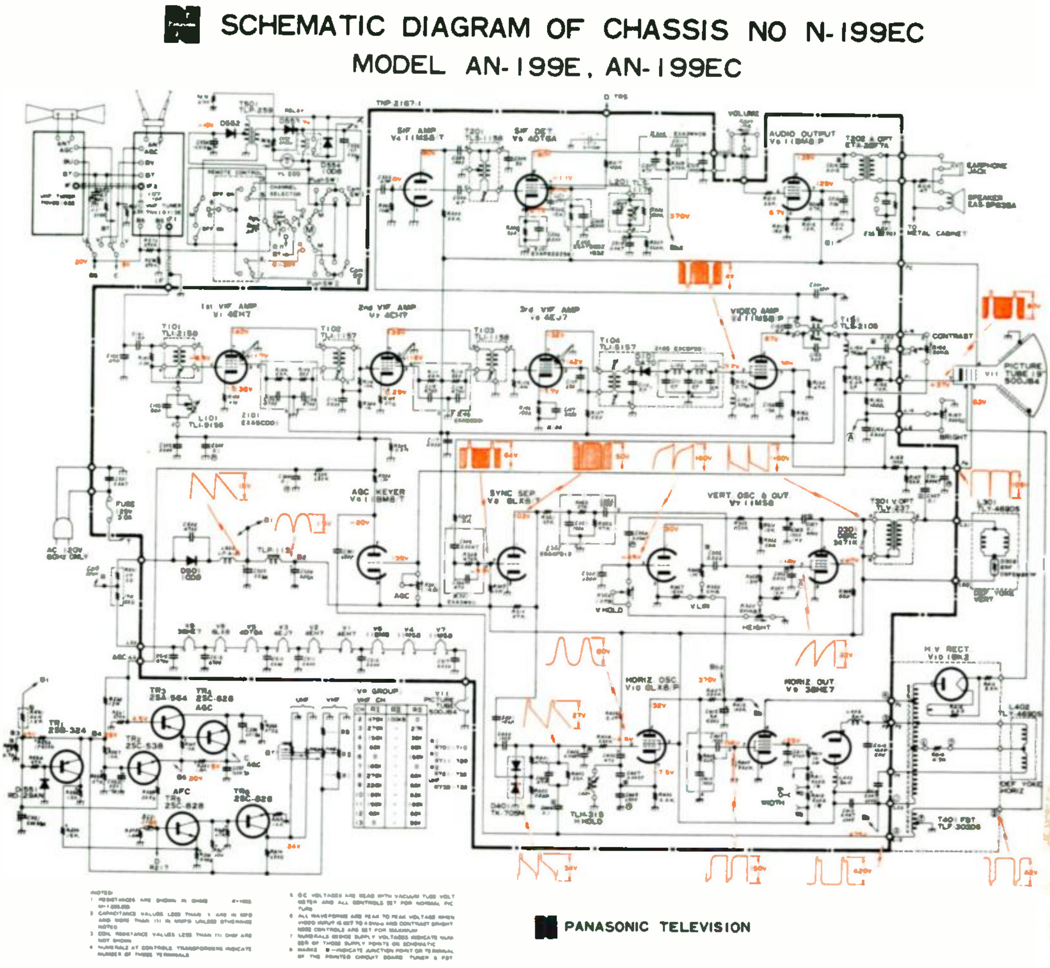


Figure 17-Schematic of a popular TV set. Courtesy of Panasonic.

SERVICE MANUALS

The balance of this lesson is devoted to excerpts from a service manual for a popular TV set. It contains all the information necessary to adjust, troubleshoot, repair or align the set. Notice in particular, the waveforms with their amplitudes as shown on the schematic (Fig. 17). These are oscilloscope traces of the waveforms that should appear at these points.

In addition to schematic drawings, this manufacturer's literature contains complete disassembly instructions. This enables you to remove the set from the case without guessing about what screws to remove. It also contains complete alignment instructions and a location list of service adjustments. Views of the circuit boards are shown to assist the technician in locating parts or circuitry.

Study this information for both content and presentation. It is the type of service literature you will be dealing with in your service business.

MODELS AN-199E &AN -199EC

PANASONIC® Service Manual

PORTABLE TELEVISIONS

MODELS AN-199E & AN-199EC

SPECIFICATIONS

Power Input Rating:	AC 120V, 60c/s
Power Consumption:	120 Watt
Antenna Impedance:	300 Ohm Balanced Type, Both VHF & UHF
Receiving Channels:	2–13 CH (VHF), 14–83CH (UHF)
Intermediate Frequency:	Video 45.75 Mc Sound 41.25 Mc
Vacuume Tubes:	11 (Picture Tube Included)
Semiconductors:	6 Transistors 1 Selenium Diode 1 Germanium Diode 5 Silicon Diode 1 Thermistor 1 Varistor
Picture Tube:	184 Square Inches 114° Deflection Aluminized
Speaker:	3- ½ Inches Round Type
Audio Output:	2.0 Watts Maximum
Automatic Circuit:	AGC (Keyed Type) Horizontal AFC (Saw-Tooth Type)
Dimensions:	Height 16- ⅛" Width 22- ⅜" Depth 14- ⅜"
Weight:	35.21b

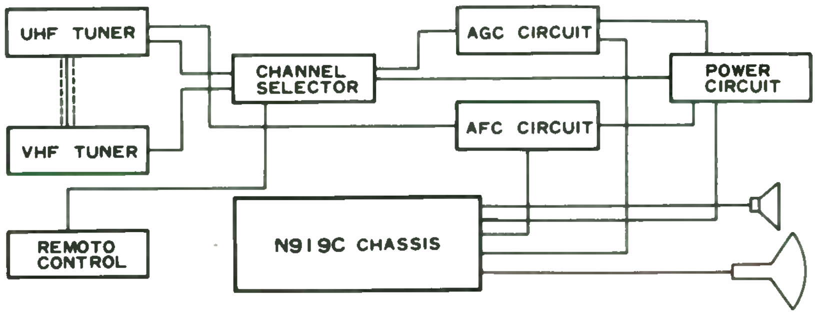
MATSUSHITA ELECTRIC CORP. OF AMERICA
Pan-Am Bldg., 200 Park Ave., New York, N.Y. 10017
HAWAII/MATSUSHITA ELECTRIC OF HAWAII. INC., 205 Kalihi St. Honolulu, Hawaii 96819
CANADA/MATSUSHITA ELECTRIC OF CANADA LTD., 1054 Kipling Ave., North.Rexdale,Ont.

Figure 17 (continued)-Courtesy of Panasonic.

CONTENTS

Figure 17 (continued)-Courtesy of Panasonic.

BLOCK DIAGRAM



(Fig. 1)

CAUTION:

The high voltage supply at the picture tube anode will give an unpleasant shock, but does not supply enough cuurrent to give a fafal burn or shock. However, secondary human reaction to otherwise harmless shocks have been known to cause injury. Always discharge the picture tube-anode to the receiver chassis before handling the tube.

