PEAK AND BAND-PASS R. F. TUNING CIRCUITS

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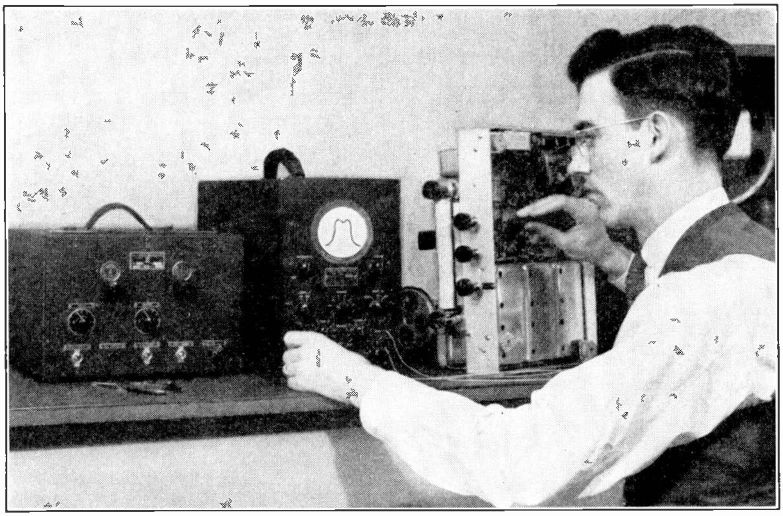
Peak and Band-Pass R. F. Tuning Circuits

Importance of Response Curves

PRACTICAL radio men are today more concerned than ever before with the shapes of the resonant response curves for R.F. amplifiers, for they have come to realize that these curves reveal the exact characteristics of a receiver or transmitter and tell when undesirable effects have been introduced by adjustments or by defects in circuit parts.

Older receivers, as well as a great many modern receivers, use R.F. tuning circuits which are adjusted for peak response. On these receivers a serviceman need only adjust for maximum output, never giving a thought to the shape of the peak response curve. A modern high-fidelity radio receiver has band-pass R.F. tuning circuits, however, and actual viewing of the response curve greatly simplifies the adjusting of the receiver to give the desired gain and fidelity within the limitations of the tuning circuits. A thorough understanding of the peculiar characteristics of R.F. tuning circuits and an ability to read the story told by each shape of response curve will prove particularly valuable when using a cathode ray oscilloscope for radio receiver testing and servicing.

You are already familiar with peak response curves like those shown in Fig. *1A*, for they have been discussed in previous lessons. You know that a sharp peak response curve for an R.F. amplifier indicates high gain and high selectivity, while a broad peak response represents somewhat lower gain and lower selectivity but better fidelity. Likewise you are familiar with the band-pass response curves shown in Fig. *1B*, and know that R.F. tuning circuits having these curves give better fidelity at the expense of gain. In this lesson we will study in detail the tuning



All-wave superheterodyne receiver being aligned for band-pass response, using a frequency-wobbulated R.F. signal generator (extreme left) and a cathode ray oscilloscope. The final double-peak response curve, secured after all adjustments are made, can be seen on the screen of the cathode ray tube. Note that the receiver chassis is set on end, for convenience in making connections and adjusting under-the-chassis trimmer condensers.

circuit conditions which give to an R.F. amplifier any of these four response curves or any of the many possible variations of these curves.

General Analysis of a Modulated R.F. Carrier

If we used a special cathode ray oscilloscope to analyze an R.F. carrier which is 100% modulated with a single sine wave signal (of frequency f_m), we would see on the screen of the cathode ray tube a pattern much like that in Fig. *2A* (the dotted lines indicating the modulation envelope would of course be absent). Either a mathematical analysis or actual measurements will

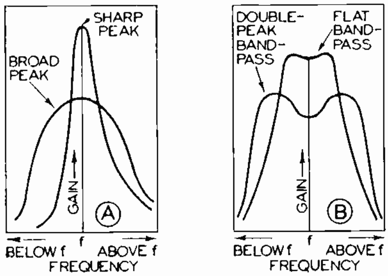


Fig. 1. Typical peak and band-pass response curves of R.F. amplifiers.

show that we really have three different R.F. signal frequencies in this modulated carrier, as indicated in Fig. *2B*:

- f, the *R.F. carrier frequency*
- f_1, the *lower side frequency*, which is equal to the carrier frequency *minus* the modulation frequency ($f_1 = f - f_m$)
- f_2, the *upper side frequency*, which is equal to the carrier frequency *plus* the modulation frequency ($f_2 = f + f_m$)

Furthermore, with 100% modulation the voltage of each side frequency signal will be *exactly one-half* that of the carrier signal. (With less than 100% modulation, the amplitude of each side frequency will be *less than one-half* that of the carrier.) In dealing with R.F. tuning circuits, we must consider all three of these R.F. signals, for the side frequencies must be amplified the same amount as the carrier frequencies if distortion is to be avoided.

When a 100%-modulated R.F. carrier is sent through an R.F. amplifier which has a perfectly flat top response, the side frequencies will be amplified equally as much as the carrier and the output wave pattern will be identical to the input wave pattern. If, however, we send this 100%-modulated R.F. carrier through a tuned R.F. amplifier which is considerably off tune, severe amplitude distortion occurs because the side frequencies and the carrier are amplified different amounts, and the output wave pattern might be as shown in Fig. *2C* (this pattern corresponds to the condition where one side frequency is not amplified at all and the other side frequency is amplified twice as much as the carrier; Fig. *2D* indicates the output voltage relationship under this condition). Output wave patterns thus tell directly whether distortion is occurring in an R.F. amplifier.

Unfortunately the average cathode ray oscilloscope used by servicemen is not designed to amplify R.F. carrier voltages sufficiently to give useful modulated R.F. patterns on the screen; an extra R.F. amplifier would have to be used, or a costly and bulky laboratory type oscilloscope secured. A response curve of the R.F. amplifier in question gives essentially the same information about distortion, however, and is easily produced with an ordinary radio servicing oscilloscope. A typical peak response curve is shown in Fig. *2E;* this curve tells how much amplification the side frequencies will get at any modulation frequency value. Each response curve has a story to tell you; to show how these stories can be read, we will consider a typical example in which the carrier frequency is assumed to be 1,000 kc., with 100% modulation.

When the modulation frequency is 100 cycles, the side frequencies will be 999.9 kc. and 1,000.1 kc.; by referring to Fig. *2E*, where these side frequencies are designated as f_3 and f_4, we can readily see that these will receive essentially the same amplification (gain) as the 1,000 kc. carrier. This means that after the modulated signal has passed through the R.F. amplifier, the two side frequencies will each be the same fraction of the carrier voltage (one-half in this case of 100% modulation) as they originally were.

With a 5,000-cycle modulation signal, however, the resulting 995 kc. and 1,005 kc. side frequencies (f_1 and f_2 in Fig. *2E*) receive considerably less amplification than the carrier (f); this means that after the modulated signal has passed through the R.F. amplifier, the two side frequencies will be a considerably lower fraction of the carrier voltage than they originally were (each will be *less than one-half* the carrier voltage in our case of 100% modulation). With only one modulation frequency, this attenuation of side frequencies is simply equivalent to a reduction in the modulation percentage, provided that both side frequencies are equally attenuated; after demodulation, then, the 5,000-cycle audio signal voltage will be lower than if there were no attenuation of side frequencies.

Frequency Distortion. When a number of different modulation frequencies ranging from 0 to 5,000 cycles (such as we have in radio receivers which are tuned to sound broadcasts) are present in an R.F. amplifier having the response curve in Fig. *2E*, there will be a large number of side frequencies in the range from 995 kc. to 1,005 kc. Those farthest away from the carrier frequency, corresponding to the higher modulation frequencies, will be amplified the least, with the result that a certain amount of frequency distortion will be present in the audio signal after demodulation. If not too severe, this frequency distortion can be corrected in a receiver by the use of equalizing circuits which make the audio amplifier provide increased amplification for those higher modulation frequencies which were cut down in the R.F. tuning circuits. Servicemen often use this little equalizing trick to com-

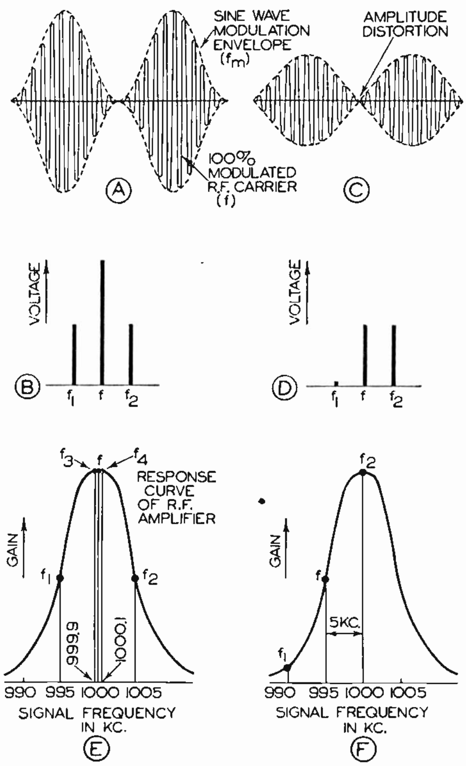


FIG. 2. These diagrams tell you what happens to a modulated R.F. carrier signal when the R.F. amplifier is properly tuned (*A*, *B* and *E*) and when it is improperly tuned (*C*, *D* and *F*.)

pensate for frequency distortion in a highly selective R.F. amplifier. In television circuits the modulation frequencies may range from 0 to over 2.5 megacycles, and the amount of equalization required in picture signal amplifiers may therefore be quite great.

Amplitude Distortion. When the side frequencies associated with an R.F. carrier are attenuated or cut down unequally by a tuning circuit (so that with a single modulation frequency, one side frequency will have a greater amplitude than the other), *amplitude distortion* as well as frequency distortion will be present. This fact is not so easily shown without mathematics, but by considering the extreme case where only one side frequency is allowed to pass, the other being cut out entirely by the tuned circuit, we can get some idea as to why this statement holds true.

Suppose that the R.F. amplifier in our previous example is tuned to 1,000 kc. but is fed with a 995 kc. carrier modulated at 5,000 cycles (5 kc.); now we have the condition represented by Fig. *2F*, where the upper side frequency (1,000 kc.) is fully amplified, the carrier is amplified about half as much, and the lower side frequency receives hardly any amplification at all. The R.F. amplifier under this condition allows only one side frequency to pass through with the carrier, as was indicated in Fig. *2D;* both will have the same amplitude at the output, and the wave form of the amplifier output voltage will be as shown in Fig. *2C*. (Originally, as in Fig. *2B*, the amplitude of the carrier f was twice that of the upper side frequency f_2; reducing the carrier amplitude one-half without reducing the amplitude of f_2 thus makes both amplitudes equal.

Observe that the outer peaks of modulation in Fig. *2C* have sine wave shapes, but the valleys or troughs are V-shaped; this is clearly a case of amplitude distortion, for the modulation envelope no longer corresponds to the sine wave modulation signal (like that in Fig. *2A*) at the input of the tuning circuit. (The curve in Fig. *2C* was obtained by adding together and plotting the values of the carrier and the side frequency at each instant of time; it can be verified with a cathode ray oscilloscope and suitable special laboratory equipment.) Lower percentages of modulation than 100% and different off-tune carrier frequencies will of course give slightly different wave forms for the envelope in Fig. *2C*, but amplitude distortion will be evident in all cases.

You can expect distortion similar to that in Fig. *2C* whenever a tuning circuit is not properly tuned to the input carrier or when it has an unsymmetrical resonant curve, for both conditions result in unequal amplification of upper and lower side frequencies. The resulting amplitude distortion cannot be corrected for in the audio system; it will be present in the receiver output, and will often be annoying to the radio listener. The elimination of amplitude distortion in the R.F. system is therefore a matter of vital importance to the radio serviceman as well as the receiver designer.

Analyzing Typical Response Curves

Four typical resonant response curves of actual radio receivers, such as might be obtained by using a cathode ray oscilloscope and the necessary associated equipment, appear in Fig. *3*. In each case f represents the carrier frequency to which the R.F. amplifier is tuned, while f_1 and f_2 represent the lowest and highest side frequencies involved. When properly interpreted, these curves reveal considerable information about distortion.

Sharp Peak. An R.F. amplifier having the sharp peak response curve shown in Fig. *3A* will cause severe attenuation of the higher modulation frequencies (severe frequency distortion). (Remember that low modulation frequencies correspond to side frequencies close to and both above and below f, while high modulation frequencies correspond to side frequencies near f_1 and f_2.) Since the gain at f_1 is less than at f_2 in this example, some amplitude distortion is also to be expected; this may not be severe, since the difference between the two values is not great. In R.F. amplifiers which have peak response curves, the greatest amount of amplitude distortion occurs because of improper tuning, which gives the condition represented by Figs. *2C, 2D* and *2F*. It is primarily for this reason that highly selective receivers, which naturally have sharply peaked response curves, are equipped with tuning aids.

Rounded Peak. Rounding or broadening of the peak of a response curve, by cutting down the amplification in the vicinity of the carrier frequency more than at the extreme side frequencies, is easily accomplished by a service technician who understands R.F. tuning circuits. The result is a broad peak response curve similar to that shown in Fig. *3B*, which gives considerably less frequency distortion at the expense of selectivity and gain.

Distorted Double Peak. Band-pass R.F. tuning circuits will, if properly designed and adjusted, give a double peak response curve with steep sides, insuring good fidelity and selectivity. Unless the adjustments are carefully made, however, there is a possibility that a distorted double peak response curve like that shown in Fig. *3C*, in which one peak is higher than the other, will be obtained. Naturally a curve such as this is undesirable, for one side frequency is amplified more than the other, with resulting amplitude distortion. Furthermore, if the valley between the peaks is too deep, the lower modulation frequencies (having side frequencies in this valley) will be attenuated and frequency distortion will be evident.

Symmetrical Double Peak. When a serviceman adjusts a band-pass tuning circuit for high fidelity and good selectivity, his goal is the rarely-attained ideal square top response curve; ordinarily, however, he is entirely satisfied if he can secure the symmetrical double peak response curve shown in Fig. *3D*, which has a negligible valley between the peaks. He knows that when an R.F. amplifier has a symmetrical double-peak response curve such as this, amplitude distortion will not occur and frequency distortion will be negligible in the R.F. or I.F. amplifier. A properly designed band-pass tuning circuit can give far better selectivity than a circuit having a peak response which has been broadened to give equally as good fidelity. (The steeper the sides of the response curve outside the f_1-f-f_2 region, the better is the selectivity.)

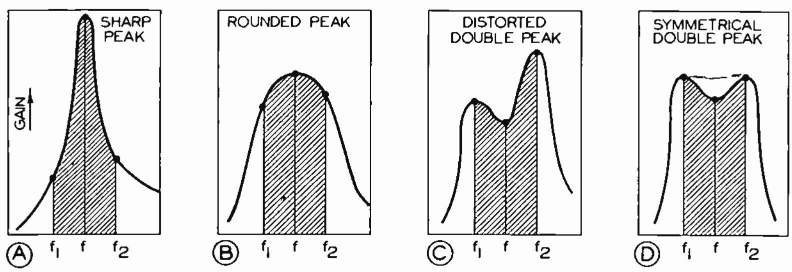
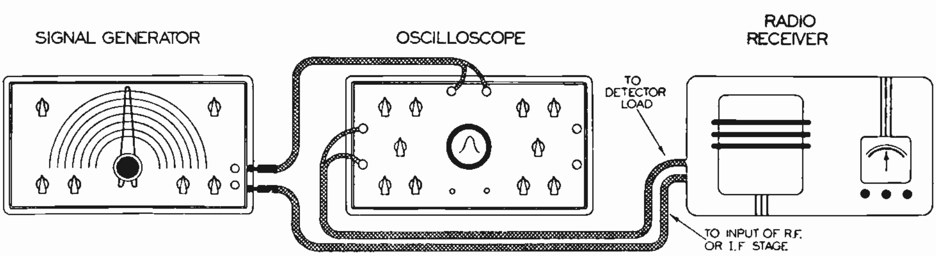


FIG. 3. These four response curves are representative of those which can be viewed on the screen of a cathode ray oscilloscope when actual R.F. and I.F. amplifiers are being tested. The shaded areas and vertical lines are of course not seen on the C.R.O. screen; they have been added here in order to show the range of side frequencies handled by the amplifier along with the carrier in each case.

Alignment of R.F. Tuning Circuits. The final factory inspection of a radio receiver generally includes a check of the response curve for the R.F. section, to make sure that it has the desired shape. This is referred to as a check of the alignment. Oftentimes this alignment may be disturbed by rough handling during shipment and by general aging of the receiver, making it necessary for the serviceman to realign the tuning circuits.

It is a well-known fact that most radio receivers are designed to have a compromise between selectivity, gain and fidelity, so they will please the greatest possible number of listeners. It is when a particular listener wants the highest possible fidelity or wants maximum gain and selectivity for reception of distant stations that the serviceman is called in to change this compromise response characteristic. Realigning a receiver to have a sharp-peak response gives maximum possible gain and selectivity; usually this is easily done with an ordinary all-wave signal generator and an output indicator. Correct aligning for high fidelity cannot be easily carried out without additional equipment, however; a frequency-wobbulated signal generator* and a cathode ray oscilloscope are essential in this case. It is not the purpose of this lesson to describe the service procedures followed in realigning radio receivers, but rather to point out the various factors in tuned circuits which control the response characteristic.



The response curve of the radio receiver at the right appears on the screen of the cathode ray tube in the radio servicing oscilloscope (center) when proper connections are made between the receiver, the oscilloscope and the frequency-wobbulated R.F. signal generator at the left.

Factors Controlling Response

The shape and height (maximum gain) of the response curve for a tuned R.F. amplifier are essentially determined by one or more of the following factors: *1, The Q factors of the coils used in the amplifier; 2, the L/C ratio of each tuned circuit in the amplifier; 3, the types of coupling used to connect the tuned circuits to each other and to vacuum tubes; 4, the characteristics of the vacuum tubes.* Although these factors have been discussed to a certain extent in previous lessons, they are so important to our study of tuning circuits that I will review them briefly at this time.

Q Factor of a Coil. In previous lessons it was pointed out that any tuning circuit has a certain amount of loss due primarily to the A.C. resistance of the coil (the resistance of the condenser and the circuit wiring is so low that it is usually neglected entirely). The ohmic value of this A.C. resistance of a coil depends not only upon the D.C. resistance of the wire used in making the coil, but also upon "skin effects" associated with high frequency currents, upon losses occurring in the dielectric materials used for the coil form and insulation, and upon the nature of the load which is coupled to the coil. The Q factor of a coil was de-

*A frequency-wobbulated signal generator is a special type of R.F. signal generator whose output frequency can be made to vary regularly and automatically above and below a definite R.F. value to cover any desired range of side frequencies.

$$\text{Q factor of a coil} = \frac{\text{Coil reactance in ohms}}{\text{Coil A.C. resistance in ohms}}$$

fined as the *coil reactance divided by this coil A.C. resistance,* all values being measured at the same frequency. Furthermore, since it is the coil which controls the tuning circuit losses, the Q factor of the coil can be considered as the Q factor of the entire tuning circuit.