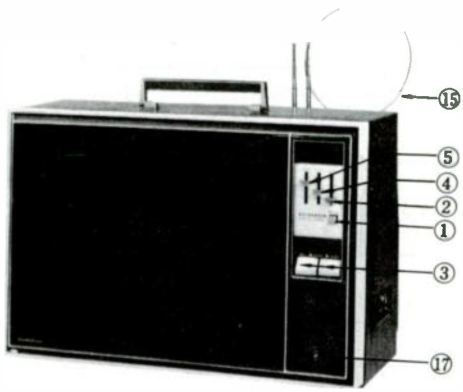
Certain portions of the high voltage generating circuit are dangerous and extreme caution should be observed. The picture tube is highly evacuated and, if broken, glass fragments will be violently expelled.

WHEN HANDLING THE PICTURE TUBE, ALWAYS WEAR GOGGLES AND PROTECTIVE CLOTHING.

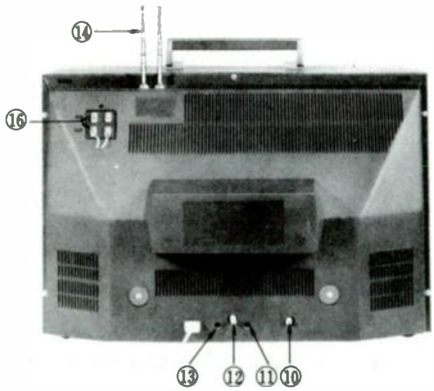
Figure 17 (continued)-Courtesy of Panasonic.

SERVICE ADJUSTMENTS

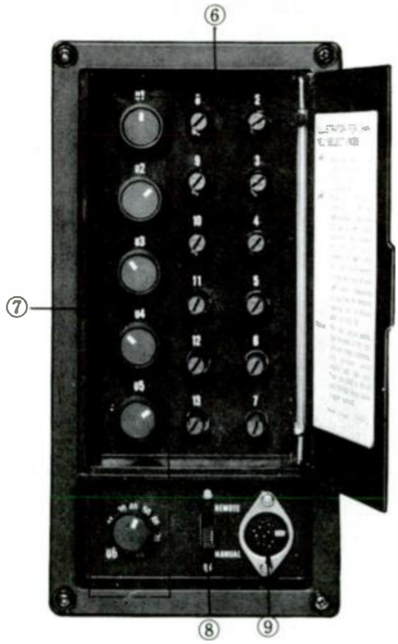
LOCATION OF ADJUSTMENTS



(Fig. 2)



(Fig. 3)



(Fig. 4)

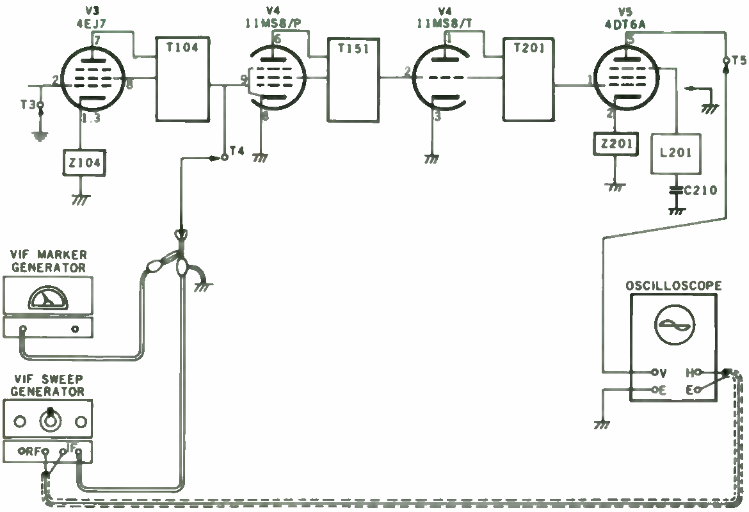
① ON-OFF SWITCH
② SOUND VOLUME
③ VHF & UHF CHANNEL SELECTOR
④ BRIGHTNESS
⑤ CONTRAST
⑥ VHF FINE TUNING
⑦ UHF CHANNEL SELECTOR
⑧ REMOTE-MANUAL CHANGE SWITCH
⑨ REMOTE CONTROL SOCKET
⑩ HORIZONTAL HOLD
⑪ VERTICAL LINEARITY
⑫ VERTICAL HOLD
⑬ HEIGHT
⑭ VHF ANTENNA
⑮ UHF ANTENNA
⑯ ANTENNA TERMINAL
⑰ EARPHONE JACK

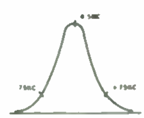
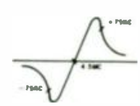
Figure 17 (continued)-Courtesy of Panasonic.

GENERAL ALIGNMENT INSTRUCTIONS

SOUND I-F ALIGNMENT

1. Connect the output terminal of the SIF sweep to G1 (T4) of V4 11MS8.
2. Earth G1 (T3) of V3 4EJ7.
3. Connect the input terminal of the oscilloscope with the plate (T5) of V5 4DT6A.
4. Earth G3 of V5 4DT6A.
5. Adjust T151 and T201. Make the response curve maximum.
6. When the adjustment of the SIF AMP is finished, remove the earth of G3 of V5 4DT6A.
7. After adjusting coil L201, make the 4.5M marker come to the center of the inclined part of the S curve.



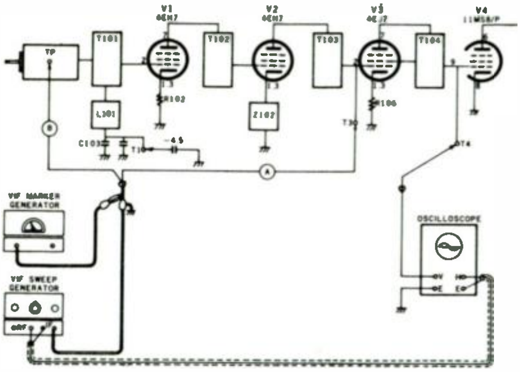
STEP	Ⓐ	Ⓑ
INJECTION POINT	OSCILLOSCOPE . . . . . . T5 SWEEP GENERATOR . . T4	OSCILLOSCOPE . . . . . . T5 SWEEP GENERATOR . . T4
RESPONSE CURVE		
NOTE	V3 4EJ7 G1(T3) . . . Ground V5 4DT6A (T5) . . . . Ground	V3 4EJ7 G1(T3). . . . Ground V5 4DT6A(T5). . . . . Disconnect Ground

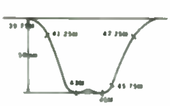
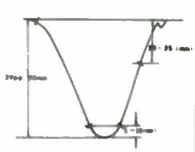
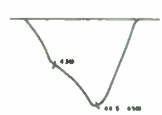
SOUND I-F ALIGNMENT

Figure 17 (continued)-Courtesy of Panasonic.

VIDEO I-F ALIGNMENT

1. Apply a −4.5V bias voltage to the AGC circuit (T1) of the VIF as the earth (ground).
2. Connect the vertical terminal of the oscilloscope with G1 (T4) of V4 11MS8.
3. Connect the output terminal of the VIF sweep with G1(T3) of V3 4EJ7, and adjust the Detector Transformer (T104)
4. Next, connect the output terminal of the VIF sweep with the Test Point of the tuner and adjust each step of the transformer.
5. Adjust the 47.25M trap after adjustment of the VIF's overall wave shape.
6. After adjustment, be sure that abnormal oscillation is not present after the bias is removed.
7. Prior to the adjustments noted above, make the sound volume minimum, and make both the contrast and the brightness maximum.