What Q Factor Tells Us About Tuning Circuits. The Q factor of the coil in a tuning circuit is a numerical value, often referred to simply as Q; it tells us the following important facts about the two types of tuning circuits:

Series Resonant Circuits—

1. **At resonance, the A.C. voltage across the coil is Q times the source voltage.**
2. **At resonance, the impedance of the tuned circuit is entirely resistive, and is equal to the impedance of the coil in ohms divided by the Q factor of the coil.**

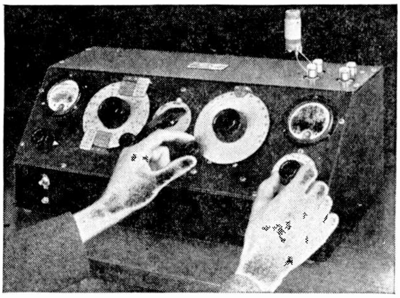
Parallel Resonant Circuits—

1. **At resonance, the current through the coil is Q times the source current.**
2. **At resonance, the impedance of the tuned circuit is Q times the coil impedance, and is entirely resistive.**

Up to a few years ago, engineers and scientists discussed the behavior of tuned circuits in terms of the A.C. resistance of the coil; this practice is quite correct, and may still be found in many text-books. Modern engineers prefer to think in terms of Q factor, however, since they now have instruments with which they can measure the Q factor of a coil directly.*

One of the instruments available for measuring the Q factor of a coil is shown in Fig. *4;* it is known as a Q factor meter, and can also be used for measuring the Q factor of any resistor or condenser.

In a coil or condenser the radio engineer desires pure reactance at any frequency, with no resistance to cause loss of useful power, and consequently he wants the Q factors of these parts (the ratios of reactance to resistance)



Courtesy Boonton Radio Corp.

FIG. 4. This Q-factor meter is typical of the instruments used by radio engineers for measuring the Q factor of coils, condensers and resistors. The device being measured (a coil in this case) is connected to two of the terminals at the top of the instrument.

to be as high as possible in most cases. The Q factor meter reveals that the Q factors of condensers are very high (resistance is very low) in comparison with coils; the meter can also be used to compare various coils (or condensers) as to quality.

Although a resistor is ordinarily thought of as a pure resistance, it often has appreciable inductance, particularly when of the wire-wound type. The Q factor of a resistor (the ratio of

*Q factor is actually the reciprocal of power factor. You will remember from previous Lessons that the power factor of a device is equal to its resistance divided by its impedance; where the impedance is essentially reactance, power factor can be considered equal to resistance divided by reactance, just as Q factor is equal to reactance divided by resistance under the same conditions. You can always find the Q factor of a device (if the power factor is known) by dividing the number 1 by the power factor. Good coils and condensers have a high Q factor and a low power factor; good resistors have a low Q factor and a high power factor.

REVIEW DATA FOR A.C. CIRCUITS

Resistance. That opposition to current flow in an A.C. circuit which results in power loss; it is often called A.C. resistance.

Reactance. That opposition to current flow in an A.C. circuit which does not result in power losses. Reactance may be either inductive (due to a coil or inductance) or capacitive (due to a condenser or capacitance).

Impedance. The total opposition to current flow in an A.C. circuit. Impedance combines the effects of both resistance and reactance, and therefore determines how much alternating current will flow.

When the resistance of a device is very small with respect to its reactance, as in coils and condensers, the impedance will be just slightly larger than the reactance, and for all practical purposes we can consider the impedance and reactance to be equal.

reactance to resistance) should therefore be as low as possible in circuits where only resistance is desired.

How to Increase the Q Factor of a Coil. For a coil of given inductance, keeping the losses in the coil at a minimum insures a high Q factor. Losses which are due to capacity between the turns of the coil can be reduced by using insulating materials and coil coatings which have low dielectric losses. Losses due to the coil form can be reduced by improving the quality of the material used in the coil form. Losses due to skin effects in the wire at high frequencies can be reduced by using a large number of enamel-covered wires which are braided together to form what is known as "litz" wire. (Unfortunately, litz wire is valuable only at frequencies between about 200 and 900 kc.) At high frequencies, losses can be kept down by making the coil with large solid wire, with flat copper ribbon or with copper tubing, all turns being equally spaced.

The shape of a coil has considerable effect upon its Q factor, for coil losses vary with the shape of the coil, particularly when the winding is in several layers. When designing multilayer R.F. coils, radio engineers generally test out several shapes and select that which gives the highest Q factor for the coil.

Shielding an R.F. coil by placing it in a metal can or compartment increases the losses in the coil, reduces the coil inductance, and also reduces the coil Q factor. With a Q factor meter like that shown in Fig. 4, the designer can select a shield for a given coil which will not excessively reduce the Q factor.

Large coils which are made from heavy copper wire, tubing or ribbon can have Q factors of over 500. In radio receivers, where small coils must be used because of space limitations, Q factors of 150 are considered excellent; in order to obtain this high value for radio receiver coils, it is necessary to use coil forms at least two inches in diameter and use heavy solid wire or litz wire for the windings.

Even though an engineer is able to choose a coil size, shape and type of wire which will keep losses low and thus give a high Q factor at a particular frequency, this is no guarantee that the Q factor will remain high for other frequencies. The graph in Fig. 5 shows that *the Q factor of a practical coil varies with frequency.* This graph tells us that in general, a coil which has a very high Q factor at a low frequency will lose its Q factor rapidly at higher frequencies (curve *1*), whereas a coil with a reasonably high Q factor at low and medium frequencies will tend to retain this Q factor value as frequency is increased (curve *2* in Fig. *5*). Naturally these facts about how the Q factor for a coil varies with frequency are of extreme importance in connection with the tuning circuits of radio receivers, for these circuits are made to respond to a wide range of carrier frequencies.

L/C Ratio for Tuning Circuits. In a tuning circuit the ratio of coil inductance to condenser capacity, commonly known as the L/C ratio, oftentimes has an important effect upon the selectivity of the circuit, determining the ability of the circuit to reject frequencies which differ from the resonant frequency. In series resonant circuits a large L/C ratio (secured by using a high-inductance coil) gives best selectivity, but in parallel resonant circuits it is the lowest L/C ratio which gives the best selectivity (assuming, of course, that the losses in the coils are the same for all L/C ratios).

When comparing the L/C ratios for two different tuning circuits, it is important that the same unit of inductance be used for each coil and the same unit of capacity be used for each condenser. For example, a typical 500-to-1,500 kc. tuning circuit uses a 250 microhenry coil and a 400 micro-microfarad (mmfd.) maximum capacity variable condenser; with this condenser set at 100 mmfd., the L/C ratio is 250 ÷ 100, or 2.5. For comparison purposes, then, the capacity and inductance used in another circuit should be expressed in these same units when figuring out the L/C ratio.

Coupling Methods for R.F. Tuning Circuits

The method used for coupling an R.F. tuning circuit to a tube in an R.F. amplifier or for coupling two tuning circuits together naturally has a great deal to do with the operation of the amplifier. Four basic coupling methods are in general use:

Method *1*. *Directly coupled resonant load* like that in Fig. *6A*, where a parallel resonant circuit is directly connected to the plate of the amplifier tube.

Method *2*. *Tuned secondary transformer load* like that in Fig. *8A*, where a series resonant circuit is inductively coupled to the plate of the amplifier tube.

Method *3*. *Double-tuned transformer load* like that in Fig. *9A*, where two resonant circuits which are mutually coupled inductively serve as the plate load for the amplifier tube.

Method *4*. *Double-tuned capacity-coupled load,* like that in Fig. *11A*, where two resonant circuits which are mutually coupled capacitively serve as the amplifier tube plate load.

Coefficient of Coupling. We are particularly interested in the amount of coupling provided between the resonant load circuit and the plate circuit of the R.F. amplifier tube by each of the basic coupling methods. Direct coupling such as that in method *1* provides maximum possible coupling between the source (the vacuum tube plate circuit) and the load (the resonant circuit).

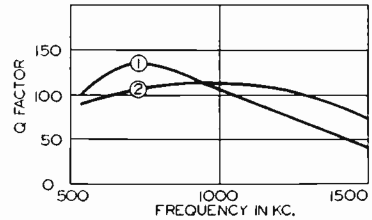


Fig. 5. Chart showing how Q factor varies with frequency for two representative broadcast band coils.

With transformer loads as in methods *2* and *3*, where mutual inductance (M) provides the coupling between circuits, we can change the amount of coupling by changing the position of either L_1 or L_2. When all of the flux produced by current flowing in the primary coil (L_1) links with the secondary coil (L_2), we have maximum coupling and maximum possible mutual inductance. When the primary and secondary coils are so positioned with relation to each other that only a part of the flux produced by one coil links with the other coil, the mutual inductance between them will be low and we have the condition of weak coupling. Under this condition the ratio of the actual mutual inductance to the maximum obtainable mutual inductance with very close coupling is a measure of the amount of coupling; this ratio is always a number less than *1*, and is known as the *coefficient of coupling*. When two resonant tuning circuits are coupled, as in methods *3* and *4*, the coefficient of coupling is quite important in determining the response characteristic of the circuit.

Effect of Vacuum Tube Characteristics. At the present time the use of pentode tubes in the R.F. amplifiers of radio receivers is becoming almost universal. Screen grid tubes are still to be found in some receivers, but triode tubes will be found only in the very old R.F. amplifier circuits. There are two features of pentode tubes which are significant in connection with tuning circuits and which should therefore be considered before we study coupling methods: *1, pentode tubes have high A.C. plate resistance values,* because the plate is farther away from the cathode than in an ordinary triode tube; *2, pentode tubes have high amplification factors,* because the control grid is considerably closer to the cathode than in an ordinary triode tube. For example, a 6K7 super-control pentode tube has an A.C. plate resistance of about 1,000,000 ohms and an amplification factor (μ) of about 1,000; a 6J7 pentode tube has an A.C. plate resistance greater than 1,500,000 ohms and a μ of over 1,500.

In a practical modern R.F. amplifier the effective load resistance rarely reaches a value higher than about one-tenth the A.C. plate resistance of the pentode tube. This condition corresponds to that of a generator which has an internal resistance of at least 1,000,000 ohms, connected to a load resistance of not more than 100,000 ohms; you can readily see that variations in the load resistance will have little effect upon the A.C. plate current. You could actually short out the load resistance without affecting the A.C. plate current more than 10%, since the resistance of the generator itself has the greatest amount of control over circuit current. Engineers say that under this condition we have a *constant-current generator.*

Because the A.C. plate resistance of a pentode tube in an R.F. amplifier stage of a receiver is extremely high with relation to its plate load resistance, *we can consider a pentode tube as a constant-current generator* for any given grid input signal voltage, and thus simplify greatly our study of resonant circuits. The constant-value A.C. plate current which the tube will deliver is easy to determine if the mutual conductance of the tube is known. Here is the rule: The A.C. plate current in microamperes in a pentode tube is equal to the *grid A.C. voltage in volts multiplied by the mutual conductance of the tube in micromhos.* Remember that with pentode tubes, whatever changes you make in the tuning circuit or circuits which serve as the load will have only negligible effect upon the A.C. plate currents.

The high amplification factor of a pentode tube produces a reasonably high output voltage despite the great loss in signal voltage due to the fact that the load resistance is less than the A.C. plate resistance.

Importance of Studying Coupling Methods. Now let us make a more detailed study of each of the basic coupling methods in order to see what the engineer can do to secure the desired amount of selectivity, gain and fidelity for a particular purpose when designing radio apparatus using one of these circuits, and in order to see what the serviceman can do to alter the selectivity, gain or fidelity characteristics of a receiver. This discussion will show you the importance of making exact tube and parts replacements in R.F. circuits. Substituting some newly developed tube or part for older equipment may lead to serious trouble, unless the substitution is made with full knowledge

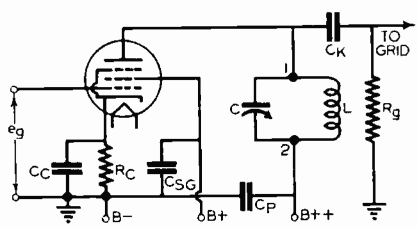


FIG. 6A. Directly coupled resonant load (a parallel resonant circuit whose terminals are *1* and *2*) as commonly used in a pentode R.F. amplifier stage.

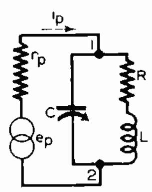


FIG. 6B. Simplified equivalent circuit of the directly coupled resonant load arrangement in Fig. *6A*.

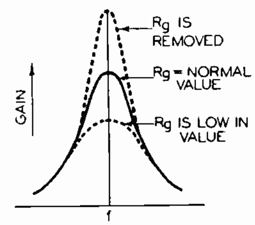


FIG. 7. Effects of grid resistor values upon the shape of the response curve for the circuit of Fig. *6A*.

of the design problems involved in the change.

Directly Coupled Resonant Loads

Simplified Circuit. We can simplify our study of the directly coupled parallel resonant load circuit in Fig. *6A* by omitting all parts which have no effect upon the performance of the amplifying circuit and redrawing our circuit in the form shown in Fig. *6B*. Observe that the R.F. by-pass condensers, the D.C. voltage supply leads for the tube electrodes and the automatic C bias resistor have been omitted, and the resistance of coil *L* is now represented by a separate resistor *R*. The vacuum tube has been replaced by an A.C. voltage source e_p (shown as an A.C. generator) in series with the A.C. plate resistance r_p, with the value of e_p being equal to the A.C. grid input voltage e_g multiplied by the amplification factor (μ) of the tube; this is simply the equivalent vacuum tube circuit idea which you have already studied, and which can be proven correct either by mathematics or experiment. In the simplified circuit of Fig. *6B*, this A.C. voltage e_p is divided between the load circuit (across points *1* and *2*) and the A.C. plate resistance r_p; only when the resonant resistance of this load is many times greater than r_p will the load get practically all of the source voltage e_p.*

Effect of Coil Inductance and Q Factor on Over-all Amplification. We know that the resonant resistance of the parallel resonant circuit in Fig. *6B* depends upon the coil reactance and upon the Q factor of the coil; for any given frequency, then, increasing the inductance of the coil will increase its reactance, will increase the resonant load resistance, and will therefore increase the over-all amplification. Likewise, increasing the Q factor of the coil will increase the over-all amplification.

*The voltage produced across the load for a one-volt grid input signal is a measure of the true amplification of a stage. In any pentode circuit such as we have here, we simply multiply the mutual conductance of the tube in micromhos by the resonant resistance of the load in ohms and divide the result by 1,000,000 to get the true or over-all amplification. Any change which increases the load resistance will therefore increase the over-all amplification.

For circuits which handle only a single frequency, such as I.F. amplifier stages, the designer endeavors to select a coil which has the highest usable inductance and at the same time has a high Q factor. From this it should be obvious to you that when a coil in the tuning circuit of an R.F. amplifier becomes defective, the mere substitution of another coil having the same inductance is not a guarantee that the correct over-all amplification will be obtained. The practical radio man uses exact duplicate replacement coils in order to make sure that he is using a coil with the correct Q factor as well as the correct inductance.

Effect of Frequency upon Over-all Amplification. Suppose we have a parallel resonant load circuit which tunes over the frequency range from 500 kc. to 1,500 kc.; will the over-all amplification remain the same at all frequencies in this range? Curve *2* in Fig. *5* shows that as frequency is increased above the middle-frequency range, the Q factor of a practical radio coil decreases; this reduction in Q factor would tend to reduce the over-all amplification at the higher frequencies. On the other hand, increasing the frequency three times (from 500 kc. to 1,500 kc.) would increase the reactance of the coil three times, thus increasing the resonant load resistance three times and consequently increasing the over-all amplification about three times. In most cases this increase in amplification due to an increase in coil reactance will completely overshadow the decrease due to a reduction in Q factor at high frequencies. Consequently we can say that increasing the signal frequency being fed to a tuned R.F. amplifier which uses a parallel resonant circuit as a plate load will in most cases *increase the over-all amplification* of the amplifier. Only when the Q factor drops rapidly with frequency, as in curve *1* in Fig. *5*, will the over-all gain remain constant or drop when frequency is increased.

Effect of Frequency upon Selectivity. The selectivity of an R.F. amplifier circuit is defined as the ratio of the amplification provided at the desired signal frequency to the amplification provided at the nearest undesired signal frequency. The effect of frequency upon selectivity can be demonstrated by considering an actual case, that where a broadcast band receiver using the circuit represented by Figs. *6A* and *6B* is first tuned to 500 kc. and then to 1,500 kc. For simplicity we will assume that in each case the nearest undesired frequency is 100 kc. away.

Remember that lowering the resonant resistance (or reactance if off resonance) of the tuned load circuit in this amplifier will lower the over-all amplification of the amplifier. Let us first assume that the Q factor remains constant over the range from 500 kc. to 1,500 kc.* Under this condition we know that the amplification at resonance for 1,500 kc. will be three times the amplification for 500 kc.

At frequencies considerably off resonance, a parallel resonant circuit like that in Fig. *6B* acts like that reactance (capacitive or inductive) which is lowest in ohmic value. At 400 kc. (100 kc. below the desired 500 kc. signal), then, the circuit will have a reactance essentially equal to the reactance of the coil, and this reactance will determine the amplification at this nearest undesired signal frequency in our example. Selectivity at 500 kc. will then be the ratio of the amplification at 500 kc. to the amplification at 400 kc. At 1,400 kc. (100 kc. below the desired 1,500 kc. signal), the reactance of the coil will be approximately three times its value at 400 kc. and there-

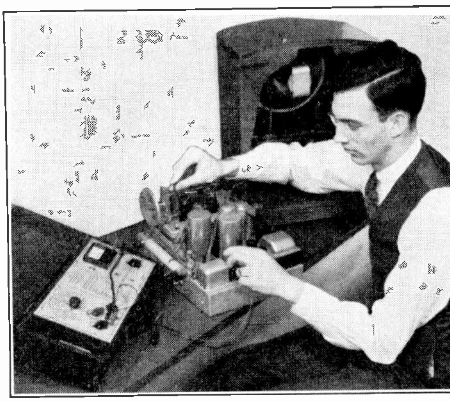
*The Q factor of a practical coil actually varies considerably with frequency; a constant Q factor is assumed here in order to simplify this discussion.

fore the amplification at the nearest undesired signal in this case will be three times what it was for the nearest undesired signal in the previous case. Since the amplification at 1,500 kc. is likewise three times the value at 500 kc., we will get the same selectivity ratio in both cases. This means that *when the Q factor is assumed to be constant over the tuning range, the selectivity of a parallel resonant circuit will likewise remain essentially constant over the tuning range.*

With the coils generally used in the tuning circuits of radio receivers, however, the Q factor will be found to decrease considerably as frequency is increased. This decrease in Q factor lowers the amplification at resonance but has no effect upon amplification at off-resonance frequencies; consequently the selectivity ratios for higher frequencies will be reduced. In actual circuits the selectivity will vary in much the same manner as the Q factor of the coil varies; the curves in Fig. *5* thus can tell us how selectivity varies with frequency. In general, you will find it easier to separate stations in the middle region of a radio receiver tuning range than at the extreme high or low frequency ends, for coil Q factors are generally highest in the middle region.

Effect of C Bias Voltage Variations. It is a known fact that in super-control pentode tubes, increasing the negative C bias voltage has the effect of decreasing the mutual conductance of the tube, thereby lowering the A.C. plate current and reducing the over-all amplification of the stage. Variations in C bias voltage have little effect upon the selectivity of R.F. amplifiers using pentode tubes, however, for the resonant load characteristics are not affected by C bias voltage variations.

Effect of Loading the Tuned Circuit. There is one simple way of changing the selectivity and gain of a tuned circuit such as that shown in Fig. *6A,* and this is to change the load on the tuned circuit by changing the value of grid resistor R_g. Obviously the gain will be lowered when the value of R_g is reduced, for this grid resistor acts in parallel with the resonant circuit and therefore reduces the load resistance in the plate circuit of the tube (assuming that coupling condenser C_K has negligible reactance). Off resonance, however, the value of R_g has little effect upon the amplification of undesired



All-wave superheterodyne receiver being aligned for peak response. An R.F. signal generator and an output meter are the only instruments needed; the N. R. I. 1175A All-Purpose Tester shown in the photo provides both of these. The output of the R.F. signal generator section is fed into the receiver, and the multimeter section is used as an output meter.

frequencies, for now the reactance of the tuned circuit will be considerably lower than the value of R_g ordinarily used, and the reactance of the tuned circuit will control amplification. Loading the tuned circuit of an R.F. amplifier by reducing the value of R_g thus *lowers selectivity* by lowering the amplification ratio for desired and undesired signals.

The effects of various values of R_g are shown graphically in Fig. *7*; the middle response curve is for the condition where the usual fairly high value of R_g is in the circuit of Fig. *6A*. The lower dotted curve is for a lower value of R_g, and clearly shows that both the gain and the selectivity of a tuned circuit in an R.F. amplifier are lowered when the tuned circuit is loaded by reducing the ohmic value of the grid resistor for the following stage; fidelity is considerably improved, however, for the broad peak insures uniform amplification of all side frequencies. The uppermost dotted curve is for the condition where R_g is removed entirely; now amplification is very high and selectivity is good, but fidelity is very poor because side frequencies are amplified very much less than the carrier frequency. Thus you can see that the fidelity of a receiver using a tuning circuit like that in Fig. *6A* could be improved by reducing the value of R_g, provided that a loss in amplification and selectivity is permissible. Likewise, DX (distance-getting) performance could be increased by using a higher value of R_g.

High-gain Directly Coupled Resonant Load Circuit. In some inexpensive receivers which have few tubes, the circuit in Fig. *6A* is modified slightly to eliminate the amplification-reducing effect of R_g. Instead of coupling to the next tube through C_K and R_g, a second coil is inductively coupled to coil L and connected to the grid and cathode of the following tube. (The circuit arrangement is exactly as in Fig. *9A* with tuning condenser C_2 removed.) By using a large mutual inductance between the two similar coils, the entire resonant circuit voltage can be transferred to the following stage without appreciable loss. If there are more turns on the secondary than on the primary, a step-up in output voltage can be secured. Fidelity is somewhat poor with this arrangement, however, for a sharp peak response curve is secured. The peak can be broadened by shunting the tuning condenser (C in Fig. *6A*) with a 20,000 to 200,000 ohm resistor, but this will, of course, lower the gain.

Tuned Secondary Transformer Loads

The R.F. amplifier circuit arrangement shown in Fig. *8A*, which uses a tuned secondary transformer load, is widely used in tuned radio frequency receivers and in the station selector (preselector) circuits of superheterodyne receivers. Since it is modern practice to use pentode or screen grid tubes in this circuit also, the A.C. plate current will be essentially independent of conditions in the resonant load circuit; we will assume this condition during our discussion of this circuit.

A simplified version of the tuned secondary transformer load circuit in Fig. *8A* appears in Fig. *8B*. Observe

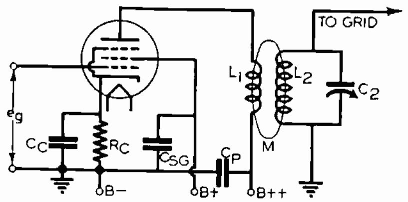


FIG. 8A. Tuned secondary transformer load circuit as commonly used in a pentode R.F. amplifier stage.

that the primary and secondary coils, L_1 and L_2, are each divided into two parts in this equivalent circuit. Those sections on each coil which link each other completely through mutual inductance M provide the only coupling between the two circuits; the remaining sections, which do not link each other at all, are known as the primary and secondary leakage inductances respectively. The primary leakage inductance is always equal to the original primary inductance minus that inductance which totally links with the secondary coil, and this totally-linking portion is in turn equal to the primary inductance multiplied by the coefficient of coupling of the original circuit. This same reasoning also applies to the sections of the secondary inductance.

Resonance exists in the secondary circuit for a desired signal frequency when the reactance of tuning condenser C_2 is equal to the reactance of the secondary leakage inductance at that frequency; the reactance of the other secondary coil section can be neglected, for it is cancelled out through mutual inductance M by the corresponding primary coil section. At resonance, then, the secondary resistance R_2 is the only factor which limits secondary current. This secondary resistance has an effect upon the primary circuit; engineers say that it is reflected into the primary circuit, with the reflected value of resistance being determined by the value of mutual inductance M, by the signal frequency and by the original value of R_2. Increasing the mutual inductance, increasing the frequency or decreasing the ohmic value of R_2 will increase the value of reflected resistance in the primary circuit.* When the ohmic value of the reflected resistance equals the A.C. plate resistance of the tube, maximum gain is obtained in this tuned secondary transformer load circuit. It is almost impossible to secure this condition with screen grid and pentode tubes because of their high A.C. plate resistance values, but it can be done with triode tubes which have low A.C. plate resistance values.

In all practical circuits which use screen grid or pentode tubes, the reflected resistance in the primary circuit is negligibly small in comparison to the A.C. plate resistance of the tube. The primary signal current is therefore unaffected by any conditions in the secondary circuit which might change the value of reflected resistance. Furthermore, the reactance of the primary leakage inductance is also negligibly small in comparison to the A.C. plate resistance, and consequently the changes in this reactance with frequency can be neglected. Thus we find that the only two factors which control the A.C. plate current in a practical R.F. amplifier of the tuned secondary transformer load type are the mutual conductance of the tube and the applied A.C. grid voltage. The signal voltage e_s which is induced in the secondary depends upon this A.C. plate current and mutual reactance of M.

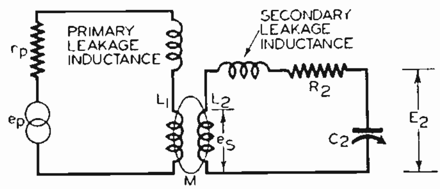


Fig. 8B. Simplified equivalent circuit of the tuned secondary transformer load circuit in Fig. *8A*.

This means that desired as well as undesired signal voltages applied to the grid of the tube in Fig. *8A* will produce the same induced voltage in the secondary circuit of the plate load; it remains for the series resonant secondary circuit to tune out all but the desired frequencies.

Effect of Tuned Secondary Circuit on Amplification. The voltage across secondary tuning condenser C_2 in Fig. *8A* is applied directly to the grid of the following tube, and therefore anything which increases the value of this voltage at resonance will make the over-all amplification of the stage greater. Since the tuned secondary is a series resonant circuit, this voltage is equal to the source voltage e_s multiplied by the Q factor of the secondary coil. Anything which increases the Q factor of the coil therefore increases

*Although undoubtedly you will never have to determine exactly what the reflected resistance value is, the formula for doing this is presented here for reference purposes: Multiplying the mutual reactance of M by itself once and then dividing by the secondary circuit resistance R_2 gives the reflected resistance in the primary circuit. (Reflected resistance in ohms = $2\pi fM \times 2\pi fM \div R_2$, where $\pi = 3.14$, f = frequency in cycles and M = mutual inductance in henrys.)

the over-all amplification. This is a good reason for using high Q coils in circuits of this type.

For a given grid input voltage, increasing the secondary induced voltage will also increase the over-all amplification of the stage; this can be done by using a tube which has a higher mutual conductance, by increasing the mutual inductance M between the primary and secondary, and by increasing the frequency of the desired signal.

To reduce the gain of an R.F. amplifier circuit like this, as is often necessary in actual receivers in order to prevent overloading of one or more following stages or to reduce the output volume to a desired lower level, the mutual conductance of the tube can be reduced. In a super-control pentode tube, the usual procedure for doing this involves increasing the negative C bias voltage on the tube.

When tuning the secondary circuit over a given frequency range, the amplification of the circuit will depend upon the manner in which the Q factor of the coil varies with frequency. Q factor normally decreases with frequency, but the reduction in gain due to this effect will be offset by an increase in gain due to the increased mutual reactance* of M at higher frequencies; the result is that the amplification of a typical tuned secondary transformer load circuit varies slightly over its tuning range.

Effect of Tuning Circuit on Selectivity. If the Q factor of the coil in a tuned secondary transformer load circuit remained constant over a given frequency range, the selectivity would also remain constant; Q factor decreases at the higher frequencies, however, so selectivity will likewise decrease.

*Mutual reactance equals mutual inductance times frequency in cycles per second times the number 6.28.

The peak of the response curve can be broadened or rounded by shunting the tuning condenser in Fig. *8A* with a 20,000 to 100,000 ohm resistor. This will reduce the gain at resonance by reducing circuit current but will have little effect at off-resonance frequencies.

Double-Tuned Transformer Loads

The double-tuned transformer load circuit shown in Fig. *9A* is widely used in the I.F. stages of superheterodyne receivers. One advantage of this circuit is that it can provide high selectivity while keeping the number of tubes at a minimum; another advantage is that the circuit can be adjusted to give an almost flat-top response curve for high fidelity. We will consider first the adjustment of this circuit for peak response and for band-pass response, and will then analyze the factors which control the circuit gain, selectivity and fidelity.

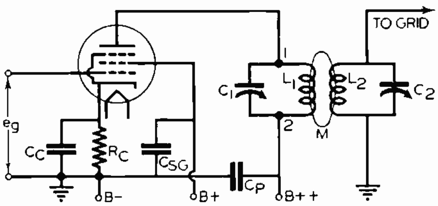


FIG. 9A. Double-tuned transformer load circuit as commonly used in a pentode R.F. amplifier stage.

The circuit of Fig. *9A* has been redrawn in simplified form in Fig. *9B* in order that we can concentrate our study upon those parts which affect the performance of the tuned circuit. Again we have the coils divided into totally coupled sections and leakage inductance sections, as before. R_1 represents the A.C. resistance of the primary coil, while R_2 represents the A.C. resistance of the secondary coil.

Adjusting for Peak Response. With the circuit of Fig. *9B*, a single-peak response characteristic can be obtained at any desired I.F. value by adjusting tuning condenser C_2 until its reactance exactly equals the secondary leakage reactance of the secondary winding at that I.F. value. Condenser C_1 is then adjusted in the same way in order to tune the primary circuit to resonance at the desired I.F. value. In a practical case this adjustment is made by connecting an R.F. voltmeter across C_2 to measure the secondary circuit output voltage E_2; C_1 and C_2 are then adjusted for maximum voltmeter reading.

At resonance, there is only the secondary circuit resistance R_2 to be reflected into the primary tuned circuit through mutual inductance M. This increases the resistance in the primary circuit, and therefore decreases the Q factor of the primary circuit. The presence of the secondary circuit thus reduces the voltage across primary tuning condenser C_1, thereby reducing the amount of resonant stepped-up current through coil L_1 and reducing the amount of voltage induced in the secondary winding for resonance step-up by the secondary series resonant circuit. A double-tuned transformer load circuit which uses identical coils in both tuning circuits always gives less gain than a single parallel resonant load circuit using only one of these coils.

Increasing the mutual inductance M by increasing the coupling between primary and secondary coils tends to make the resistance which is reflected into the primary circuit larger, thus reducing E_1, but at the same time the increased mutual inductance serves to increase the voltage which is induced in the secondary. Since the two effects tend to offset each other, there is naturally a particular value of mutual inductance which will give the highest possible gain. By experiments as well as calculation, engineers have determined that this optimum condition occurs when the mutual inductance M is such that the resistance which is reflected into the primary circuit is exactly equal to the primary circuit resistance R_1.

In practical radio circuits, condensers C_1 and C_2 in Fig. *9A* are usually of the same capacity, and consequently the primary and secondary coils must be alike in order to secure resonance at the same frequency. Since double-tuned transformer load circuits are ordinarily found in I.F. amplifier stages, these condensers will be of the trimmer type, independently adjustable. With any given coils, the condenser settings required for resonance are definitely fixed, and only the coupling between coils can be varied in

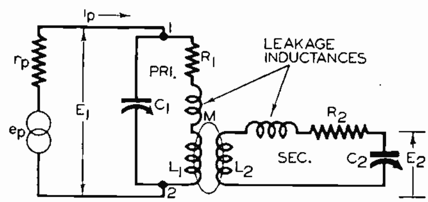


FIG. 9B. Simplified equivalent circuit of the double-tuned transformer load circuit in Fig. *9A*.

order to secure optimum conditions. That coupling which gives the maximum possible gain is called the optimum or critical coupling. With identical coils, optimum coupling is obtained when the coefficient of coupling is exactly equal to 1 divided by the Q factor of the coil. For example, if the coil has a Q factor of 100, the coefficient of coupling for optimum gain will be $1 \div 100$, or .01.

Once a double-tuned transformer load circuit is adjusted for optimum coupling, either increasing or decreasing the coupling from this value will reduce the over-all gain. Increasing the coefficient of coupling also reduces the selectivity, broadening the peak of the response curve because of the increase in the resistance reflected into the primary circuit, but decreasing the coupling serves to increase the selectivity. When double-tuned transformer load circuits are used to give a single-peak response, the coupling is kept less than the critical value (the coils are under-coupled) in order to improve the selectivity at a sacrifice of gain.

Adjusting for Double-Peak Response. Let us assume first that there is no coupling whatsoever between the secondary circuit and the primary circuit, both being tuned to the frequency of the source. Clearly there will be no voltage induced in the secondary coil under this condition, and consequently there will be no output voltage. Now as we bring the secondary coil closer to the primary coil, energy will be transferred through the mutual inductance

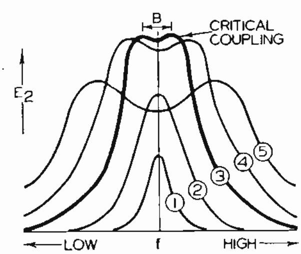


FIG. 10. Effect of variations in coupling upon the shape of the response curve for the double-tuned transformer load circuit in Fig. *9A*.

between the two coils and an output voltage will be produced across C_2. As we gradually increase the coupling up to the critical coupling value, this output voltage will continue to increase. Increasing the coupling beyond the critical value will at first have no effect upon the output voltage and will then gradually cause the output voltage to lower. What actually happens is shown in Fig. *10*; curve *1* represents a very small amount of coupling, while curves *2, 3, 4* and *5* represent increasing greater amounts of couplings, with curve *3* representing the conditions for critical coupling.

Let us see why double peaks occur in curves *4* and *5* in Fig. *10*. When coupling is below the critical value, both primary and secondary circuits have the same resonant frequency (assuming correct tuning) and single-peak response is secured. Increasing the coupling beyond the critical value without changing the tuning condenser settings causes the leakage inductance in each circuit to decrease, and consequently the resonant frequency of the secondary circuit becomes higher than before (the lower the effective inductance for a given capacity value, the higher is the resonant frequency of a resonant circuit). Increasing the coupling beyond the critical value likewise lowers the primary leakage inductance, making the primary circuit resonate also at a higher frequency. A signal at this higher frequency will thus undergo resonant step-up in both the primary and secondary circuits, giving a high output voltage.

When we exceed the critical coupling value, we have another interaction between the two circuits to consider. Consider conditions for a signal which is lower than the original resonant frequency of the secondary. At this lower frequency the series resonant secondary circuit will act as a capacity and will reflect into the primary circuit as an inductance which increases the effective primary inductance, bringing the primary circuit to resonance at this lower frequency. Likewise, the parallel resonant primary circuit alone will act as an inductance at the lower frequency and will reflect into the secondary as a capacity which brings the secondary to resonance at the lower frequency also. Primary and secondary circuits are thus resonant to both a higher and a lower frequency than the resonant frequency of either circuit alone, and as a result we have double-peak or band-pass response.

At critical coupling, an essentially flat-top response curve is obtained, with fairly steep sides and double peaks just beginning to form. The ap-

RESONANT CIRCUIT DATA

At frequencies below the resonant frequency:

A series resonant circuit acts as a capacity.
A parallel resonant circuit acts as an inductance.

At frequencies above the resonant frequency:

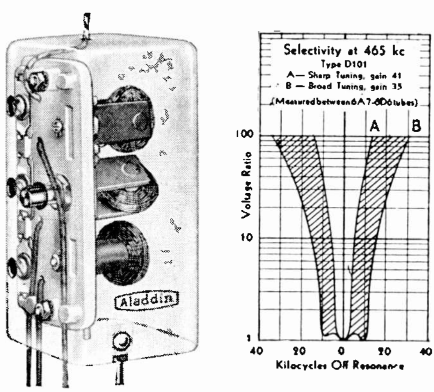
A series resonant circuit acts as an inductance.
A parallel resonant circuit acts as a capacity.

General rule: At any off-resonant frequency, a series resonant circuit acts like that part which has the highest reactance, while a parallel resonant circuit acts like that part which has the lowest reactance.

proximate distance between these peaks, as measured in kc., is easily computed; it is equal to the coefficient of coupling multiplied by the carrier frequency to which the R.F. amplifier is tuned. For example, suppose that the coils in Fig. *9A* each have a Q factor of 150, and the two resonant circuits are tuned to 460 kc. Critical coupling will be obtained when the coefficient of coupling is 1 divided by 150, which equals .0067; the separation between peaks at this condition of critical coupling will then be equal to 460 (the frequency in kc.) multiplied by .0067, or about 3 kc. The actual practical band width for this particular case will be somewhat wider (about 4.5 kc. in this example), for it is determined by the distance between the steep sides of the response curve rather than by the distance between the peaks.

In the above example, we can triple the amount of separation between peaks (thereby tripling the band-width) by tripling the amount of coupling, but this will give a valley between peaks as in curves *4* and *5* in Fig. *10*. If, in addition to tripling the coupling, we reduce the Q factors of the coils to one-third of their original values, we can secure this same tripling of band-width without having a valley between peaks, but the gain will be considerably less when this is done. Clearly we must sacrifice one advantage in order to secure another, in this particular case.