STEP	Ⓐ	Ⓑ		
INJECTION POINT	OSCILLOSCOPE . . . . . T4 SWEEP GENERATOR . T3	OSCILLOSCOPE . . . . . . T4 SWEEP GENERATOR . . TUNER T.P.		
ALIGNMENT	T104	T101, T102, T103 V.TUNER CONVERTER	L101	
RESPONSE CURVE				
NOTE	TLI-5157 Top & Bottom Cores	TLI-2158 (43M) TLI-1157 (43M) TLI-1158 (45M) V.Tuner Converter(45M)	TLI-9156	VIF⊖Bias . . 0V

VIDEO I-F ALIGNMENT CHART

Figure 17 (continued)-Courtesy of Panasonic.

DISASSEMBLY INSTRUCTIONS

REAR COVER REMOVAL

1) Remove the seven rear cover screws Ⓐ
2) Disconnect leads from the UHF & VHF antenna.
3) Remove the back cover by pulling it straight away from cabinet.

CHASSIS REMOVAL

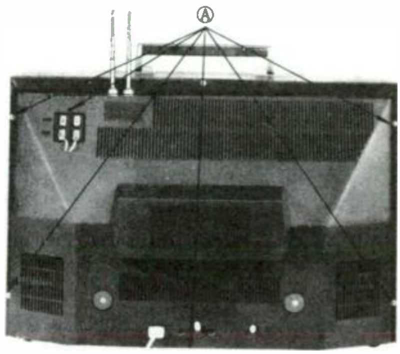
1) Disconnect the CRT anode Ⓑ CRT socket Ⓒ and deflection coil Ⓓ
2) Remove the two chassis holder screws Ⓔ
3) The chassis assembly can be removed from the cabinet

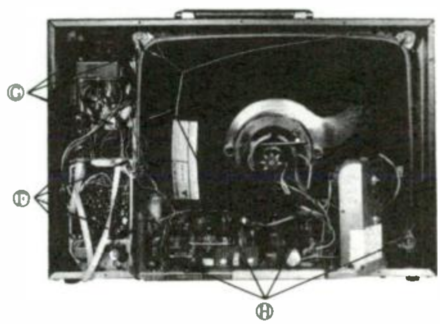
TUNER AND CONTROL ASSEMBLY REMOVAL

1) Remove the four tuner bracket holder screws Ⓕ
2) Remove the four control Volume bracket holder screws Ⓖ

PICTURE TUBE REMOVAL

1) Remove the picture tube mounting screws Ⓗ
2) Remove the picture tube carefully.





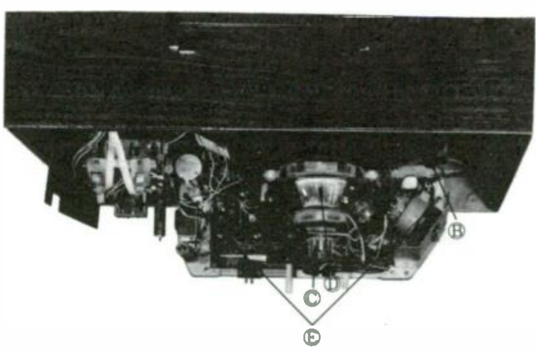


Figure 17 (continued)-Courtesy of Panasonic.

CHASSIS (TNP-2167-1)

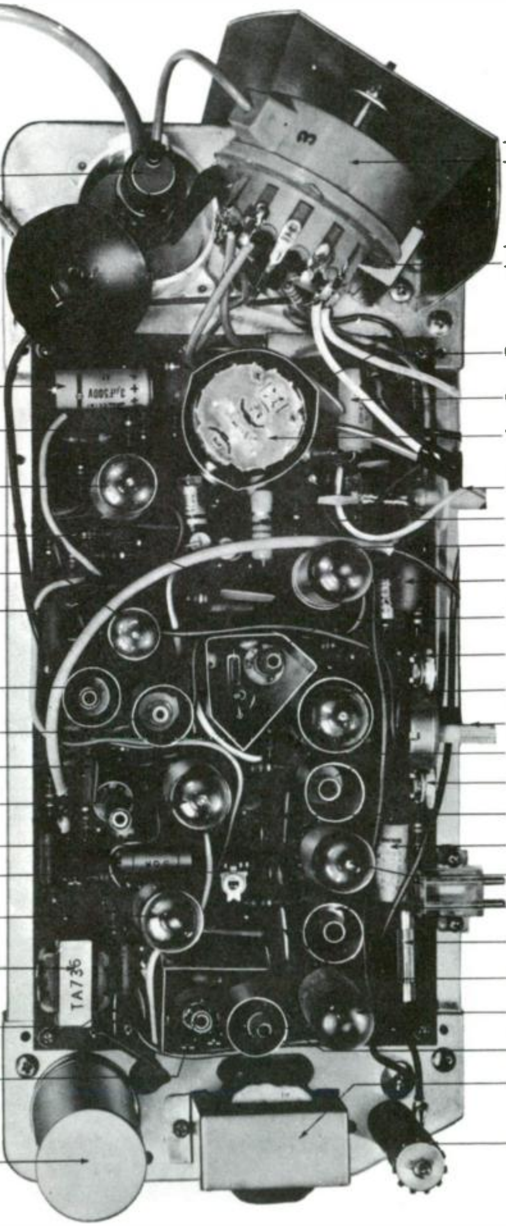


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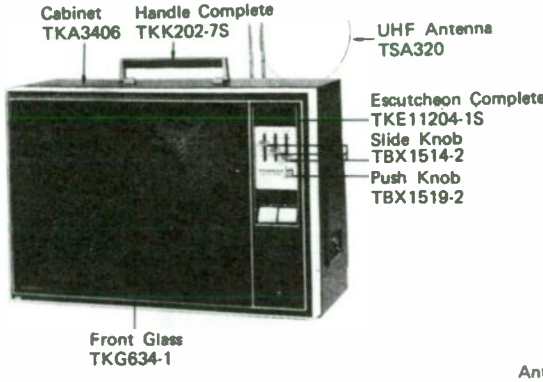
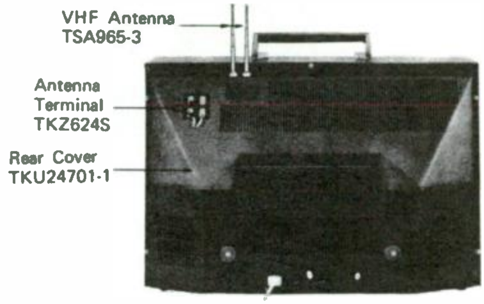
Figure 17 (continued)-Courtesy of Panasonic.

CABINET





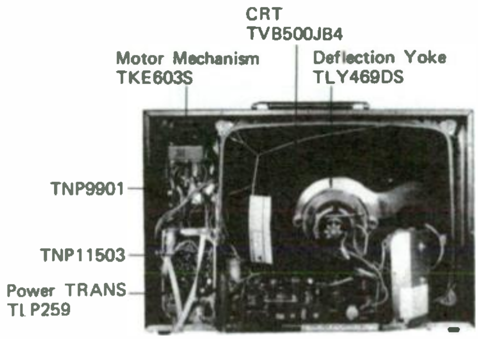


Figure 17 (continued)-Courtesy of Panasonic.