When an engineer designs band-pass circuits like that in Fig. *9A*, he endeavors to choose coils which will give the desired band-width at critical



Courtesy Aladdin Radio Industries, Inc.

This Aladdin type D I.F. transformer provides any desired performance characteristics from high fidelity to extreme selectivity without appreciable variation in gain, at the option of the user. Rotating the center coil by means of a knob on the front panel of the receiver serves to vary the coupling between the other two coils. In the under-coupled position, as represented by curve *A*, we have sharp tuning and severe cutting of side frequencies above about 4,000 cycles, while curve *B* corresponds to over-coupling, with practically uniform amplification of all side frequencies up to 10,000 cycles off resonance. Three built-in trimmer condensers, one for tuning each coil, give additional control over transformer characteristics.

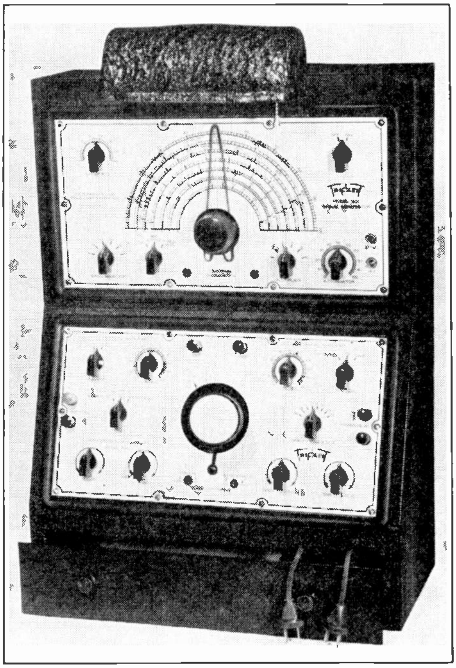
coupling. If he finds that this is impossible, he increases the coupling beyond the critical value enough to secure the desired band-width. This gives somewhat lower gain (curve *5* in

Fig. *10* represents lower gain than curves *3* and *4*).

Adjusting Actual Band-Pass Circuits. Band-pass circuits in practical radio frequency amplifiers are easily adjusted with the aid of a cathode ray oscilloscope which is connected to reproduce the response curve of the amplifier. By watching the effects of each adjustment upon the shape of this response curve, the radio serviceman knows definitely when he has secured the desired shape.

Ordinarily a serviceman does not know whether a particular band-pass circuit is over-coupled (greater than critical coupling), or is under-coupled (less than critical coupling). For this reason he must always try to adjust the circuit for peak response before making band-pass adjustments. In the case of Fig. *9A*, this is done simply by feeding into the amplifier an R.F. signal of a definite frequency and adjusting tuning condensers C_1 and C_2 for maximum output voltage at the detector load, as indicated either by an output meter or by a cathode ray oscilloscope. It does not matter which condenser is adjusted first. The adjustments are repeated several times. If there are several band-pass circuits in an amplifier, each is adjusted in this same way for peak response. Inability to secure a single-peak response when this is done means that the coils are over-coupled; in this case the preliminary adjustment is omitted.

A cathode ray oscilloscope and a variable frequency signal generator are now connected to the amplifier in the proper manner to produce on the cathode ray oscilloscope screen the actual response curve of the entire amplifier. Assuming that the circuit in Fig. *9A* is the only band-pass circuit in the amplifier, the capacity of C_1 is increased slightly and the capacity of C_2 is decreased the same amount (or C_1 may be decreased and C_2 increased) to make the flat top appear. If the coils have approximately critical coupling, only small changes in the condenser settings will be needed to secure double peaks. When coupling is considerably less than the critical value, however, the two condensers may have to be changed considerably from their peak response settings before the two peaks will appear. If the coils in a double-



Courtesy Triplett Electrical Instrument Co.

A cathode ray oscilloscope (lower section) and a frequency-modulated signal generator (upper section) are here mounted in a single cabinet. They can be connected to a radio receiver in a few minutes for producing the response curve of the receiver, and have a host of other radio servicing and testing uses as well.

tuned circuit are over-coupled, *it will be impossible to adjust for a single-peak response;* the two peaks will always be present, and changes in condenser settings will merely serve to change the distance between peaks and alter the symmetry of appearance.

The more the condenser settings are changed, the greater will be the distance between the two peaks and the deeper will be the valley between the peaks. If the peaks of the response curve of a double-tuned circuit are excessively high with respect to the valley between them when the desired band-width is secured, they can be reduced by *shunting the primary and secondary circuit tuning condensers with 20,000 to 100,000-ohm resistors.* This actually pulls the two peaks closer to the level of the valley, thus making the response more uniform over the entire band-width. It may be necessary to experiment with different values of resistors in the primary and secondary circuits in order to reduce both peaks equal amounts, if condenser adjustments alone are not sufficient to give a symmetrical response curve.

Double-Tuned Capacity-Coupled Loads

Two resonant circuits may be coupled together by capacity coupling, as illustrated in Fig. *11A,* instead of inductive coupling. Circuit action is much the same with either type of coupling, so there should be no difficulty in understanding how the simplified version of this capacity-coupled arrangement, shown in Fig. *11B,* behaves under various operating conditions.

When both tuned circuits are at resonance, the secondary tuned circuit made up of L_2, C_2 and C_M will act as a resistance. If we measure the resonant resistance between points *2* and *3,* in

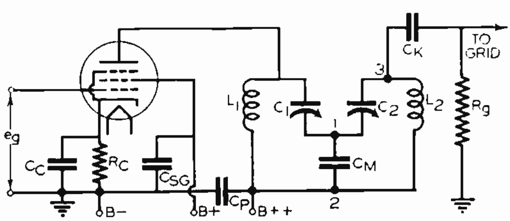


FIG. 11A. Double-tuned capacity-coupled load circuit as commonly used in a pentode R.F. amplifier stage.

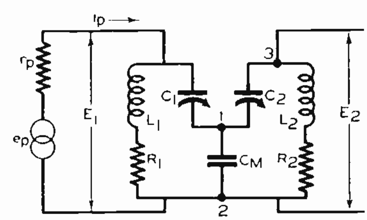


FIG. 11B. Simplified equivalent circuit of the double-tuned capacity-coupled load circuit in Fig. *11A.*

In many modern high-fidelity receivers, controls are provided which vary the coupling between the primary and secondary coils of one or more double-tuned transformer load circuits in order to permit a choice between peak response and band-pass response. These transformers will have critical coupling when this control is set for band-pass performance. In some circuits which use variable coupling, you may find that the variable coupling control is labeled "volume control" on the schematic circuit diagram and on the panel of the receiver. In this case the coupling will always be less than the critical value, and under this condition any changes in coupling will affect the receiver gain far more than it will the receiver selectivity. We thus have simply a unique volume control.

the circuit of Fig. *11A,* we find it to be quite high.

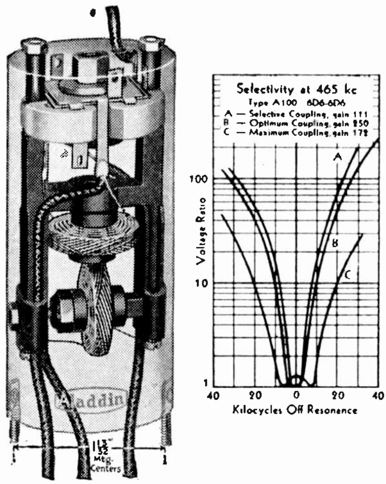
You will note that tuning condenser C_2 and coupling condenser C_M are in series between points *2* and *3.* A part of the total high resistance between these points will therefore exist across the terminals of coupling condenser C_M, and experience has shown that the actual value of this resistance will be proportional to the reactance of C_M. Increasing the reactance of coupling condenser C_M will therefore increase the effective resistance across it and thereby increase the resistance which is reflected into the primary circuit.

At resonance, the resonant resistance of the primary tuning circuit made up of L_1, C_1 and C_M determines the value of the signal voltage E_1 which will be produced across the primary coil.

Again we assume that the pentode tube maintains the plate current i_p essentially constant; the resonant circuit current through the primary coil is of course greater than i_p and varies in value as circuit conditions are changed. The greater the resistance reflected into the primary circuit by the secondary, the lower will be the resonant circuit current through the primary coil and the lower will be the voltage across the primary. Just as with inductive coupling, maximum secondary circuit output voltage is obtained with critical coupling between the primary and the secondary, under which condition the resistance reflected into the primary is equal to the primary circuit resistance R_1. When C_1 is equal to C_2, as is usually the case in a practical circuit, the coefficient of coupling is the ratio of C_1 to C_M.

Just as with other band-pass circuits, increasing the coefficient of coupling beyond the critical value results in a double-peak response curve. The reasons for the existence of a double peak under these conditions are quite easily understood. When the capacity of coupling condenser C_M is made lower than the critical value, thereby raising its reactance, raising the voltage developed across it for transfer from primary to secondary, and increasing the coupling, the combined capacity of condensers C_2 and C_M in series will be *less* than before, making the resonant frequency of the secondary higher than before. Likewise the lower capacity of C_M in series with C_1 will raise the resonant frequency of the primary to the same high value. We have thus accounted for the higher-frequency peak on the band-pass response curve.

Now consider the effects of interaction between the two tuned circuits when the coefficient of coupling is beyond the critical value and the incoming signal is below the resonant frequency. Looking at the primary circuit first, we note that secondary circuit components L_2 and C_2 in series are shunted across C_M; the reactance of C_2 being greater than that of L_2, this shunt combination will act as a condenser in parallel with C_M, increasing the effective capacity of C_M in the primary circuit. This higher value of C_M acting in series with C_1 increases the effective capacity in the primary circuit and therefore causes the primary circuit to resonate at a lower frequency than the original value. Exactly the same analysis will show that the secondary circuit will also resonate at this lower frequency. Thus we have accounted for the lower-than-normal peak in the band-pass response curve.



Courtesy Aladdin Radio Industries, Inc.

Here is an adjustable coupling I.F. transformer (Type A Aladdin Polyiron transformer) which you may encounter in high quality radio receivers and particularly in commercial receivers. The curves at the right show its performance at different degrees of coupling. Note that the coils are at right angles to each other; moving the lower coil in either direction along its shaft by means of adjusting screws changes the coupling. Critical or optimum coupling is secured when the lower coil is not directly under the upper coil; curve *B* represents this condition, giving the ratio of the voltage output at resonance to the voltage output at frequencies up to 40 kc. above and below resonance. Amplification at the resonant frequency (465 kc.) is 250 for this condition, an unusually high value. Moving the coil more nearly under the upper coil gives under-coupling, with reduced gain but improved selectivity, as indicated by curve *A*. Moving the lower coil out from the critical coupling position gives over-coupling, with double peak response for high-fidelity band-pass results.

The reason why double peaks are not secured when the coefficient of coupling is less than the critical value is quite simple. Under this condition the capacity of C_M is so high that interaction between the two circuits is negligible. As a result, each circuit resonates at only one frequency, and a single peak response curve is secured.

With capacitive coupling between two resonant circuits, the separation between peaks at critical coupling is equal to the operating frequency multiplied by the coefficient of coupling, just as in the case of inductive coupling. Increasing the Q factor of the coils in the circuit of Fig. *11A* increases the value of coupling required for critical coupling, thereby lessening the separation between peaks at critical coupling, but higher gain is secured. Increasing the coupling (by reducing the capacity of C_M) increases the separation between peaks and therefore increases the band-width.

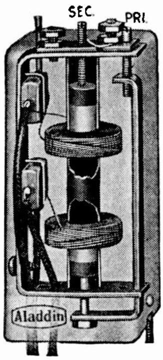
Just as with any double-tuned circuit, the separation between the two peaks may be increased, giving greater band-width, by detuning the primary and secondary circuits (by increasing the capacity in one circuit and decreasing the capacity an equal amount in the other). This deepens the valley between the peaks, but loading of the primary and secondary circuits with resistors will flatten the peaks and give a more uniform response curve over the entire band-width.

The procedure just described for widening the band-width and loading the tuning circuit is commonly used in the tuned circuits of television receivers, where a band-width of the order of 6 megacycles (6,000,000 cycles) is generally required. This procedure reduces the gain considerably, and consequently television receivers require more amplifier stages than broadcast band receivers. Both capacitive and inductive coupling are used in the double-tuned circuits of television receivers.

Combination Capacitive and Inductive Coupling

In tuned circuits which are to operate over a definite range of radio frequencies, such as the preselector circuits in superheterodyne receivers, the amount of coupling between tuned circuits is not entirely independent of frequency. As a result, the response curve of the circuit will vary in shape and size at different frequencies, with the nature of the variation being dependent upon the type of coupling used.

Fixed mica condensers are permanently connected across the coils in this type L inductance-tuned Aladdin I.F. transformer. Tuning is accomplished by changing the positions of the Polyiron pulverized iron cores inside each coil; this is done by adjusting the set screws at the top, labeled *PRI.* and *SEC.* Coupling is always less than the critical value. A gain of about 100 is secured when the coils are adjusted for peak response.



Courtesy Aladdin Radio Industries, Inc.

Consider the double-tuned transformer load circuit in Fig. *9A* first. Assuming that the coil Q factors remain the same as we tune from a low to a high radio frequency, we see that the reactance of mutual inductance *M* increases with frequency, producing a greater induced voltage in the secondary circuit and therefore giving a greater gain at the higher frequencies.

With the capacity-coupled circuit shown in Fig. *11A*, on the other hand, the reactance of coupling condenser C_M decreases as we tune from a low to a high frequency, with the result that less voltage is fed into the secondary tuned circuit at higher frequencies, and less gain is realized at higher frequencies.

Capacitive and inductive coupling are often used in the same circuit in order to make an amplifier have the same gain at both low and high frequencies. A typical band-pass R.F. amplifier circuit which uses both types of coupling is given in Fig. *12*; as you can see, primary coil L_1 is inductively coupled (through mutual inductance M) to secondary coil L_2, and these two coils are also coupled together capacitively by coupling condenser C_M. The antenna is inductively coupled to coil L_1 in the first tuned circuit through mutual inductance M_A. Resistor R_g, having a high ohmic value, provides a conductive path around coupling condenser C_M, so that the negative C bias voltage across R_C and C_C will be applied to the grid of the tube.

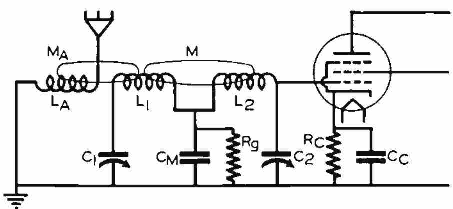


FIG. 12. Double- tuned R.F. amplifier input circuit using both inductive (M) and capacitive (C_M) coupling to equalize the gain at all frequencies in the tuning range.

Tuned Secondary with Fixed Tuned Primary Circuit

When a single resonant circuit gives more gain at high frequencies than at low frequencies, the circuit illustrated in Fig. *13* is often used to equalize the gain over the entire tuning range. The primary winding L_1 has a distributed capacity between turns which is in effect equivalent to a condenser C_1 connected across the winding. The primary coil can be so designed that the coil and its distributed capacity form a parallel resonant circuit which resonates at a low frequency in the tuning range, giving resonant current step-up at low frequencies and thereby inducing larger voltages than normal in the secondary circuit at the lower frequencies in the tuning range. At the higher frequencies, however, the primary circuit is off resonance and the value of mutual inductance M alone determines the amount of voltage induced in the secondary.

Unfortunately, this use of a fixed tuned primary circuit to boost the gain at low frequencies works entirely too well, boosting the gain at low frequencies so much that we have the reverse of the initial unequal gain condition. It is for this reason that a small amount of capacity coupling is used between the high R.F. terminal of the primary coil and the high R.F. or grid terminal of the secondary coil; a stiff copper wire connected to the primary and curled partly around the secondary winding at the grid terminal end provides sufficient capacity coupling for the purpose. This wire does not connect to the secondary coil, as only capacity coupling is desired.

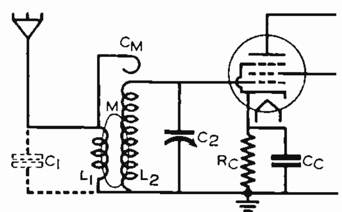
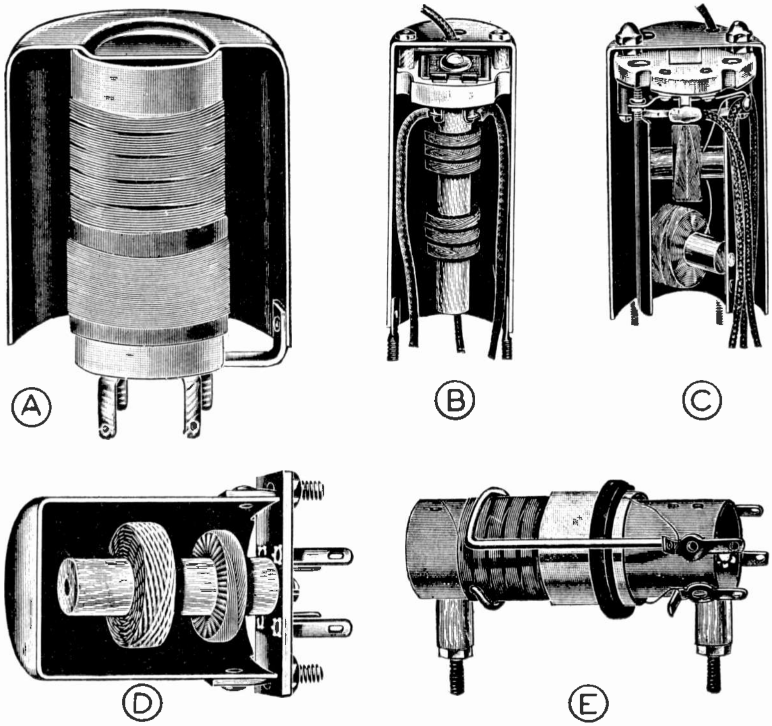


FIG. 13. Another R.F. amplifier input circuit which uses both inductive and capacitive coupling to equalize the gain over the tuning range. Fixed tuning of the primary coil is provided by the distributed capacity (C_1) between turns of the coil.

The circuit diagram in Fig. *13* illustrates the use of this capacity-coupling wire in the antenna system of a receiver. Antenna coil L_1, along with its distributed capacity, tunes to about the lowest frequency in the tuning range of the secondary circuit (this tuning range being controlled by L_2



Typical R.F. transformers which can be used in the tuning circuits described in this lesson. Getting the required inductance is only a small part of the coil designer's work; he must also consider such important things as the Q factor and how it varies with frequency, the degree of coupling needed for desired results, effect of the shield, and gain-equalizing methods. The examples shown here are all Gen-Ral coils, made by General Mfg. Co.

A—Shielded R.F. transformer having a bank-wound secondary made of litz wire, with an ordinary single-layer primary wound over the lower end of the secondary. With the average pentode tube this transformer gives a gain of 42 at 550 kc. and a gain of 62 at 1,500 kc.; this nearly uniform gain over the tuning range is secured by proper design of the secondary coil. You will find this coil used in circuits like the tuned secondary transformer load arrangement of Fig. *8A*.