PARTS IDENTIFICATIONS

CONDUCTOR VIEW (TNP-2167-1)

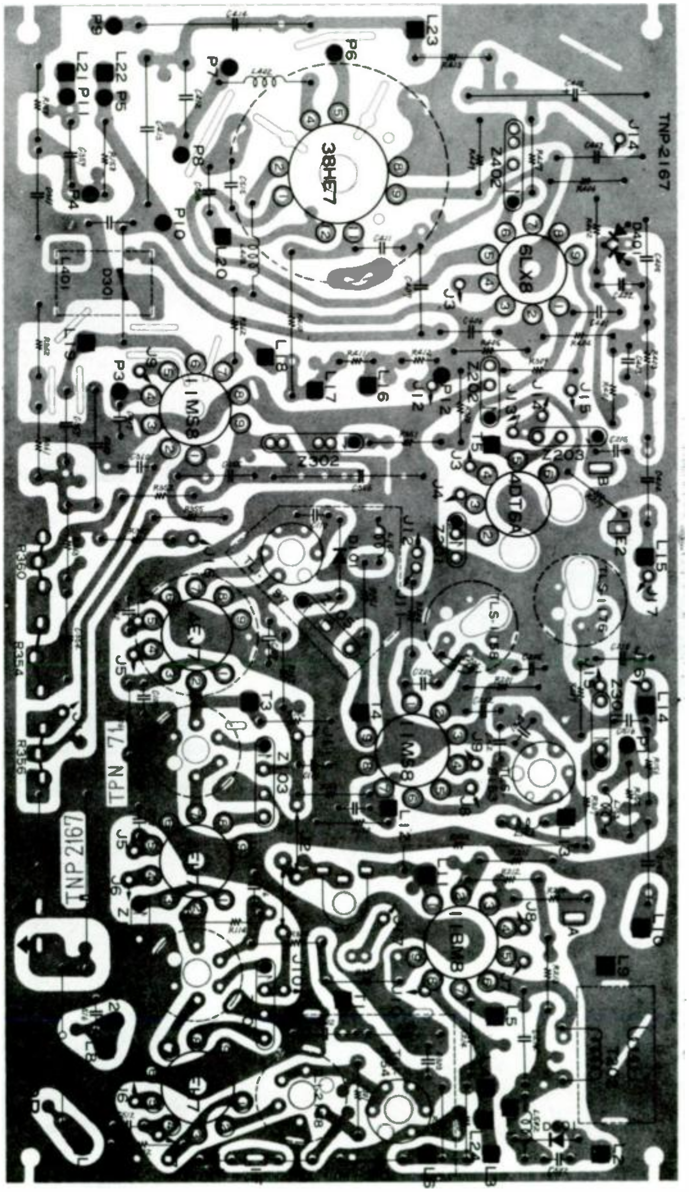


Figure 17 (continued)-Courtesy of Panasonic.

COMPONENT VIEW (TNP-2167-1)

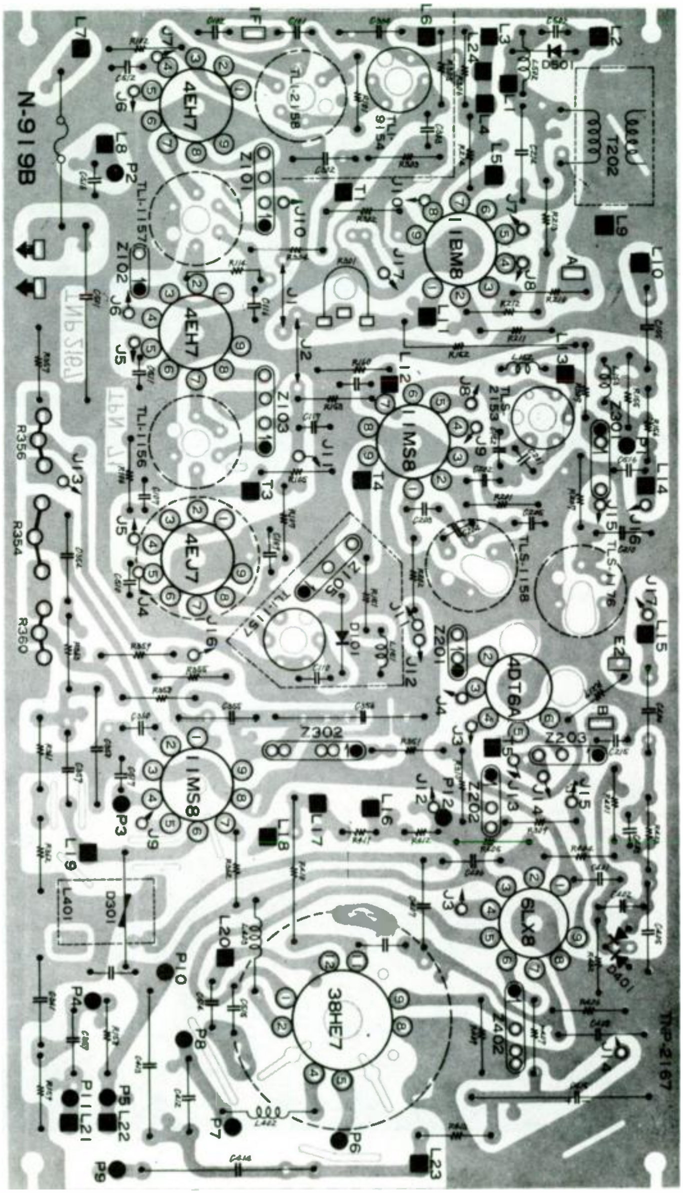


Figure 17 (continued)-Courtesy of Panasonic.

PARTS IDENTIFICATIONS

COMPONENT VIEW (TNP-9901)

CONDUCTOR VIEW (TNP-9901)

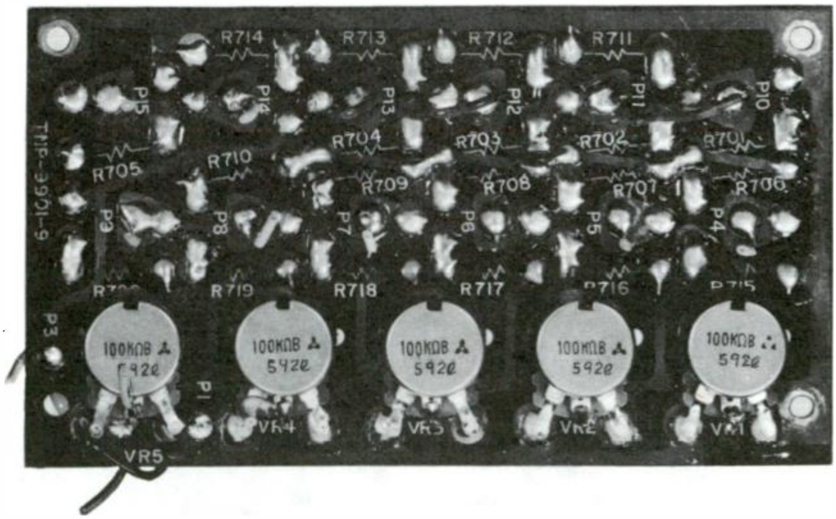
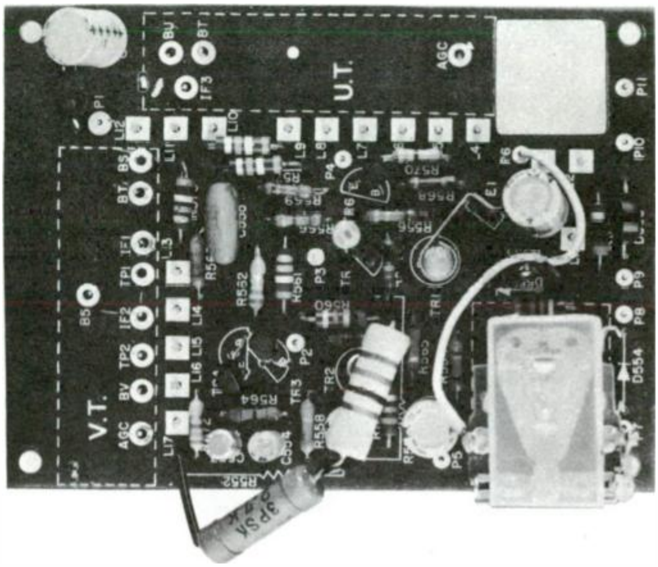