B—Shielded I.F. transformer. Triple-section cross-wound primary and secondary coils are used to give a high Q factor. The coupling (spacing between coils) is adjusted during manufacture for optimum results. Tuning condensers are built into the housing, one being connected across each coil. Look for units like this in double-tuned transformer load circuits such as that in Fig. *9A*.

C—Shielded I.F. transformer. The cross-wound coils are made with litz wire and are weakly coupled (coefficient of coupling is less than the critical value) to give sharp peak response. Also used in circuits like Fig. *9A*.

D—Shielded R.F. transformer having cross-wound primary and secondary coils mounted permanently on a wood dowel; coupling cannot be adjusted. This construction gives fair gain, but this varies considerably over the tuning range. Used in circuits like Fig. *8A*.

E—Unshielded antenna coil for broadcast band. Secondary is made of litz wire, bank-wound directly on coil form, while the lattice or cross-wound primary is located over one end of the secondary. The primary is self-tuned (by its distributed capacity) to about 550 kc., and a heavy-wire coupling ring provides capacity coupling between primary and secondary, so that the gain is very nearly uniform throughout the broadcast band. Fig. *13* illustrates how the coil is used.

and C_2). A stiff wire attached to the antenna post (the high R.F. terminal) of primary coil L_1 loops around the grid end of secondary coil L_2. This arrangement gives practically uniform gain over the entire tuning range. You will find this stiff wire scheme used for capacity coupling between coils in practically all of the small universal A.C.-D.C. tuned radio frequency receivers. (In some receivers this stiff wire is replaced by several turns of insulated wire or by two short insulated leads twisted together.)

R.F. Tuning Circuits Used in Actual Receivers

Although the R.F. tuning circuit diagrams already presented in this lesson are typical of those used in most radio receivers, there are a number of minor variations of these circuits which will occasionally be encountered. Three different receivers which use out-of-the-ordinary R.F. tuning circuits have been selected for study. The circuit diagrams of the R.F. sections of these sets are shown in much the same way as they appear in the respective service manuals, in order to make you familiar with the different drawing techniques used in actual practice.

General Motors Model MA T.R.F. Receiver. The first two stages of this receiver are shown in Fig. *14*; in the actual receiver there are three R.F. stages, giving four tuned circuits which can be tuned over the 550 kc. to 1,500 kc. broadcast band by a single tuning control. Observe that type 24 screen grid tubes are used; since these have very high A.C. plate resistance values, their A.C. plate currents can be considered essentially constant under all circuit conditions. This receiver clearly does not have A.V.C.; the volume is controlled by a dual rheostat which simultaneously varies the resistance across the antenna input coil (this is done by R_1) and varies the C bias voltage on the R.F. tubes (this is done by R_2). The cathode, screen grid and plate by-pass condensers for each tube are mounted in a single case (indicated by dotted lines and labeled C_P).

You will readily recognize L_1-C_1 as the first tuning circuit, this being fed with the antenna signal by a direct connection from the antenna to a tap at point *1* on L_1. But notice that the antenna signal must first pass through coil L_A, which is *not* inductively coupled to L_1; we suspect immediately that this is used by the designer to equalize the gain over the tuning range. Coil L_A actually serves to tune the antenna at the low frequency end of the tuning range, reducing the antenna impedance to a minimum value and thereby causing a large signal current to flow into the portion of coil L_1 between point *1* and ground. At the higher frequencies in the range, the antenna is off tune, antenna current is lower and the gain of the input tuning circuit is consequently lower also. Thus coil L_A can

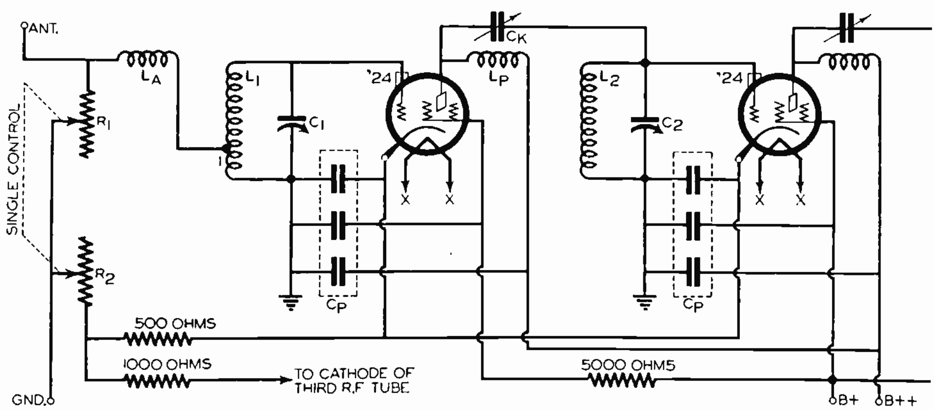


FIG. 14. A portion of the circuit diagram of the General Motors model MA T.R.F. receiver, illustrating an interesting method used to equalize the gain over the entire tuning range.

counteract a tendency for tuning circuit L_1-C_1 (or any other tuning circuit in the receiver) to give higher gain at the higher frequencies.

Now let us analyze the second tuning circuit, made up of L_2-C_2. The voltage developed across R.F. choke L_P by the flow of A.C. plate current through this high-impedance choke is applied to this second tuning circuit through coupling condenser C_K. Coil L_P has a certain amount of distributed capacity which tunes it to resonance at a low frequency in the tuning range, thereby raising its impedance at low frequencies and increasing the signal voltage which it can deliver to the second tuning circuit.

Since the reactance of coupling condenser C_K decreases at the higher frequencies, this condenser will transfer more voltage at the higher frequencies. Coil L_P thus serves to raise the gain at low frequencies, while C_K raises the gain at high frequencies; observe that C_K is adjustable so that any amount of equalization of gain over the tuning range can be attained. This condenser need be adjusted only as a part of the regular alignment procedure for the receiver.

General Electric Model F-107 Superheterodyne Receiver. You know that the higher the coil Q factor in a tuning circuit, the higher is the gain and the selectivity of the circuit. Sometimes, however, the circuit designer runs into a condition where he has exactly the desired selectivity but has too much gain. To reduce this gain in order to prevent overloading, he could use shunt resistors across tuning condensers, but this would also reduce selectivity and would therefore be undesirable. One designer solved this problem by choosing R.F. coils which gave the desired selectivity, then tapping one of the coils to remove only a fraction of the total available voltage. The result is the I.F. amplifier section illustrated in Fig. *15*, where the tap at point *1* allows only about 60% of the total available voltage in this tuning circuit to be impressed upon the grid of the second I.F. tube. If necessary, an even greater reduction in gain could be secured by using a similar tap for the plate connection on the primary winding of this I.F. transformer.

RCA-Victor Model 5M Auto Radio Receiver. An antenna input coupling circuit which is widely used in auto radios is shown in Fig. *16*. The filter circuit made up of C_1, L_1 and C_2 is known as a low-pass filter and is used

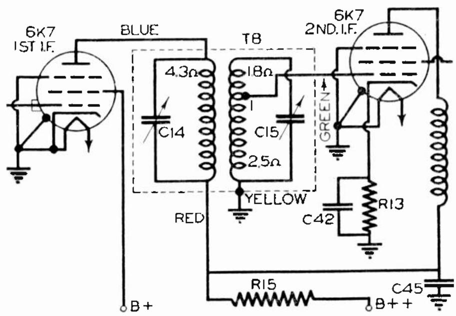


Fig. 15. Here is one I.F. stage of the model F-107 General Electric receiver, an example of a fixed frequency amplifier. This circuit diagram (taken from the service manual for the set) tells how the I.F. transformer leads in this receiver can be identified by their color. Note that the D.C. resistance of each coil is indicated, for continuity testing purposes.

to allow only R.F. signals which are below 1,500 kc. to pass. This is highly important in an auto radio receiver, for the spark coil type ignition systems used in automobiles develop ultra-high frequency radio waves which can create interfering signals if they enter the input circuit of the radio receiver. R.F. signals in the desired frequency range pass through this filter without appreciable opposition and develop a signal voltage across input coil L_2. This signal voltage is in turn fed through coupling condenser C_3 into the first resonant circuit, the coupling being through that section of coil L_3 which is below point *1* and then through condenser C_6 to ground. As a result there is both inductive and capacitive coupling, giving equalization of gain over the entire tuning range. Tuning condenser C_5 tunes the portion of L_3 between point *1* and the grid of the first tube over the entire tuning range; C_4 is simply a trimmer condenser used for alignment purposes. The three vertical lines and one diagonal line above coil L_3 symbolically indicate that the coil uses a pulverized iron core, with the diagonal line indicating that the position of the core and therefore the inductance are adjustable. This core thus provides an aligning adjustment at the low frequency end of the tuning to equalize the gain; in a circuit of this type, we are safe in assuming that the primary will tune to a lower frequency in the range to counteract increasing gain provided by the secondary circuit at the higher frequencies. The low resistance of the secondary coil indicates that this coil has a high Q factor.

Conclusion. I do not expect you to be able to analyze in a few minutes any R.F. tuning circuit which you may encounter after your study of this lesson, for there apparently is no limit to the number of variations which are being used by circuit designers. I do say, however, that after you have studied a

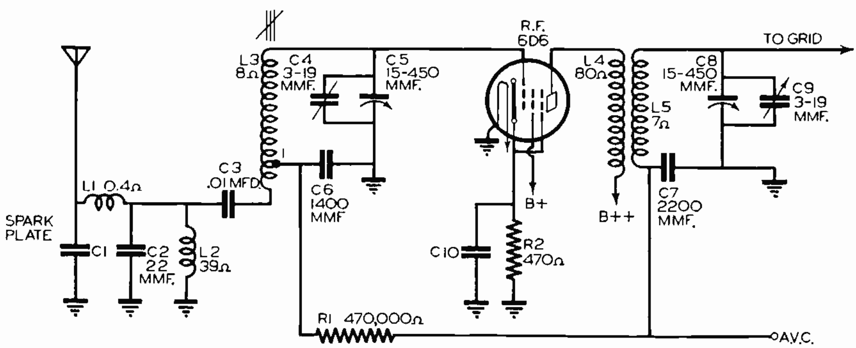


Fig. 16. Input circuits of the model 5M RCA Victor Auto Radio. Condenser *C1*, labeled *SPARK PLATE*, provides a shunt path to ground for high-frequency interference signals produced by the spark plugs and ignition system of the automobile.

range, while high frequency trimmer C_4 permits alignment at the high frefrequency end of the range.

Turning now to the plate circuit of the first tube, you might say at first glance that this contained a conventional tuned secondary transformer load. Closer examination would show, however, that while the D.C. resistance of the primary coil was 80 ohms, the secondary coil had a D.C. resistance of only 7 ohms. These figures tell us that the primary coil must be made of many turns of fine wire and hence must have a high inductance and high distributed capacity. This distributed capacity tunes the primary to some frequency in the tuning range in order number of other schematic circuit diagrams in the same way as we have analyzed the three diagrams at the end of this lesson and after you have acquired practical experience with the behavior of tuning circuits in actual radio receivers, you will find yourself in a far better position to service radio receivers and know what to expect from them than if you simply made adjustments blindly without knowing exactly what you were doing. You will know *why* certain things happen when certain screws and knobs are turned in a receiver, and will be able to determine whether or not the fidelity or selectivity of a particular receiver can be improved.

TEST QUESTIONS

Be sure to number your Answer Sheet 22FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What does a sharp peak response curve for an R.F. amplifier indicate as regards gain and selectivity?

2. Will an R.F. amplifier which has a sharp peak response curve cause severe attenuation of the higher modulation frequencies?

3. Will amplitude distortion occur when an R.F. amplifier has a symmetrical double-peak response curve?

4. How is a high Q factor obtained for a coil which has a given inductance?

5. Does the Q factor of a practical coil vary with frequency?

6. Why can a pentode tube in the R.F. amplifier stage of a receiver be considered as a constant-current generator?

7. What effect does the loading of a tuned circuit in an R.F. amplifier have upon its selectivity and gain?

8. Name two advantages which are secured by using a double-tuned transformer load circuit.

9. Is it possible to adjust for a single-peak response when the two coils in a double-tuned circuit are over-coupled?

10. If the peaks in the response curve of a double-tuned circuit are excessively high with respect to the valley between them, how can they be reduced?

BROADCAST, ALL-WAVE AND TELEVISION SUPERHETERODYNE RECEIVER PRINCIPLES

23FR-2

PIONEER HOME STUDY RADIO SCHOOL

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THE "SUPER" IS KING TODAY!

To the man who has anything at all to do with Radio, the superheterodyne circuit is by far the most important R.F. amplifier circuit used in sound and picture signal receivers; the super is now king of Radio receivers and will, in my estimation, hold this position for many years to come.

Naturally, then, this text-book is worth its weight in gold to any one who seeks for success in Radio. Master the fundamental principles, study each section of the superheterodyne circuit over and over again, know why you get squeals, interference and noise under certain conditions—in other words, know supers "backward and forward," *and you'll get ahead.*

This text-book is crammed with *practical* facts, *practical* circuits and *practical* servicing hints, most of these being based upon radio theories presented in previous lessons. For this reason I strongly recommend that after your first reading of this book you review previous lessons covering the subjects which give you the most trouble; for example, if the operation of the local oscillator in a superheterodyne is not quite clear to you, review "The Vacuum Tube as an A.C. Generator in Radio and Television Circuits."

The causes for the various superheterodyne ailments—squeals, "monkey chatter," interference, etc.—are given in these lessons; by understanding these causes and applying effect-to-cause reasoning, you eliminate guess work or groping in the dark. When working with supers you will be able to recognize each effect as being caused by such and such a defect, and be able to complete the repair while others might still be looking for the trouble.

J. E. Smith

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Broadcast, All-Wave and Television Superheterodyne Receiver Principles

THE SUPERIORITY OF THE SUPERHETERODYNE

BASICALLY, the superheterodyne principle of R.F. amplification involves the conversion of each incoming signal to one definite fixed R.F. frequency which is known as the intermediate frequency or the I.F. value.* It is much easier to get optimum (best) results from an R.F. amplifier which always works at the same frequency, as in the I.F. amplifier in a superheterodyne receiver, than from an amplifier which is tuned through a wide range of R.F. frequencies, as in the T.R.F. receivers.

Review of R.F. Amplifier Operation. If you will review in your mind the action of an R.F. amplifier, you will recall that the gain and selectivity of any stage is dependent upon the resonant resistance of the plate load; this resonant resistance depends upon L/C, the ratio of coil inductance to condenser capacity, and upon the losses in the tank circuit. In tuning to different frequencies we vary the condenser capacity and thus vary the L/C ratio; for this reason and because tank circuit losses are different at each frequency, uniform amplification is not readily obtained. Thus the amplification and the selectivity of a T.R.F. receiver are different at each setting of the tuning dial.

In the superheterodyne receiver, on the other hand, practically all of the gain and selectivity are produced at one fixed R.F. value, regardless of the frequency of the incoming signal; selectivity and sensitivity are therefore uniform at all tuning dial settings.

A comparison of the performance curves of a superheterodyne receiver with a T.R.F. receiver having approximately the same number of tubes will show very clearly the superiority of the superheterodyne. Such curves are given at *A*, *B*, *C* and *D* in Fig. *1*; sensitivity is here measured in terms of microvolts of signal input required to get a 50-milliwatt output, and thus the lower the input value in microvolts, the more sensitive is the receiver. The sensitivity curve for the superheterodyne (at *A*) is practically constant for all frequencies in the tuning band, while the same curve for the T.R.F. set (Fig. *1B*) varies considerably and represents much lower sensitivity. The selectivity curves in Fig. *1C* and *1D*

* When a signal demodulator (second detector), audio amplifier, loudspeaker and power pack are added to an R.F. amplifier which depends upon the superheterodyne principle of amplification, the result is a complete superheterodyne receiver. The above-mentioned sections of the receiver are of conventional design and are all covered thoroughly elsewhere in the Course.

give, for each frequency value off resonance, the ratio of signal input at resonance to the signal input required to give the same output at the off-resonance frequency. Curve C (for the super) thus represents very good selectivity which is uniform at all frequencies in the band, while curve D (for the T.R.F. receiver) has poor selectivity at 600 kc. and increasingly poorer selectivity at higher frequencies in the band.

If a T.R.F. receiver were designed for all-wave reception, it would be necessary to make provisions for changing every coil in the set each time the band* is changed. In a superheterodyne receiver, however, only the coils in one section (that which accepts the incoming carrier signal and converts it to a lower frequency) need be changed; for this reason every practical all-wave receiver is a superheterodyne. In addition, the gradually increasing public demand for high fidelity reception, which entails amplification of wide side bands over the entire range of carrier frequencies, is easier to meet with the fixed R.F. amplifiers used in supers. It is no wonder that the superheterodyne R.F. amplifier is the most widely used system today; only the compact and inexpensive small receivers occasionally are manufactured now with T.R.F. circuits.

REVIEW OF SUPERHETERODYNE PRINCIPLES

Before the fixed R.F. amplifier can do its job, the incoming signal with its picture or sound modulation must be converted to the frequency selected for the fixed R.F. amplifier. Here is how it is done. When two signals of different frequencies are mixed together, we still have the two signals, but when both are sent through a detector or demodulating tube circuit, the plate current will consist of many components; there will be signals at the two original frequencies, a signal whose frequency is the difference between the original frequencies, a signal whose frequency is the sum of the original frequencies and harmonics of all four of these frequencies, and each of these signal frequencies will carry the original modulation. By placing a resonant or tank circuit in the plate circuit of the detector, we can tune to any signal component and thus separate it from the others. Inasmuch as it is easier to make selective high-gain amplifiers for low R.F. values, the *difference* between the two original frequencies, known as the I.F. value, is always selected. The *resonant load in the plate circuit of the first detector* must be highly selective, so it will tune to the desired difference frequency or I.F. value (and its side frequencies) while rejecting all other frequencies.