Figure 17 (continued)-Courtesy of Panasonic.

COMPONENTS VIEW (TNP-11503)



CONDUCTOR VIEW (TNP-11503)

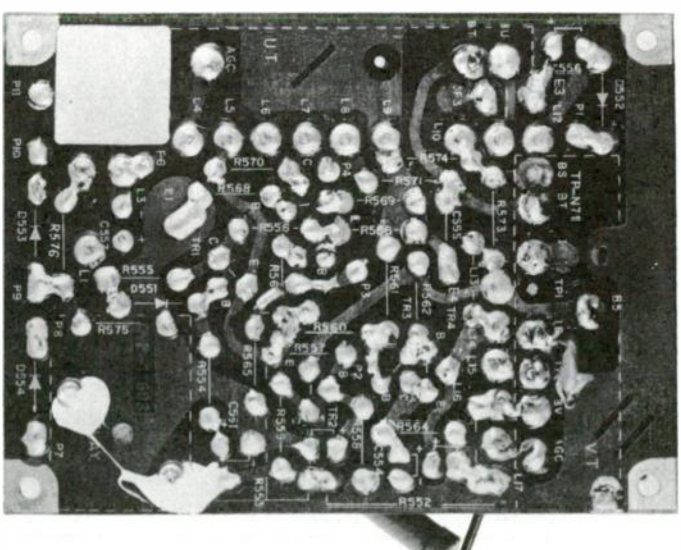


Figure 17 (continued)-Courtesy of Panasonic.

REPLACEMENT PARTS LIST

AN-199E

Ref. No.	Part No.	Part Name & Description				Per Set (Pce.)
	• TKK9521-1	Fine Tuning cover				1
	• TBX1532-2	Knob (UHF fine)				1
	• TBX1532-1	Knob (UHF fine)				5
	TBX1519-2	Koob (Push)				1
	• TBX1514-2	Knob (Slide V. R.)				3
	TKZ624S	ANT terminal				4
	• TQB23867	Instruction book complete				1
	(EAE5TD	Earphone				1
	• TPC85811	Packing case				1
	TPD7211	White cushion				1
	TPD7212	White cushion				1
	TPD7149	White cushion				1
	TPD7150	White cushion				1
	TPD8916	White cushion				1
	• TKK2537	Knob base (for right side)				1
	TSA965-3	VHF Antenna				2
	TSA320	UHF Antenna				1
	TSX137	AC cord				1
	EAS9P63SA	Speaker				1
	TJS27180	Earphone socket				1
	• TY615	Remote control				1
	• TSE158	Rotary switch				1
	• TSE327	Slide switch				1
	• TSE439S	Power switch				1
	• TSE444	Channel switch				1
	• TEK603S	Motor mechanism				1
	TJS29220	6P socket				1
	TJS46130	P. L socket				1
	• TVL303	Pilot lamp				1
TNP 11503						
TRANSISTORS & DIODES						
TR3	• TVS2SA564	Transistor				1
TR1	• TVS2SB324	Transistor				1
TR2	• TVS2SC538	Transistor				1
TR4, 5, 6	• TVS2SC828	Transistor				3
D554	TVS10D8	Diode				1
D552, 553	TVSFR2P	Diode				2
D551	TVSRD29AN	Diode				1
RESISTORS & CAPACITORS						
R566	• ERD14TJ221	Carbon	220Ω	5%	¼W	1
R564	• ERD14TJ271	Carbon	270Ω	5%	¼W	1
R570	• ERD14TJ681	Carbon	680Ω	5%	¼W	1
R563, 565, 569	• ERD14TJ122	Carbon	1.2KΩ	5%	¼W	3

Figure 17 (continued)-Courtesy of Panasonic.

REPLACEMENT PARTS LIST

AN-199E

Ref. No.	Part No.	Part Name & Description	Per Set (Pce.)
	TUNER & CIRCUIT BOARD		
	TNP11503	Printed Circuit Board Complete	1
	TNP9901	Printed Circuit Board Complete	1
	TNP2167-1	Printed Circuit Board Complete	1
	TUBES & DIODES		
V11	TVB500JB4	Picture tube	1
V1, V2	TVT4EH7 (E)	Vacuum tube 1st & 2nd VIF AMP	2
V3	TVT4EJ7 (E)	Vacuum tube 3rd VIF AMP	1
V5	TVT4DT6A (E)	Vacuum tube SIF.DET.	1
V8	TVT6LX8 (E)	Vacuum tub. SYNC SEP. & HORIZ OSC.	1
V10	TVT1BK2 (E)	Vacuum tube H. V. RECT	1
V4, V7	TVT11MS8 (E)	Vacuum tube SIF AMP & VERT. OSC & OUT	2
V6	TVT11BM8 (E)	Vacuum tube Audio OUT & AGC Keyer	1
V9	TVT38HE7 (E)	Vacuum tube HORIZ OUT	1
	TRANSFORMERS & COILS		
	TLY469DS	Deflection Coil	1
	TLR9317	Balum	1
	TLP113	Power choke	1
	TLV237	Vertical output trans	1
	TLF303DS	Flyback trans	1
T501	• TLP259	Power trans	1
	RESISTORS & CAPACITORS		
	ERC12GK470	Solid 47Ω ½W ±10%	1
	ERC12GK472C	Solid 4.7KΩ ½W ±10%	1
	ERM30G530A	Wire Wound 53Ω 30W	1
	ECEP180HBX1A	Capacitor	1
	EXA3ZPO3	C-R combination	1
R209	EVAGOAO1AA16	Variable resistor ON-OFF VOLUME	1
R154	EVAGOAO1AB24	Variable resistor CONTRAST	1
R157	EVAGOAO1AC25	Variable resistor BRIGHT	1
	EVDN8A25KB15	Variable resistor	1
R551	• ERM20H152	Wire Wound 1.5KΩ 20W	1
	MISCELLANEOUS		
	• TKE11204-1S	Escutcheon complete	1
	• TKP98081	Metal Panel	1
	• TKK398 1	Smoke board	1
	• TBM821-1	Lavel	1
	TKG634-1	Front glass	1
	• TKA3406	Cabinet	1
	TKS310-1	Bottom plate	1
	TKU24701-1	Rear cover	1
	TKK202-7S	Handle complete	1
	TKK9205-4S	Handle holder	2

Figure 17 (continued)-Courtesy of Panasonic.