The frequency conversion process in a superheterodyne receiver produces the I.F. carrier by combining the *incoming modulated R.F. carrier signal* and the *local R.F. oscillator signal*. If, for example, the incoming

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* The range of frequencies which can be covered by a given combination of a coil and a condenser when one of them is variable is called a *band*.

frequency is 1,000 kc. and the local R.F. oscillator signal frequency is 1,175 kc., the plate current of the detector circuit will contain these two frequencies, as well as 2,175 kc. (the sum frequency) and 175 kc. (the difference frequency); the 175 kc. frequency is here selected as the I.F. value. The following stage, called the I.F. amplifier, is designed to pass and amplify only this 175 kc. signal and such side frequencies as are required to give the desired fidelity characteristic to the receiver. When a 500 kc. signal is tuned in, a local oscillator signal of either 325 kc. or 675

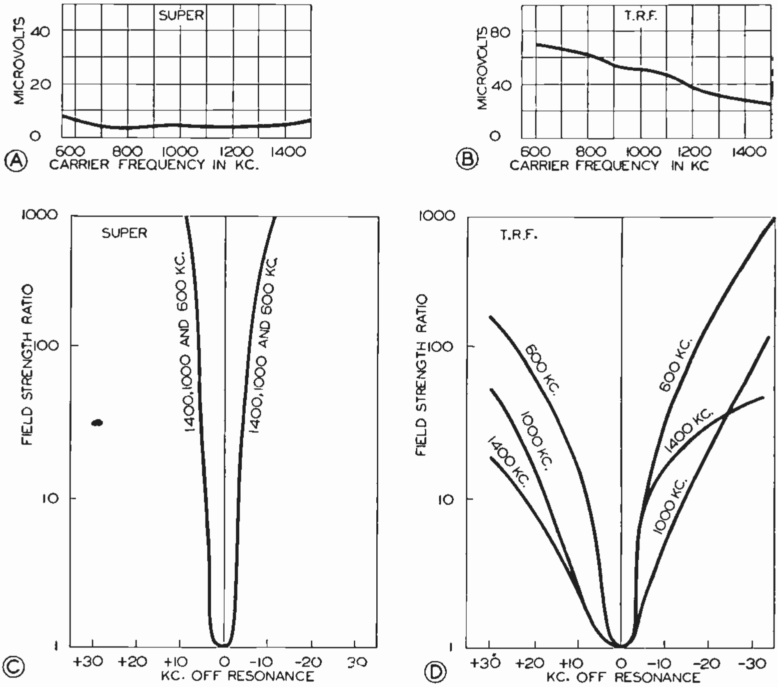


FIG. 1. These sensitivity and selectivity curves for a superheterodyne receiver and for a T.R.F. receiver having the same number of tubes show clearly the superiority of the superheterodyne circuit.

kc. will produce a frequency difference of 175 kc.; if the incoming signal is 1,500 kc., a local signal of either 1,675 kc. or 1,325 kc. will produce the required I.F. value. This brings up the question as to whether we should make the oscillator frequency lower or higher than the signal frequency.

Let us consider this problem for a receiver which is to tune from 500 kc. to 1,500 kc., with the I.F. at the fixed value of 175 kc. Clearly the local oscillator must vary in frequency either from 325 kc. to 1,325 kc. or from 675 kc. to 1,675 kc. In the first case (325 to 1,325) there is a 4 to 1 change from the highest to the lowest frequency and in the second case (675 to 1,675) a 2.5 to 1 change. From a practical point of view, it is difficult to tune a coil and condenser combination over a range having a frequency change which is greater than about 3.3 to 1; it is for this very practical reason that the local oscillator in a superheterodyne is generally made to produce a frequency *higher than that of the incoming signal.* In this example, then, the oscillator would vary in frequency from 675 kc. to 1,675 kc. as the receiver was tuned from 500 kc. to 1,500 kc.

Turning now to a block diagram of a superheterodyne type of R.F. amplifier (Fig. *2*), we find that there are four important sections: *1,* the preselector; *2,* the local oscillator; *3,* the mixer-first detector; and *4,* the I.F. amplifier. Before we study these sections in detail, let me point out the important functions of each.

Preselector. Strictly speaking, the preselector is nothing more than a number of resonant circuits which can be adjusted to the frequency of the desired R.F. signal; the preselector may or may not have R.F. amplifier stages. Theoretically, the preselector is not necessary in order to convert an R.F. signal to a lower frequency value, but if you omit the preselector, interfering signals will get into the mixer-first detector and

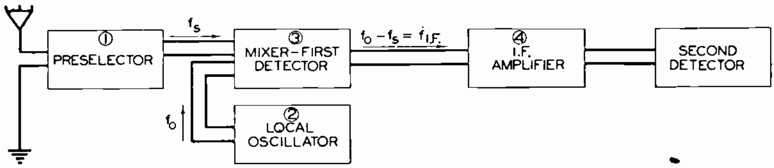


FIG. 2. Block diagram showing the four important sections of a superheterodyne R. F. amplifier circuit; the second detector and the stages following it are identical for T.R.F. receivers and superheterodyne receivers, and hence are not discussed in this book.

there react with each other or with the local oscillator signal to produce undesired signals at the I.F. value. Some gain (amplification) in the preselector is always desirable, because the mixer-first detector inherently creates noise which can be over-ridden only by a strong R.F. signal.

Local Oscillator. Frequency conversion cannot take place unless a local signal which differs from the incoming R.F. value by the I.F. value is produced. A local oscillator is therefore of fundamental importance in the superheterodyne circuit. The tuning condensers of preselector and oscillator can be controlled independently or ganged together and controlled by a common tuning dial; the latter practice is now universally followed, for with it the oscillator is always at the correct setting to deliver a signal differing from the incoming signal by the I.F. value. Ganging together the oscillator and preselector tuning condensers gives, in addition to single-dial tuning, the elimination of what is known as *repeat point reception.* Let me explain: With a separately tuned oscillator there would be two oscillator dial settings at which a station could be heard, one being higher and the other lower than the incoming signal but each differing from it by the I.F. value, and there would be one repeat point for each incoming signal.

Mixer-First Detector. This is the actual point of frequency conversion. Of great importance is the ability of this section to act as a detector for both the incoming and local oscillator signals, provided they are of reasonable intensity. Its plate circuit must contain a high L/C (high Q factor) tank circuit having a resonant frequency equal to the I.F. value (the difference frequency), so that the original signals, the sum frequency and all harmonics will be by-passed across the plate load.

I.F. Amplifier. Here the I.F. signal, modulated with the original pic-

Courtesy General Electric Co.

Superheterodyne receivers play an important part in the two-way police radio system at Schenectady, New York. The receiver is at the left on the table, and the transmitter is at the right.

ture or sound signal, gets its real boost in gain. The I.F. amplifier must be able to amplify the I.F. signal and some or all of the important side-band frequencies, depending upon the type of receiver performance desired. The I.F. amplifier can be made highly selective, cutting out undesirable signals as well as unimportant side-band frequencies of the radio signal being received, or can be made to have broad band-pass characteristics, passing a wide range of side frequencies; in the first case it is said to have good *adjacent channel selectivity,* and in the second case it has *high fidelity* response characteristics.

This "preview" of the action of a superheterodyne R.F. amplifier will be of great help as you study the details of each section, for the operation of one section may affect the operation of other sections. First we will consider the preselector.

IMPORTANCE OF THE PRESELECTOR

It is perfectly possible to impress a desired signal directly (without tuning) on the grid-cathode terminals of the mixer-first detector tube in a superheterodyne R.F. amplifier circuit and secure, with the aid of the local oscillator, a beat frequency output signal having the desired I.F. value. Of course this is never done in practice, but this condition is very nearly approached in some of the lower-priced superheterodyne receivers. By considering first the defects encountered in a theoretical direct input circuit (one having no preselector), we can learn a great deal about the importance of the preselector and the problems involved in its design.

Direct Input Circuit. The mixer-first detector section of a superheterodyne circuit which has no preselector is given in Fig. *3*; any signal f_s which is picked up by the antenna flows through resistor R to ground, and the R.F. voltage developed across this resistor is fed *directly* to the grid of the tube. The local oscillator feeds into the cathode circuit of the tube a signal which we will designate as f_o; assume that the frequency of this signal can be independently controlled by varying the setting of oscillator tank condenser C_o. The resonant circuit in the plate lead of the tube is adjusted to the desired I.F. value $f_{I.F.}$, so only the I.F. current produces a voltage drop across the I.F. resonant circuit for further amplification. For the present we need not consider any other parts or sections of this superheterodyne circuit.

Repeat Points (*Double Spot Tuning*). Assume that only one signal, having a frequency of 1,000 kc., is being picked up by the antenna in Fig. *3*, and that the I.F. resonant circuit is adjusted to an I.F. value of 100 kc. Under these conditions the required 100 kc. beat frequency $f_{I.F.}$ will be produced when the oscillator is tuned to 1,100 kc. But we can also secure this 100 kc. beat frequency by setting the oscillator to 900 kc.; thus there are two oscillator tuning dial settings at which the 100 kc. incoming signal will be passed on to the I.F. amplifier. This phenomenon is called *repeating* or *double spot tuning*, for we have *repeat points* on the oscillator tuning dial. These repeat points are present in any superheterodyne circuit *when the oscillator can be separately tuned*, even if resistor R is replaced with a highly selective preselector circuit; the *repeat point for any one station is always separated from the correct oscillator dial setting by twice the I.F. value.*

Service Hints. Superheterodynes having separately tuned oscillators have long been obsolete, but repeat point interference can also occur in a single-dial receiver if the selectivity of its preselector is too low or is impaired by a circuit defect or improper adjustment. You would hear a station at its correct dial setting and at a repeat point setting which will be *below* the correct dial frequency setting by twice the I.F. value (assuming that the oscillator tunes *above* the frequency of the incoming signal). If no circuit defect can be located, try shortening the antenna, especially in the case of a midget receiver.

Image Interference. From your own experience you know that signals of many different frequencies are always present in the antenna circuit of a receiver; let us, therefore, assume that in addition to the desired 1,000 kc. signal, there is an undesired 1,200 kc. signal in the antenna circuit of Fig. *3*. The oscillator is naturally set at 1,100 kc. in order to convert the desired signal to the I.F. value of 100 kc., but notice that the undesired 1,200 kc. signal can also mix with the 1,100 kc. oscillator signal and produce a 100 kc. beat frequency. In the case of a sound receiver, then, the listener will hear interference; the desired 1,000 kc. signal and the undesired 1,200 kc. signal will both get through the I.F. section and be reproduced by the loudspeaker. This condition, called *image interference,* occurs when an interfering signal whose frequency is above the desired signal *by twice the I.F. value* is heard along with the desired signal.

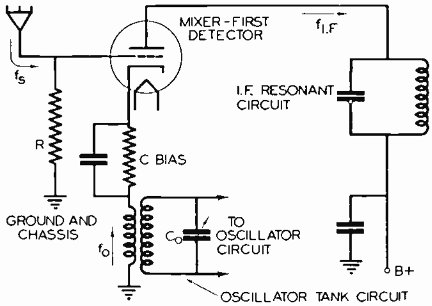


Fig. 3. Schematic diagram of the mixer-first detector section of an imaginary superheterodyne receiver which has no preselector.

Service Hints. Obviously a selective preselector is a cure for image interference trouble, for the preselector will then amplify only the desired signal, and will prevent the undesired signal from reaching the grid of the mixer-first detector tube. Realigning of the preselector should be tried if there are R. F. amplifier stages. Shortening the antenna is another remedy, for a very long antenna broadens the response characteristic of the first resonant circuit in the preselector, thus letting the undesired signal get through. If only one station is causing image interference, place in the antenna circuit a wave trap which is tuned to the frequency of this station.

The difference between repeat point reception and image interference is this: If you hear a station at a dial setting which is twice the I.F. value *below* the correct setting for that station, you are tuned to the *repeat point* of the station. If, however, there happens to be another station broadcasting on this repeat point frequency, you will hear both stations, and there is *image interference.*

Image Interference Ratio. The ideal preselector, which will allow only a single frequency or a narrow band of frequencies to pass and will absolutely reject all other frequencies, does not exist. An engineer is quite satisfied if he can design a preselector which *reduces* the strength of the interfering station (at the image frequency) 1,000 times;* this

* This ratio value must be considerably higher in receivers which have high gain I.F. amplifier sections; in all-wave receivers, however, ratios as low as 100 to 1 for the higher frequency bands are considered acceptable because of difficulties encountered in designing all-wave sets having better ratios.

number is called the *image interference ratio* and in this case means that the undesired image signal will be heard 1,000 times weaker than the desired signal.

Testing a Preselector. It is interesting to know how the engineer tests the effectiveness of a preselector. The receiver is tuned to a selected test frequency, a modulated R.F. signal generator is connected to the antenna and ground posts of the receiver and tuned to this same frequency, and an output meter is connected across the loudspeaker terminals. Readings are taken of the signal generator output voltage (some signal generators have a calibrated dial which indicates this voltage directly, while in others the output voltage must be measured with a meter) and of the output meter indication. The signal generator is now tuned to a frequency which is higher by twice the I.F. value of the set (the image frequency) and the output of the signal generator is raised until the output meter reading is the same as before. The signal generator output voltage at the image interference setting divided by its output voltage at the test frequency setting is the image interference ratio. This ratio tells how many times stronger the image signal must be in order to produce the same output as the desired signal.

Image interference is always a problem to a radio receiver designer; it often takes two or even three tuned circuits in cascade to get an image interference ratio of 1,000, and this naturally increases the cost of building the receiver. Special image-rejecting circuits have been developed, and an even simpler solution involves using a high I.F. value, somewhere between 250 and 500 kc.

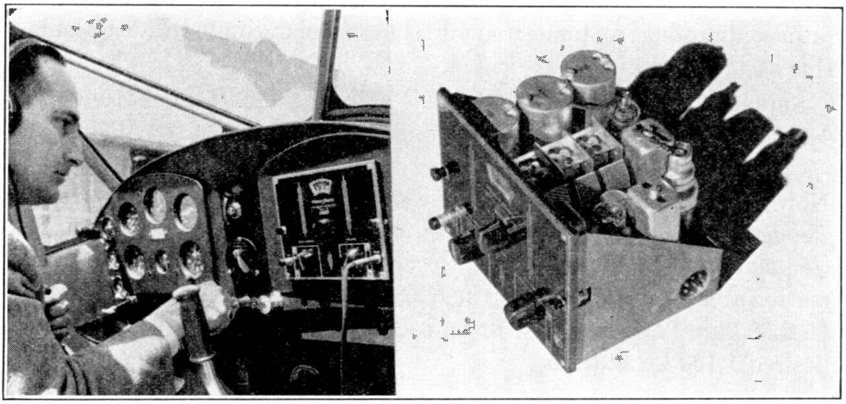
Let us see what advantage is secured by using a high I.F. value. Assume that a certain receiver which is tuned to a 1,000 kc. signal has an I.F. of 500 kc. The oscillator will therefore be at 1,500 kc., and the image interference frequency will be 2,000 kc. Only a simple preselector tuned to 1,000 kc. is here needed to reject the undesired 2,000 kc. signal, since the difference between the frequencies of desired and undesired signals is so great. Thus, superheterodynes having high I.F. values will have simple preselectors, while highly selective preselectors are imperative for sets with low I.F. values (values between about 135 kc. and 250 kc.) Local stations of image frequency are sometimes so powerful, however, that even an image interference ratio of 1,000 is insufficient to prevent interference.

Intermodulation Interference. When two undesired signals whose frequencies differ by exactly the I.F. value exist in the antenna circuit of Fig. *3,* they are fully capable of producing an I.F. beat without the aid of the local oscillator and causing what is known as *intermodulation* interference. Without a preselector, then, interference which sounds like garbled (unintelligible) speech would be heard at every dial setting. When a preselector is used, only those R.F. signals which get through the preselector can produce this trouble; two interfering stations, in addition to the desired station, must reach the mixer-first detector.

Service Hints. If garbled speech continues when you prevent generation of a local signal by touching the grid of the oscillator tube, intermodulation interference is present. Improving the selectivity of the preselector blocks out the interfering stations and thus eliminates the trouble. If this is impractical, try cutting out one of the interfering stations with a wave trap; try a shorter aerial; try changing the I.F. value of the receiver about 10 kc. (or to a value ending in 5).

Squeals Produced by Intermodulation. When conditions in a superheterodyne are such that *intermodulation* is present, a squeal which varies in pitch as the desired station is tuned in will be heard, this squeal sometimes becoming constant in pitch when the receiver is exactly tuned to the desired station. An example will illustrate how these squeals are produced.

Suppose that the receiver has an I.F. of 262 kc. and its preselector is so broad (has such poor selectivity) that when the receiver is tuned to a 1,000 kc. station an undesired signal at 1,160 kc. and one at 900 kc. will



Courtesy Western Electric Co.
Aviation depends upon superheterodyne receivers to guide planes accurately over desired routes and bring them down to earth safely regardless of weather conditions. The photo at the left shows a Western Electric superheterodyne receiver installed on the control panel of a Fairchild cabin plane. A close-up view of this receiver, removed from its housing, appears in the photo at the right. This receiver can be used either to pick up stations in the broadcast band for direction finding purposes or to pick up the aviation weather broadcast stations.

also pass through. These two undesired signals together produce an undesired R.F. beat frequency of 260 kc. and, since the station frequencies are constant, this beat frequency is constant, regardless of the tuning dial setting, as long as both undesired signals come through. Now as we "rock" (vary) the tuning dial a few kc. either way from 1,000 kc. in order to tune in the desired station properly, we are varying the local oscillator frequency from about 1,266 kc. to 1,262 kc. (the correct setting for a 1,000 kc. signal) to 1,258 kc. and back again, and the desired R.F. beat frequency will be varying from 266 kc. to 262 kc. (the correct value) to 258 kc. These frequencies, along with the undesired 260 kc. R. F. beat frequency, go straight through the I.F. amplifier section and react with each other at the second detector to produce an audio beat frequency which varies in pitch from 0 to 6,000 cycles and is heard in the loudspeaker as an annoying squeal. When the station is finally tuned in, the local oscillator will be at 262 kc., the undesired R.F. beat frequency will still be at 260 kc., and there will therefore be a 2 kc. squeal in the background of the desired program. This trouble is known as *intermodulation.* The cure is obviously the same as for cross-talk and image interference; the selectivity of the preselector must be improved.

Oscillator Harmonic Interference. We have assumed up to this time, and quite correctly for any well-designed receiver, that the local oscillator is feeding only its fundamental frequency of oscillation to the mixer-first detector. In many cases, especially where the oscillator and its coupling circuit are poorly designed, harmonics of the oscillator (usually only the second harmonic) may reach the mixer-first detector and react with an undesired incoming signal to produce an undesired I.F. beat signal; this condition is called *oscillator harmonic interference.* For each oscillator setting there may be two frequencies which incoming signals can have in order to beat with the second harmonic of the oscillator and produce an undesired I.F. signal. An example will explain how this occurs.

Suppose that a receiver which has a 260 kc. I.F. value is tuned to a 1,160 kc. station. The oscillator fundamental frequency will be 1,160 + 260, or 1,420 kc. and the second harmonic of this will be 2,840 kc. Now any signal which differs from 2,840 kc. by 260 kc. and which is strong enough to get through the preselector will produce an R.F. beat frequency which can cause interference. Thus either an aircraft radio station at a frequency of 3,100 kc. (2,840 + 260) or a commercial station on 2,580 kc. (2,840 — 260) or both could be heard on this set with the desired 1,160 kc. station.

You can identify oscillator harmonic interference by the fact that the frequency of the interfering signal is either above or below the second harmonic of the oscillator by the I.F. value (oscillator harmonics higher than the second are so weak that they can be neglected). The frequency difference between interfering and desired signals is so great in the case of harmonic interference that generally only strong local stations, such as local amateur, police, commercial or government code or phone stations, can ride through the preselector.

> *Service Hints.* Improving the selectivity of the preselector by realigning it to keep out the interfering signals, or adjusting the voltages of the oscillator to suppress its second harmonic are possible remedies for harmonic interference, but the installation of a wave trap which is tuned to the frequency of the offending station is the simplest cure. When the interfering signal is especially strong, it may be necessary to shield the mixer-first detector to prevent the signal from acting on it directly without going through the preselector and wave trap; a filter in the power line may also be needed.

Code Interference. One other trouble often experienced in superheterodynes is that where an undesired signal having a frequency equal to the I.F. value of the receiver gets through the preselector and is passed on by the mixer-first detector to the I.F. amplifier. Since most transmitters below 500 kc. (in the range of I.F. values) are code stations, this trouble is commonly referred to as code interference; it is heard at all points on the tuning dial, but is strongest at the lower frequency settings, around 550 kc.

Occasionally a condition will be found where the second harmonic of a powerful local long-wave transmitter is producing code interference; for example, if a receiver has an I.F. of 480 kc., a local 240 kc. station might be heard at all points on the tuning dial. This could be produced because the second harmonic of the 240 kc. carrier is getting through the preselector, but a more likely condition is that where the 240 kc. signal gets through the preselector and harmonics of it are created by the mixer-first detector tube because of its rectifying action; the second harmonic, being of the I.F. value and carrying the modulation of the

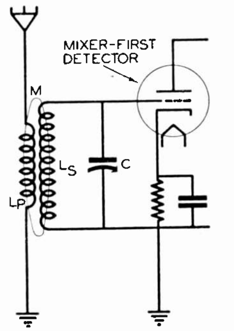


FIG. 4A. Simple tuned-secondary R.F. transformer type of preselector circuit.

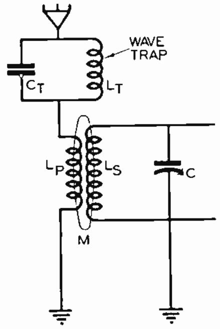


FIG. 4B. Simple preselector circuit with a wave trap.

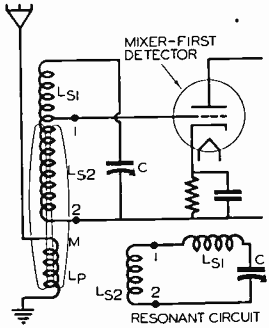


FIG. 4C. Image frequency suppression type of preselector circuit.

original code signal, would pass through the I.F. amplifier and produce interference.

> *Service Hints.* Code interference which is heard at all settings of the tuning dial can be eliminated by installing a wave trap which is tuned to the interfering code station, by shortening the antenna, or by changing the I.F. value of the receiver.

Practical Considerations. Bear in mind that the cures suggested are necessary because of the inability of the preselector in the receiver to keep out undesired signals. These cures were suggested only because the fundamental cure, redesigning the preselector for greater selectivity, costs more than the average set owner cares to pay.

PRESELECTOR CIRCUITS

Having studied the importance of the preselector, let us take up a few of the common preselector circuits.

Tuned-Secondary R.F. Transformer Circuit. The simplest of all preselectors is the tuned-secondary R.F. transformer shown in Fig. *4A;* it is often quite satisfactory in a receiver which uses a high I.F. value. The selectivity of this circuit is essentially dependent upon the mutual inductance *M* and upon the frequency of the desired incoming signal;

increasing either reduces selectivity. In a receiver which is to be used with a short antenna, the mutual inductance is usually made quite large in order that a strong input signal be obtained, but such a receiver tunes broadly (has poor selectivity) when coupled to a long antenna. Even with a high I.F. value, such a circuit will tune broadly at very high frequencies (around 20 megacycles); it is for this reason that all-wave receivers ordinarily require better preselector circuits than this.

Wave-Trap Circuit. A wave trap is often connected in series with the primary of the R.F. transformer, as shown in Fig. *4B*, in order to eliminate the interference caused by a particular station. Oscillatory (resonant) circuit C_T-L_T (Fig. *4B*) is the wave trap; it is tuned to the frequency of the interfering station by adjusting trimmer condenser C_T. (A similar trap can be inserted into the antenna lead of any radio receiver having image interference, harmonic interference, intermodulation or code interference troubles caused by one station.) The circuits shown in Figs. *4A* and *4B* are the basic preselector circuits; many variations of these are used in order to get greater selectivity and to get uniform sensitivity at all frequencies in the tuning band.

Image Frequency Suppression Circuit. Elimination of image interference is not highly successful with a simple preselector circuit when the receiver has a low I.F. value. Much better image frequency suppression can be secured with the circuit shown in Fig. *4C*, where the grid of the mixer-first detector tube is connected to a tap on a coil made up of two sections, L_{S1} and L_{S2}. The primary winding L_P is loosely coupled to the lower end of L_{S2}, so most of the magnetic flux set up by the primary acts only on L_{S2}, giving in effect the simple resonant circuit shown alongside Fig. *4C*. When C is tuned to the desired signal, a large tank current flows and an appreciable voltage for the mixer-first detector is developed between points *1* and *2*.

The action of this circuit on the undesired (image frequency) signal is as follows: L_{S1} and C together form a series resonant circuit which is equivalent to a short circuit across points *1* and *2* at resonance. The value of L_{S1} is so chosen that resonance will occur at the image frequency; the undesired image signal is thus shorted out by L_{S1} and C. This action can occur only at one image frequency for a particular value of L_{S1}; radio engineers usually design this circuit to give full image suppression at the midpoint of a tuning band (at 1,000 kc. for the broadcast band), but the selectivity of L_{S1}-C is so broad that there is effective image suppression to a lesser degree at other frequencies in the band.

It has often been suggested that condensers C_T and C in the circuit of Fig. *4B* be ganged together, so that wave-trap circuit C_T-L_T will automatically be tuned to the image frequency at each dial setting. This is quite possible, but such a procedure would only serve to suppress the image frequency; code interference and intermodulation interference could still get through the preselector.

Band-Pass Preselectors. In the three preselector circuits just considered, only one tuned circuit contributed to the selectivity of the receiver; an extra tuned circuit connected in cascade as shown in Figs. *5A, 5B* and *5C* will greatly improve the selectivity and consequently will reduce interference troubles; this extra circuit also permits adjustments which give band-pass characteristics to the preselector. The circuit shown in Fig. *5A* is simply the circuit of Fig. *4A* with an additional resonant circuit, made up of L_{S2} and C_2, mutually coupled inductively to L_{S1}. Figure *5B* shows two resonant circuits which are *directly* coupled inductively, with coil section L_{M2} common to both resonant circuits. Capacitive coupling is used in the circuit of Fig. *5C*, with condenser C_K common to both resonant circuits. For a fixed value of coupling, a single peak resonance characteristic is obtained when condensers C_1 and C_2 are tuned for maximum receiver output. Increasing the coupling between the resonant circuits or tuning C_1 above and C_2 below the reso-

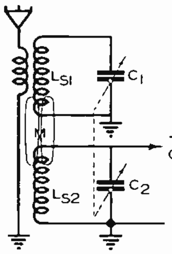


FIG. 5A. Band-pass preselector circuit with mutual inductance coupling. The dotted lines indicate that the two tuning condensers are ganged together to give a single-dial tuning control.

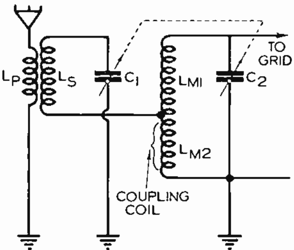


FIG. 5B. Band-pass preselector circuit with direct inductive coupling, coil section L_{M2} being common to both tank circuits.

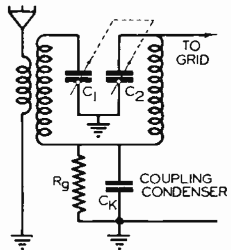


FIG. 5C. Band-pass preselector circuit with capacitive coupling. R_g is a .5 to 1.0 megohm resistor which provides a D.C. grid return path to ground for the application of the C bias.

nant frequency gives a flat or double peak response characteristic; when this is done, the circuits are referred to as *band-pass preselectors.*

Although band-pass preselectors are quite effective in eliminating or at least reducing the many types of interference troubles, they have one important drawback in that they reduce the strength of the incoming signal considerably. One way of overcoming this loss in signal strength is to step up the gain of the intermediate frequency (I.F.) amplifier section, but two undesirable effects, thermal agitation and converter noise, become annoying when this is done; let us consider them.

1. Thermal Agitation. Free electrons are moving around at random continually in any conductor, producing tiny pulses of electron current. In the coil of a resonant circuit these pulses of electron current are resonant amplified along with the signal currents. The effect of these pulses of electron current is commonly designated as *thermal agitation* of electrons; it is greatest for resonant circuits which have a high Q factor, which operate at a high temperature and which have a wide response characteristic. A hissing or frying noise which is heard in the loudspeaker and is especially loud when the receiver is tuned between stations is an indication that thermal agitation is present; because of this effect, the practical limit to the sensitivity of a receiver is about one microvolt (which means that the smallest signal voltage which can be made to give 50 milliwatts output to the loudspeaker is approximately one microvolt).

2. Converter Noise. Even more troublesome than thermal agitation is an effect which occurs in the mixer-first detector tube; electrons emitted by the cathode arrive at the plate in spurts or "shots," and the number of electrons making up the plate current varies from instant to instant. These variations are amplified by succeeding stages along with the desired signals, and are heard in the loudspeaker as a noise which sounds much like sand falling on a hollow tin barrel; the phenomenon is known either as the *shot effect,* as the *electron grain effect,* or as *frequency converter* noise.* Although the shot effect is present in practically all vacuum tubes, the variation in plate current due to it is ordinarily so small in comparison to the average plate current that the effect is negligible; in a tube which operates as a detector, however, the average plate current is so low because of the high negative C bias that the variations in current affect an appreciable part of the total plate current. Frequency converter noise is most noticeable when a receiver is tuned to a weak signal; strong signals tend to "drown out" or over-ride the noise. The strength of the signal fed to the input of the mixer-first detector must be large enough to make the signal-to-noise ratio at the output of this section as great as possible and thus minimize the effects of frequency converter noise.

It is highly desirable to have a stage or two of R.F. amplification ahead of the frequency converter section in order to build up the strength of the incoming signal so it will over-ride any converter noise which is present in the mixer-first detector tube. The greater the signal strength with respect to the noise, the less annoying will be the noise.

R.F. Amplified Type of Preselector. A widely used preselector circuit which contains a stage of R.F. amplification to increase the signal strength at the input to the mixer-first detector is shown in Fig. *6;* the amplification of this stage must be made high enough to eliminate frequency converter noise, yet not so high that it increases the total gain of the receiver to the point where thermal agitation effects in the R.F. antenna transformers will come through. The first resonant circuit, consisting of L_1 and C_1, is sometimes replaced by a band-pass resonant circuit of the form shown in Figs. *5A, 5B* and *5C,* or by an image suppression circuit like that in Fig. *4C* in order to increase further the image interference ratio.

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* The mixer-first detector and the local oscillator together constitute the frequency converter section.

THE LOCAL OSCILLATOR

Requirements of a Local Oscillator. If the local oscillator in a superheterodyne receiver is to perform its job satisfactorily, it must meet the following requirements: *1,* At any oscillator setting the frequency generated must be constant in value (there shall be very little *frequency drift*); *2,* the voltage which the local oscillator supplies to the mixer-first detector must be at least ten times *greater* than the voltage of the most powerful signal which is fed to the mixer-first detector by the preselector; *3,* the variation in oscillator voltage output shall be as small as possible as the frequency of the oscillator is changed by tuning; since absolute constancy is practically impossible, a maximum variation of 3 to 1 is considered by engineers to be satisfactory; *4,* the output of the oscillator shall have negligible harmonic content; *5,* the oscillator must not in itself radiate radio waves which would interfere with nearby

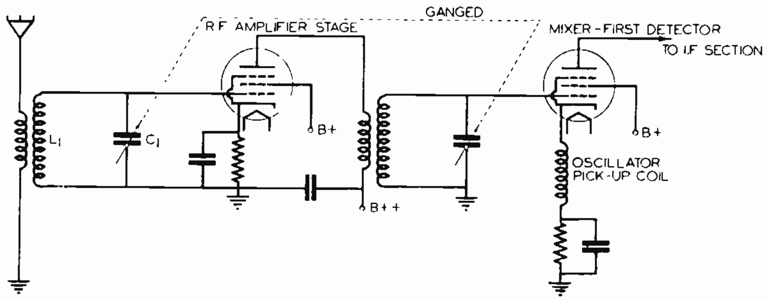

FIG. 6. A widely used preselector circuit, in which one stage of R.F. amplification boosts the strength of the incoming signal before it reaches the mixer-first detector. This additional amplification makes the desired incoming signal over-ride any noise which may be present in the mixer-first detector, and also lessens interference troubles.

receivers; *6,* the oscillator must be coupled to the mixer-first detector in such a way that the frequency of the oscillator is not affected by changes in other receiver circuits. The reasons for some of these practical requirements are important enough to warrant further explanation.

Oscillator Frequency Drift. Government laws stipulate that the frequency of a transmitting station shall not vary to any appreciable extent; the signal which the preselector handles is therefore quite constant in frequency. Any variations in the local oscillator frequency while the receiver is tuned to a station will therefore cause the beat frequency output of the first detector to vary in frequency, and the I.F. amplifier, if sharply tuned, will cut off varying amounts of side frequencies, resulting in distortion and weakened receiver output.

In an all-wave superheterodyne receiver, where the oscillator may be operating at frequencies above 20 megacycles, slight drifts in oscillator frequency become quite noticeable unless special precautions are taken. One precaution involves broadening of the response of the I.F. amplifier (with consequent loss in the adjacent channel selectivity of the receiver), while another, the most practical means of preventing distortion due to frequency drift, involves the use of an oscillator which does not vary appreciably in frequency at any setting. Good frequency stability is secured by using in the oscillator a tank circuit which has a high Q factor; in addition the tank circuit must not be overloaded either by the oscillator tube or by associated circuits. Other frequency stability requirements include constant D.C. supply voltages, the locating of all oscillator parts away from any sources of heat and the mounting of parts in such a way that they will not be set into vibration by the loudspeaker.

Oscillator Voltage Values. To understand why the voltage which the local oscillator feeds into the mixer-first detector must be at least ten times greater than the signal input voltage to the mixer-first detector, we must consider the action of the two types of first detectors (linear and square-law) which are commonly used in superheterodynes.

1. Square Law Type of First Detector. The incoming signal in a superheterodyne, as you know, consists of an R.F. carrier frequency and many R.F. side frequencies; each of these must beat with the local oscillator to produce, after detection, the desired I.F. carrier frequency and its side frequencies. When a square law type of first detector is used, *only* the original signal frequencies and the beat frequencies (the I.F. carrier and its side frequencies) are present in the output of the first detector, with the strength of the beat frequencies depending upon the *product* of the strengths of the local and incoming signals. (These statements are the result of a mathematical analysis of the problem.) The greater the voltage supplied by the local oscillator, then, the stronger will be the desired beat frequencies; this is why a ratio of at least 10 to 1 between the voltages which the oscillator and the preselector feed into the mixer-first detector is highly desirable.

2. Linear Type of Detector. When a linear first detector is used, mathematics and experimental tests show that maximum I.F. output is obtained when the two signals (incoming and local) which are fed to the mixer-first detector are equal in strength, but on the other hand, many harmonics of the beat (I.F.) frequency are produced with this method of detection. These harmonics, being two, three, four, etc. times the resonant frequency of the first detector plate load circuit, will, of course, be tuned out here, but they may still feed back into the input of the mixer-first detector (through the plate-to-grid capacity of the detector tube or through any stray coupling which may be present) and create annoying audio beat notes (squeals) when the preselector is set to tune in a station which has approximately the same frequency as one of these harmonics. Mathematics, the trusty tool of the radio engineer, again is called upon; this time it tells us that if either one of the signals which are fed into the mixer-first detector is many times stronger than the other, the harmonic frequencies associated with linear detection become negligible; a ratio of 10 to 1 has been found sufficient in actual practice. Since it is easier to control the local oscillator than the carrier signal input strength, it is customary to make the signal voltage which the local oscillator feeds into the mixer-first detector at least 10 times *greater* than the signal voltage fed into this section by the preselector *regardless of the type of first detector used.**

Summary. With both types of detectors, then, satisfactory performance is obtained when the local oscillator-preselector output voltage ratio is greater than 10 to 1; when this ratio is less than 10 to 1, there will be a lowering of receiver gain (but no other undesirable effects) in the case of a square law detector, and there will be an increase in receiver gain accompanied by annoying squeals in the case of a linear detector.

Variations in Oscillator Voltage. The requirement that the maximum oscillator output voltage shall not be more than three times the minimum voltage at any time is necessary in order to prevent what is known as *modulation distortion.* If the combined effect of local and incoming signals is sufficient to swing the grid of the first detector positive, the grid will draw electron current and load the mixer input circuit, cutting down the peaks of the incoming modulated signal and thus producing distortion. It is possible for a radio engineer to design a receiver which will keep the local signal at least ten times as strong as the incoming signal at the mixer and which will keep the sum of these signals low enough so the grid cannot swing positive provided that fluctuations in oscillator voltage do not exceed the 3 to 1 ratio.

Harmonics. The importance of preventing the local oscillator from feeding harmonics of its fundamental frequency to the mixer-first detector was considered earlier in this lesson, in connection with the study of harmonic interference.

Radiation. An oscillator needs only an antenna of some sort in order to become a midget radio transmitter; obviously it is the job of the radio engineer to see that such an antenna is not provided in a receiver. He does this by shielding the oscillator coil, circuit parts and circuit leads and by using by-pass condensers to prevent oscillator currents from leaking into any open wires which might serve as antennas.

Coupling. The mixer-first detector circuit is generally coupled to the tank coil of the local oscillator, this coupling being made in a manner which has a minimum effect upon the frequency of the oscillator.

TYPICAL OSCILLATOR CIRCUITS

Almost any oscillator circuit which has a fair degree of frequency stability will provide the local R.F. signal required in a superheterodyne receiver, but for practical reasons those circuits are used which require

* Since the incoming signal will vary considerably in strength if an R.F. amplifier stage is used in the preselector, it is important that when the first detector is of the linear type, an automatic volume control (AVC) circuit is used to reduce the gain of the R.F. amplifier on strong signals and thus keep the ratio of the mixer input voltages higher than 10 to 1 at all times. AVC circuits are taken up elsewhere in the Course.

only one variable condenser, and which permit grounding of the rotor of the variable condenser; it is also desirable to have a circuit in which there is no high D.C. voltage across the variable condenser. Tuned grid circuits are by far the more common, for they permit use of a high Q tank circuit and minimum loading, but the Hartley and dynatron oscillator circuits will occasionally be encountered by the Radio-Trician.