REPLACEMENT PARTS LIST

AN-199E

Ref. No.	Part No.	Part Name & Description				Per Set (Pce.)
R555	• ERD14TJ152	Carbon	1.5KΩ	± 5%	¼W	1
R572	• ERD14TJ682	Carbon	6.8KΩ	± 5%	¼W	1
R557, 562 R567, 568	• ERD14TJ103	Carbon	10KΩ	± 5%	¼W	4
R556	• ERD14TJ153	Carbon	15KΩ	± 5%	¼W	1
R554	• ERD14TJ273	Carbon	27KΩ	± 5%	¼W	1
R553	ERD1PZK561	Carbon	560Ω	±10%	1W	1
R576	ERC12GK100	Solid	10Ω	±10%	½W	1
R559	ERC12GK561	Solid	560Ω	±10%	½W	1
R561, 571 R573, 574	ERC12GK394	Solid	390KΩ	±10%	½W	4
R575	ERC12GK474	Solid	470KΩ	±10%	½W	1
R560	ERC12GK225	Solid	2.2MΩ	±10%	½W	1
R552	• ERG3PSK272	Metal Oxide	2.7KΩ		3W	1
C555	• ECQM05104MZ	Polyester	0.1µF	± 20%	50V	1
C554	• ECEA6V10	Electrolytic	10µF		6V	1
C553	• ECEA16V4R7	Electrolytic	4.7µF		16V	1
C556	• ECE16V100	Electrolytic	100µF		16V	1
C557	• ECE16V220	Electrolytic	220µF		16V	1
C552	• ECE25V10	Electrblytic	10µF		25V	1
C551	• ECE50V33	Electrolytic	33µF		50V	1
	• TSE812S	Change Switch				1
TNP 9901						
RESISTORS & VARISTORS						
	ERC12GK273	Solid	27KΩ	±10%	½W	1
	ERC12GK393	Solid	39KΩ	±10%	½W	1
	ERC12GK563	Solid	56KΩ	±10%	½W	1
	ERC12GK683	Solid	68KΩ	±10%	½W	5
	ERC12GK823	Solid	82KΩ	±10%	½W	2
	ERC12GK104	Solid	100KΩ	±10%	½W	1
	ERC12GK154	Solid	150KΩ	±10%	½W	3
	ERC12GK184	Solid	180KΩ	±10%	½W	2
	ERC12GK224	Solid	220KΩ	±10%	½W	1
	ERC12GK274	Solid	270KΩ	±10%	½W	2
	ERC12GK474	Solid	470KΩ	±10%	½W	1
	• EVLV3AS15B15	Variable resistor				12
	• EVHB0AL17B15	Variable resistor				5
TNP 2167-1						
DIODES						
D301	ERV08RC3471K	Varistor				1
401	TVMTK705M	Diode				1
502	TVS10D8	Diode				1
101	TVS0A70	Diode				1

Figure 17 (continued) -Courtesy of Panasonic.

REPLACEMENT PARTS LIST

AN-199E

Ref. No.	Part No.	Part Name & Description	Per Set (Pcs.)
D101	TVS10D8	Diode	1
	TRANSFORMER & COILS		
L101	TLI9156	VIF trans & coil	1
T102	TLI1157	VIF trans & coil	1
103	TLI1158	VIF trans & coil	1
104	TLI5157	VIF trans & coil	1
101	TLI2158	VIF trans & coil	1
151	TLS2153	SIF trans & coil	1
201	TLS1158	SIF trans & coil	1
L201	TLS1176	SIF trans & coil	1
153	TLT221-999	Peaking coil	1
151	TLT301-999	Peaking coil	1
152	TLT751-999	Peaking coil	1
402, 403	TLM080-999	Peaking coil	2
401	TLH315	Horizontal-HOLD	1
T202	ETA28F7A	Audio output trans	1
	TLP412T	Choke coil	1
	RESISTORS		
R109	ERC12GK270	Solid 27Ω ±10% ½W	1
102	ERC12GK121	Solid 12' Ω ±10% ½W	1
211	ERC12GK151	Solid 150Ω ±10% ½W	1
107, 364	ERC12GK221	Solid 220Ω ±10% ½W	2
304	ERC12GK102	Solid 1KΩ ±10% ½W	1
408	ERC12GK222	Solid 2.2KΩ ±10% ½W	1
151, 214	ERC12GK272	Solid 2.7KΩ ±10% ½W	2
101, 105, 114 155, 212, 213	ERC12GK103	Solid 10KΩ ±10% ½W	6
307, 361	ERC12GK123	Solid 12KΩ ±10% ½W	2
202, 362	ERC12GK223	Solid 22KΩ ±10% ½W	2
310	ERC12GK273	Solid 27KΩ ±10% ½W	1
216, 403	ERC12GK333	Solid 33KΩ ±10% ½W	2
351,	ERC12GK393	Solid 39KΩ ±10% ½W	1
160, 413	ERC12GK473	Solid 47KΩ ±10% ½W	2
153	ERC12GK683	Solid 68KΩ ±10% ½W	1
159	ERC12GK823	Solid 82KΩ ±10% ½W	1
158, 201, 217	ERC12GK104	Solid 100KΩ ±10% ½W	3
156	ERC12GK124	Solid 120KΩ ±10% ½W	1
357, 363	ERC12GK154	Solid 150KΩ ±10% ½W	2
402, 407	ERC12GK224	Solid 220KΩ ±10% ½W	2
404	ERC12GK334	Solid 330KΩ ±10% ½W	1
401	ERC12GK474	Solid 470KΩ ±10% ½W	1
207	ERC12GK564	Solid 560KΩ ±10% ½W	1
305	ERC12GK684	Solid 680KΩ ±10% ½W	1
355, 409	ERC12GK824	Solid 820KΩ ±10% ½W	2
302	ERC12GK105	Solid 1MΩ ±10% ½W	1

Figure 17 (continued)-Courtesy of Panasonic.

REPLACEMENT PARTS LIST

AN-199E

Ref. No.	Part No.	Part Name & Description				Per Set (Pce.)
358	ERC12GK185	Solid	1.8MΩ	± 10%	½W	1
303	ERC12GK225	Solid	2.2MΩ	± 10%	½W	1
405	ERC12GK565	Solid	5.6MΩ	± 10%	½W	1
308	ERC12GK106	Solid	10MΩ	± 10%	½W	1
359	ERC12GK126	Solid	12MΩ	± 10%	½W	1
411, 412	ERD12ZK561	Carbon	560Ω	± 10%	½W	2
410	ERG2PSK102	Metaloyide	1KΩ	± 10%	2W	1
152	ERG3PSK562	Metaloyide	5.6KΩ	± 10%	3W	1
354	EVD06AS20BC6	Variable Resistor V. HOLD				1
360	EVL32A00MB55	Variable Reiststor HEIGHT				1
356	EVTV8A00MB26	Variable Resistor V. Lin				1
301	EVT38A00B13	Variable Resistor AGC				1
	CAPACITORS					
C152, 204	ECC5040D	Ceramic	4PF	0.5PF	500V	2
110	ECC5050D	Ceramic	5PF	0.5PF	500V	1
101	ECC5100F	Ceramic	10PF	± 1%	500V	1
201	ECC5390KT	Ceramic	39PF	± 10%	500V	1
102, 202	ECC5470K	Ceramic	47PF	± 10%	500V	2
403	ECC5680K	Ceramic	68PF	± 10%	500V	1
205	ECC5820K	Ceramic	82PF	± 10%	500V	1
402	ECC5101K	Ceramic	100PF	± 10%	500V	1
401,411	ECC5151K	Ceramic	150PF	± 10%	500V	2
412	ECC10141K	Ceramic	140PF	± 10%	5KV	1
109, 301, 360	ECKC5681KD	Ceramic	680PF	± 10%	500V	3
203,215	ECKC5102K	Ceramic	1000PF	± 10%	500V	2
107,116,117, 156,303,510 511,513,517	ECKC5222PU	Ceramic	2200PF	+100% -0%	500V	9
502,515	ECKC5472PU	Ceramic	4700PF	+100% - 0%	500V	2
514	ECKC14472ZU	Ceramic	4700PF	+100% - 0%	1.4KV	1
217	ECCD5390K	Ceramic	39PF	± 10%	500V	1
210	ECQMO5473KZ	Polyester	0.047μF	± 10%	50V	1
302, 304	ECQMO5104MZ	Polyester	0.1μF	± 20%	50V	2
354	ECQMO4392K	Polyester	0.0039μF	± 10%	400V	1
361,405	ECQM4392K	Polyester	0.0047μF	± 10%	400V	2
356	ECQM4472KZ	Polyester	0.033μF	± 10%	400V	1
155, 359, 404	ECQF2104KZ	Polyester	0.1μF	± 10%	200V	3
407	ECQF4392K	Polyester	0.0039μF	± 10%	400V	1
408	ECQF4682K	Polyester	0.0068μF	± 10%	400V	1
214	ECQF4153M	Polyester	0.015μF	± 20%	400V	1
355	ECQF4223K	Polyester	0.022μF	± 10%	400V	1
357	ECQF4104KZ	Polyester	0.1μF	± 10%	400V	1
406	TCMS5471KAS	Ceramic	470PF	± 10%	500V	1
358	ECND10102M	Oil	0.001μF	± 20%	1KV	1
414, 413	ECND6473K	Oil	0.047μF	± 10%	600V	2
501	ECNDU4A473M	Oil	0.047μF	± 20%	600V	1

Figure 17 (continued)-Courtesy of Panasonic.

REPLACEMENT PARTS LIST

AN-199E

Ref. No.	Part No.	Part Name & Description	Per Set (Pce.)
415	ECEB500V3	Electrolytic 3μF 500V	1
216	ECEB150V10	Electrolytic 10μF 150V	1
Z201	EXAP222Z561	C-R combination	1
203	EXAP3WKO9	C-R combination	1
301	EXAP3WKO11	C-R combination	1
302	EXAP4FD12	C-R combination	1
402	EXAP3SK01	C-R combination	1
101, 103	EXAP5CD01	C-R combination	2
202	EXAPT502Z153B	C-R combination	1
105	EXC6FD01Z153B	L-C combination	1
	MISCELLANEOUS		
	TJS21130	Tube socket (7 pin)	1
	TJS23360	Tube socket (9 pin)	5
	TJS23370	Tube socket (9 pin mica)	1
	TJS23390	Tube socket (9 pin mold green)	1
	TJS29280	Interlock plug	1
	TJS25020-1	Tube socket (C. R. T.)	1
	TJS29170	Tube socket (12 pin)	1
	TSF35302	Fuse 125V 3A	1

Figure 17 (continued)-Courtesy of Panasonic.

SUMMARY

Probably the most useful form of service literature is the block diagram. The technician can usually isolate the problem to a particular stage using the block diagram. The block diagram can also provide the technician with an understanding of how the piece of electronic equipment operates.

After a problem has been isolated to a particular stage, the technician may then use the schematic diagram to locate a defective component. Component location charts show the actual location of a specific part. This aids the technician in physically locating the component. Manufacturer's parts list describe components and usually contain the service part number for replacement purposes. Most service literature includes alignment instructions, operating precautions, and disassembly instructions. Having the proper service manual to service a particular piece of electronic equipment will greatly reduce the time required for a service operation. Service literature assures the technician that his service work and adjustments have been accomplished according to the manufacturer's suggested methods and requirements. This can reduce service call backs when service work is performed.

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TEST

Lesson Number 47

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 52-047-1.

1. Diagrams are necessary in modern servicing because
   - A. the field is large.
   - B. products are complex.
   - C. of the large variety of equipment.
   - D. all of the above.

2. A block diagram
   - A. contains complete information
   - B. provides a simplified explanation of a unit's function.
   - C. is very complex.
   - D. should seldom be used as reference.

3. A block diagram that includes signal paths is a
   - A. component list.
   - B. simplified schematic.
   - C. block-flow diagram.
   - D. component location drawing.

4. Block diagrams
   A. are of little value.
   B. are useful to experienced, observant technicians.
   C. contain complete information.
   D. illustrate component locations.

5. Schematic diagrams
   A. are symbolic presentations of circuitry.
   B. are worthless to the service man.
   C. show component locations.
   D. show mechanical details.

6. Schematic diagrams are used to
   A. show where to inject signals.
   B. show where components are located.
   C. show customer adjustments.
   D. show service adjustments.

7. To determine the service part number of a specific component, refer to the
   A. block diagram.
   B. alignment instructions.
   C. manufacturers parts list.
   D. block-flow diagram.

8. The note section on drawings
   A. should be ignored.
   B. must always be referred to first.
   C. are of little value to service men.
   D. contain non-essential information.

9. Servicing modern electronic products requires the use of
   A. drawings in many different forms.
   B. only parts lists.
   C. only block diagrams.
   D. only schematic diagrams.

10. A service manual contains
   A. incomplete information for servicing.
   B. only pictorial information.
   C. only schematic drawings.
   D. complete service information.

Notes

Notes

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

CIRCUIT DIAGRAMS

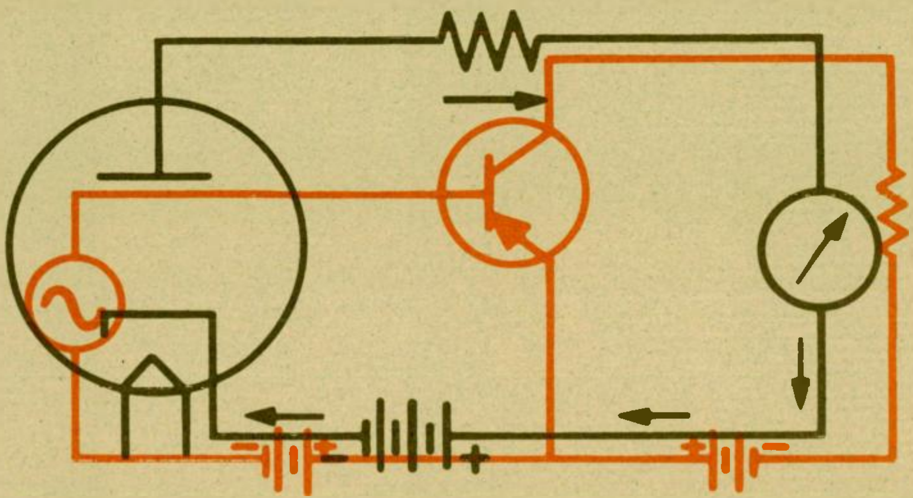
The purpose of the Circuit Diagrams Section of this course is to supply the information necessary to enable the electronic technician to meet the increasing demand for professionalism in this field.

The successful electronic technician cannot rest on past experiences. He must keep abreast of what is new in the field in order to compete for his share of business in all areas.

Electronics today is becoming a marvel of complexity, because of this, the emphasis of the course is on the development of the electronic technician's ability to do the job more skillfully and efficiently.

S. T. Christensen

REVIEW FILM LESSONS 45-47 BOOKLET



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-048
403

ADVANCE SCHOOLS, INC.
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REVIEW FILM AND KIT TEST

Lesson Number 48

The first ten questions enclosed are review questions of lessons 45, 46, and 47 which you have just studied. Questions 11 through 30 test the knowledge you have gained from assembling and operating your kits.

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

Please review your films, records, and kit manuals 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 AND KIT TEST

Lesson Number 48

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 52-048-1.

1. An example of a rotary switch is a
   - A. TV tuner.
   - B. wall switch.
   - C. push button.
   - D. relay.

2. A multideck-rotary switch could have several
   - A. poles.
   - B. contacts.
   - C. positions.
   - D. all of the above.

3. A relay is an electro-mechanical
   - A. tube.
   - B. coil
   - C. switch.
   - D. resistor.

4. A switch, capable of placing two different polarities into two different circuits would be a
   - A. SPDT.
   - B. DPDT.
   - C. DPST.
   - D. SPST.

5. The circuit-breaker type of fuse acts like a ________ when overloaded.
   - A. switch
   - B. relay
   - C. resistor
   - D. coil

6. A printed circuit board has__________laminated to an insulating material.
   - A. foil
   - B. lacquer
   - C. wires
   - D. components

7. Printed circuit (PC) boards were developed because
   - A. products had to be manufactured faster.
   - B. products were becoming more complicated.
   - C. cheaper products could be dependably manufactured.
   - D. all of the above.

8. If too much heat is used to solder a component to a printed circuit board
   - A. the board will burn.
   - B. the foil will lift off the board.
   - C. the iron will burn through the board.
   - D. none of the above.

9. Servicing from block diagrams
   - A. increases servicing speed and safety.
   - B. is the last resort.
   - C. is of little value.
   - D. is for amateurs.

10. Detailed schematics are necessary for complicated service problems. Also important are the
    - A. resistance tables.
    - B. voltage readings.
    - C. signal waveforms.
    - D. all of the above.

11. What must you do before you take a resistance reading with your multitester?
    - A. Set voltage scale.
    - B. Zero meter.
    - C. Plug red lead into DC jack.
    - D. Set AC scale.

12. Can you measure a resistance in an energized circuit with your multitester?
    - A. Sometimes.
    - B. Yes.
    - C. No.
    - D. If the leads are reversed.

13. The common or ground lead of the multitester is always:
    - A. Green.
    - B. Red.
    - C. Yellow.
    - D. Black.

14. Check the house AC voltage on your multitester and mark the closest answer.
    - A. 105 to 120 volts AC
    - B. 330 to 440 volts AC
    - C. 70 to 90 volts AC
    - D. 6 to 12 volts AC

15. When using the signal generator to align an AM Radio that has an antenna, where is the inner or hot lead of the output cable placed?
    - A. Chassis.
    - B. Speaker terminal.
    - C. Volume control.
    - D. Near the antenna.

16. If the radio has no loop or rod antenna, where should the hot lead of the generator output cable be connected?
    - A. Volume control.
    - B. Chassis.
    - C. Generator ground.
    - D. Antenna terminal.

17. When adjusting the oscillator trimmer capacitor on an AM Radio, where should the AM dial be set?
    - A. 455 KC (kHz).
    - B. 900 KC (kHz).
    - C. 1600 KC (kHz).
    - D. 750 KC (kHz).

18. When adjusting the slug of the AM Radio oscillator coil, what frequency should the signal generator be set to?
    - A. 1250 KC (kHz).
    - B. 600 KC (kHz).
    - C. 930 KC (kHz).
    - D. 475 KC (kHz).

19. When using your signal tracer to troubleshoot an AM Radio and a buzzing or crackling sound is heard, what does this indicate?
    - A. Noisy resistors.
    - B. Burnt-out tubes.
    - C. Shorted volume control.
    - D. No current flow.

20. A signal tracer may be used to check the output of a phono cartridge. Where would you connect the audio input of the signal tracer?
    - A. Turntable ground.
    - B. 12 volt power source.
    - C. Output cable of the record changer.
    - D. Turntable on-off switch.

21. When making a resistance measurement with your VTVM, the OHMS ADJ should be set for a meter reading of
    - A. infinity.
    - B. zero.
    - C. ten.
    - D. fifty.

22. When measuring an unknown AC voltage, what range should your VTVM be set to?
    - A. Low DC range.
    - B. Highest AC range.
    - C. Lowest AC range.
    - D. Ohms range.

23. If the AC section of the VTVM is inoperative, the first check should be a test of the
    - A. 6AL5 tube.
    - B. battery.
    - C. 12AU7 tube.
    - D. meter.

24. With transistor leads inserted into the correct sockets on the transistor checker, how is a defective transistor indicated?
    - A. Transistor gets hot.
    - B. Neon light blinks.
    - C. Neon lamp does not light up.
    - D. Transistor crackles.

25. How is the transistor tester battery condition checked with its own leads?
    - A. Leads inserted into sockets.
    - B. Touch test clips E and C together briefly.
    - C. Ground clip E.
    - D. Connect leads to 6-volt battery.

26. What is the highest frequency your AM portable radio will tune to?
    - A. 1600 KC (kHz).
    - B. 1350 KC (kHz).
    - C. 1200 KC (kHz).
    - D. 2000 KC (kHz).

27. What can cause your AM Radio to produce a pulsating or motor boating sound?
    - A. Low AC voltage.
    - B. Loose antenna connection.
    - C. Open capacitor.
    - D. Defective volume control.

28. In case any of the kits that you have built do not operate, what should you do first?
    —A. Recheck your wiring.
    B. Remove all parts.
    C. Change on-off switch.
    D. Buy new unit.

29. If, after assembly of the signal generator, the pilot lamp and tubes do not light, what is the possible cause?
    A. Short in the test lead.
    B. Defective transistor.
    - C. Open on-off switch or faulty power transformer.
    D. Wrong voltage.

30. What is a good hot soldered joint?
    —A. A smooth, shiny and hard surface.
    B. A black cracked finish.
    C. A dull and rough surface.
    D. A smooth green color.

You now have completed all of the questions for this test. Double check to make sure all the questions are answered, and your answers are dark and clearly marked.

Notes

Notes

"School Without Walls"
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LEARN THE FUNDAMENTALS

The review on switches, relays, printed circuits and circuit diagrams helps you:

1. To recognize and troubleshoot various types of printed circuits.
2. To understand the operating principles of electronic circuits.

In Electronic Unit Service and Repair, you *must* know how electronic circuits work and how electrical flow can be controlled. Learn these fundamentals well and your actual service and repair work will be easier.

You will complete the job faster and more efficiently – thus making more money and developing a good reputation for your service.

S. T. Christensen