Tuned Grid Oscillators. Typical tuned grid oscillator circuits are shown in Figs. *7A* and *7B*; in each, the frequency of oscillation is controlled by the values of *L* and *C*. *L* is varied only when changing from one band to another, as in an all-wave receiver, but *C* is ganged to the preselector tuning condensers and is therefore varied each time a new station is tuned in. Notice that in each case the rotor of *C* is grounded;

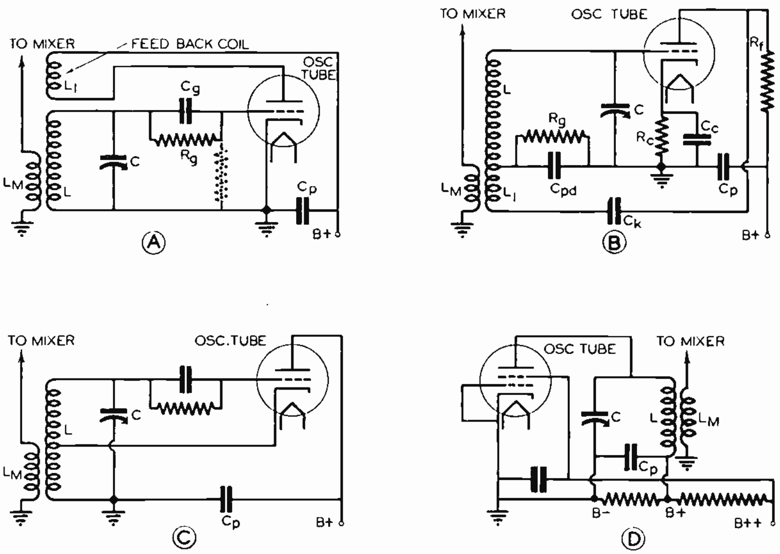

FIG. 7. Four typical oscillator circuits used in superheterodyne receivers.

this is done to simplify the construction of the ganged variable condenser of which *C* is one section.

The circuit in Fig. *7A* employs inductive or coil feed-back (coil L_1). Automatic C bias is provided by C_g and R_g (R_g will often be found connected between grid and cathode, as indicated by the dotted lines), while C_p is a by-pass condenser which keeps R.F. currents out of the plate supply source. Coil L_M, inductively coupled to oscillator tank coil *L*, is usually connected into the cathode lead of the mixer-first dectector tube.

In the circuit of Fig. *7B* the feed-back is still inductive in nature, but for convenience in manufacture coils *L* and L_1 have been combined into a single tapped coil. Resistor R_c and condenser C_c supply the customary form of automatic C bias. R_g and C_{pd} serve to increase the C bias when the oscillator tends to develop excess tank circuit power, as at the higher frequencies, thus serving to smooth out or equalize oscillator power variations; C_{pd} also serves as a padding condenser whose function will be considered later. This oscillator is shunt fed. R.F. current flows from the plate through condenser C_k, while by-pass condenser C_p and resistor R_f keep R.F. currents out of the plate supply.

Hartley Oscillator. The form of Hartley oscillator circuit where the plate is grounded (to permit grounding of the rotor of variable condenser C) is occasionally used in superheterodyne receivers; a typical circuit is given in Fig. *7C*. Condenser C_p here grounds the plate for R.F. currents. Automatic C bias is used; there is no D.C. voltage across the variable condenser.

Dynatron Oscillator. In the form of dynatron oscillator circuit shown in Fig. *7D* the variable condenser rotor is grounded. The screen grid is at a higher potential than the plate, an essential condition for dynatron operation. A fairly high D.C. voltage exists across the tuning condenser; the chief disadvantage of this is the fact that any one touching the condenser stator will get a shock.

THE MIXER-FIRST DETECTOR

The method used for mixing the output of the local oscillator with the

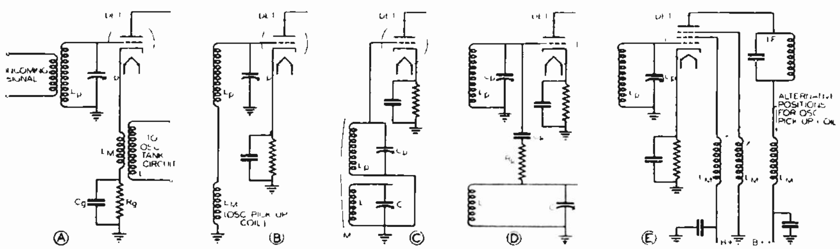

Fig. 8. Examples of different methods used for feeding the local oscillator signals into the mixer-first detector of a superheterodyne receiver. When L_M is shown, it is assumed to be coupled inductively to the oscillator tank circuit made up of L and C.

incoming signal is highly important, for this mixing must take place with a minimum of reaction on the oscillator. Examples of typical mixing circuits are given in Fig. *8*.

By far the most widely used mixer connection is that shown in Fig. *8A*, where the oscillator output coil L_M is connected into the cathode lead of the mixer-first detector tube. Both the incoming and the oscillator signal here act upon the control grid. The incoming signal acts directly upon the grid, changing its potential with respect to ground. The oscillator signal changes the potential of the cathode with respect to ground, and the oscillator voltage, together with the automatic C bias voltage furnished by R_g and C_g, thus act upon the grid in a conventional manner.

Another widely used mixer connection is that in Fig. *8B*, where oscillator pick-up coil L_M is in series with coil L_P (which feeds the incoming signal to the detector). The disadvantage of this circuit is that coil L_M

is a part of the mixer input resonant circuit, and changes in C_p as the set is tuned may affect the oscillator.

When individually shielded coils are not used, as was the practice some time ago, the oscillator tank coil L and the preselector tuning coil L_p can be mutually coupled as at Fig. *8C*, eliminating the need for coil L_M. Both oscillator and preselector tank circuit coils were then wound on the same form and both were often placed in a shielded housing or chassis to prevent radiation.

Capacitive-resistive coupling between a high R.F. potential point on oscillator tank coil L and the control grid of the mixer tube is occasionally used, the connections being as shown in Fig. *8D*. A small coupling capacity (from 10 to 100 mmfd.) is usually sufficient; resistor R_k, of high ohmic value, is placed in series with this capacity to help maintain a constant voltage feed of local signals to the mixer as the oscillator frequency is varied.

Coil L_M in the oscillator circuits of Figs. *7A* to *7D* can also be connected in either the screen grid, suppressor grid or plate lead if the mixer-first detector tube is a pentode; these three connections are indicated in Fig. *8E*. The plate lead connection is very rare, however, for changes in plate voltage which can ordinarily be produced by oscillators have relatively little effect upon plate current. These connections, often called electron-coupled methods of mixing, are used when a large oscillator output voltage is available. Harmonic I.F. feed-back is relatively unimportant as the plate-to-grid capacity of screen grid and pentode tubes is low; good shielding is, however, important.

A super control pentode tube is often used as a mixer-first detector, for it closely approximates a square law detector on weak signals, giving distortionless frequency conversion, and approximates a linear detector on large swings. It is necessary to use automatic volume control in order to make the operating point move automatically to a linear portion of the characteristic curve when a strong signal is tuned in; when this is done, strong signals cannot swing the grid positive. There is some generation of harmonics with linear operation, but this is considerably less than would occur with a tube acting as a pure linear detector at all times.

Combination Oscillator-Mixer-First Detector Circuits. The introduction of multigrid tubes permitted a single tube to serve the function of oscillator, electron mixer and first detector. The screen grid tetrode tube and the pentode tube were the first to be used for these combined functions.

A multi-function circuit using a pentode tube is shown in Fig. *9*; this circuit was widely used in midget superheterodyne receivers. The oscillator section of the circuit is of the Meissner type, with coil L, variable condenser C and padding condenser C_{pd} forming the oscillator tank circuit for tube VT. The plate of the tube is connected to (loaded by) the oscillator tank circuit L-C through two forms of coupling: *1, Inductive,* through the mutual inductance between coils L and L_1. (Condenser $C_{I.F.}$ has negligible reactance at the frequencies generated by the oscillator); *2, Capacitive,* through condenser C_{pd}, with the oscillator currents flowing from the plate through $C_{I.F.}$, L_1 and C_{pd} to ground. With this coupling arrangement the load on the oscillator tank coil is equalized over the entire band, resulting in more uniform oscillator output. Simultaneous feed-back of oscillator tank circuit voltage into the control grid circuit and mixing of the incoming and local signals are very ingeniously obtained simply by connecting feed-back coil L_M into the cathode circuit.

Having analyzed the oscillator and mixer functions of this circuit, we shall now see how it performs the duties of first detector. First of all, observe that the plate of the tube is fed (with D.C.) through coil L_p,

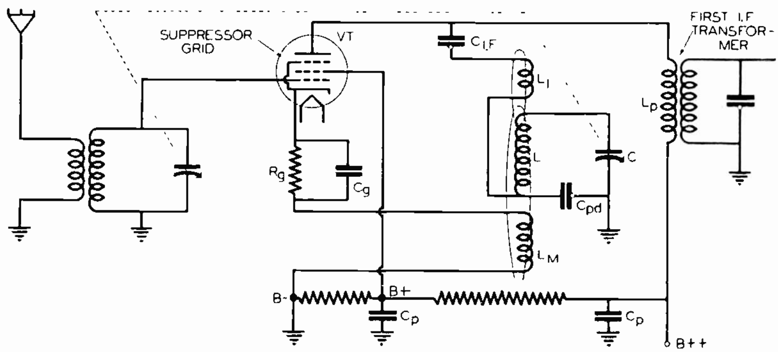

FIG. 9. Combination oscillator-mixer-first detector circuit using a pentode tube. If the suppressor grid is omitted, this circuit will apply to the screen grid tubes once widely used for the same purpose.

which serves as the primary of the first I.F. transformer and as the plate load coil for the first detector. The I.F. currents flowing out from the plate of tube VT thus flow through coil L_p and thence through by-pass condenser C_p to ground; in addition, I.F. currents flow through the path formed by $C_{I.F.}$, L_1 and C_{pd}. The reactance of L_1 to I.F. currents is negligible, so $C_{I.F.}$ and C_{pd} together act as the tuning system for coil L_p.

Automatic C bias is furnished by C_g and R_g, the value of R_g being carefully selected to make tube VT function as both oscillator and detector. Optimum operation as an oscillator is more important than as a detector, for the screen grid will block any harmonics which are the result of poor detection.

Servicing Hints. A tube may stop oscillating when emission weakens. A tube having a high g_m is almost imperative for good results. If you encounter a receiver having this circuit and it fails to work when all parts are in good condition, try lowering the value of R_g by about one-third; this will often allow the original tube and surely all other new tubes to oscillate. If R_g is reduced too much, however, frequency conversion will not take place.

Pentagrid Converter Tube. So much difficulty was experienced with screen grid and pentode tubes operating as combination oscillator-detectors that tube engineers developed a special tube which would permit independent biasing for optimum oscillator and optimum detector action. The pentagrid (five grid) tube was the result; since this tube provides all the functions of the frequency converter section, it is called a *pentagrid converter tube.*

A practical frequency converter circuit employing a pentagrid converter tube is shown in Fig. *10.* The oscillator triode section of the tube consists of the cathode, grid *1* (functioning as a control grid) and grid *2* (functioning as plate for the oscillator triode). Any desired form of oscillator circuit may be connected to these three electrodes; a standard tuned grid, plate coil feed-back oscillator circuit is shown. Coil L, condenser C (rotor grounded) and padding condenser C_{pd} constitute the tank circuit of the oscillator, while coil L_1 in the circuit of grid *2* (the oscillator plate circuit) feeds oscillator R.F. plate current back to the grid tank circuit to maintain oscillation. Condenser C_o and resistor R_o together provide automatic C bias for the oscillator; since this bias is applied directly between grid *1* and cathode, it is independent of the automatic C bias created by C_d and R_d for the first detector (this detector bias merely changes slightly the net plate voltage of the oscillator).

The action of the oscillator sets up, just beyond the second grid, an *electron cloud* which serves as the *virtual cathode* for the other tube elements. In the detector section of the tube, then, grid *4* acts as the control grid, grids *3* and *5* as a screen grid, and the plate performs its natural function. The C bias produced by R_d and C_d acts upon grid *4*, thus controlling the flow of electrons from the virtual cathode to the plate. The shielding action of grids *3* and *5* is only partially effective; it is therefore necessary to choose a detector plate load (I.F. transformer primary) which will prevent high feed-back voltages, in order to prevent I.F. harmonics and other undesired plate circuit signals from feeding back to grid *4* in the input circuit. Since the oscillator controls the number of electrons in the space cloud at any instant, this space cloud also provides electrons mixing. With oscillator and detector sections coupled together essentially only by the space cloud, it is possible to design the oscillator and detector sections of a pentagrid converter independently and secure optimum operation of each.

Disadvantages of Pentagrid Converter Tubes at Ultra High Frequencies. Although the pentagrid converter tube gives excellent results at broadcast band frequencies and at some of the higher frequencies, it is in general somewhat unsatisfactory at frequencies above about 10 megacycles. One reason for this is that despite the use of a screen grid, the oscillator section of the tube sets up a space charge which at high frequencies affects the input circuit (grid *4* in Fig. *10*) directly. At ultra high frequencies, the oscillator circuit will cause *regeneration* when tank circuit L-C-C_{pd} is tuned *below* the frequency of the incoming signal, and will cause *degeneration* when this circuit is tuned *above* the frequency of the incoming signal. Since the oscillator of a super is ordinarily tuned *above* the incoming signal frequency, degeneration and consequent loss in signal strength occurs in the high frequency band and at the higher frequencies in other bands. To avoid this degeneration, the manufacturers of some all-wave receivers make the oscillator tune below the incoming signal frequency on the highest frequency band.

Excessive oscillator frequency drift at frequencies above 10 megacycles is another trouble encountered in a pentagrid converter. The tank coil of the oscillator (L in Fig. *10*) is affected by the A.C. plate resistance of the oscillator section of the tube (the resistance between grid *2* and cathode, which is reflected back into the tank circuit through mutual inductance M). This resistance changes the oscillator frequency (as determined by the values of C, L and C_{pd}) a certain *fixed percentage* at all times; at low radio frequencies the error in oscillator frequency is so

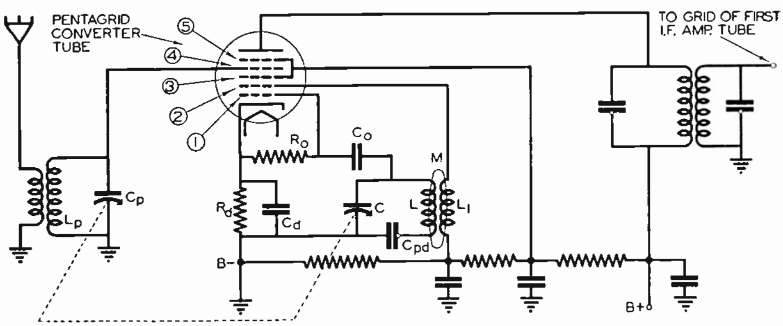

Fig. 10. A practical frequency converter circuit using a pentagrid converter tube.

small as to be negligible, but at high radio frequencies the error is larger. The variation is relatively unimportant, however, for if the preselector is a little broad, it is only necessary to change the tuning dial setting slightly to bring in the station satisfactorily. More serious trouble occurs because of variations in carrier intensity due to fading when distant stations are being received. In any oscillator, detector or combination oscillator-detector circuit the A.C. plate resistance of the tube will vary with carrier intensity because variations in the carrier cause variations in the average space current of the tube. This varying A.C. plate resistance causes oscillator frequency drift, which can be very severe at the higher frequencies. The I.F. beat will be shifting considerably from the correct I.F. value and there will be side-band cutting, with resulting distortion and loss in signal strength.

Here is an example: Suppose that a carrier of varying strength changes the A.C. plate resistance enough to cause a maximum error of 0.1% in oscillator frequency. At 1,000 kc. this percentage will give only a 1 kc. error in the I.F. beat, and the I.F. amplifier is almost always broad enough to offset such a small error. At 10 megacycles, however, this same percentage gives a 10 kc. error in the I.F. beat, and clearly there will be severe cutting of side bands; if the I.F. amplifier is highly selective, the signal may even fade out entirely unless the receiver is retuned.

Pentagrid Mixer-First Detector Tube. To overcome the inherent shortcomings of the pentagrid converter at high frequencies, engineers designed a special pentagrid mixer-first detector tube which has a *mixer* or *injector* grid. When used with a separate oscillator tube, this *pentagrid mixer-first detector tube* is a better frequency converter because it has *negligible frequency drift* and *negligible degeneration,* even at the ultra high frequencies encountered in television receivers.

A practical circuit using this new tube and capable of giving excellent frequency converter action at ultra high frequencies is shown in Fig. *11.* Tube VT is the special pentagrid mixer-first detector tube, with the mixer grid shielded from the effects of first detector circuit by a grid on each side; tube VT_1 is an ordinary triode tube connected into a conventional tuned grid oscillator whose tank circuit consists of L, C and C_{pd}. Condenser C_M provides capacitive coupling between the oscillator tank circuit and the mixer grid of VT. The stability of the oscillator is here dependent only upon the design and construction of the oscillator stage and there can be no feed-back of oscillator current to the preselector (the L_p-C_p tank circuit). Even though VT has five grids, its action is quite simple. Grids *2* and *4* are simply shielding grids for mixer grid *3,* while grid *5* is a suppressor grid. This leaves grid *1* as the control grid for the first detector; it feeds the incoming signal to the tube. Grid *3* is the point where mixing takes place, for it introduces (injects) the oscillator signal into the plate current.

Frequency Converter Ratings. When discussing the relative merits of different frequency converter systems, engineers have need for what might be called a "yardstick of comparison." What they really want to know is how well a frequency converter will change an R.F. signal voltage into an I.F. signal voltage—they want to know frequency converter *gain.*

The important factor in determining the gain is the *translation conductance* of the frequency converter; it is equal to I.F. plate current i_p divided by R.F. input voltage e_g and is designated by the symbol S_c. Knowing S_c, the gain of a frequency converter can be found by multiplying the value of S_c *in mhos* by the A.C. plate load impedance in ohms of the first detector circuit. For example, a 6A7 tube used with a reasonably powerful oscillator circuit will have a translation conductance of somewhere between 350 and 520 micromhos at ordinary frequencies, but this value will be greatly reduced at ultra high frequencies. A 6L7 pentagrid mixer-first detector used with a separate oscillator tube as in Fig. *11* will have a translation conductance of about 475 micromhos, this value changing little even at high frequencies. A commonly used value for the

A.C. plate load impedance is 100,000 ohms; if we have a converter with an S_c of 400 micromhos (.0004 mhos) and this load, its gain will be .0004 x 100,000, or 40.

OSCILLATOR-PRESELECTOR TRACKING

Ganging of the preselector and the oscillator tuning condensers simplifies tuning of a receiver and eliminates repeat points, but new adjustment problems are introduced when we attempt to make the oscillator operate above the frequency of the incoming signal by exactly the I.F. value at all times. The oscillator must follow or "track" the preselector, hence we call the alignment of the oscillator and preselector circuits a *tracking adjustment.*

Let us first see why tracking adjustments are necessary. Turning to Fig. *12A*, which shows both the preselector and oscillator tuning circuits,

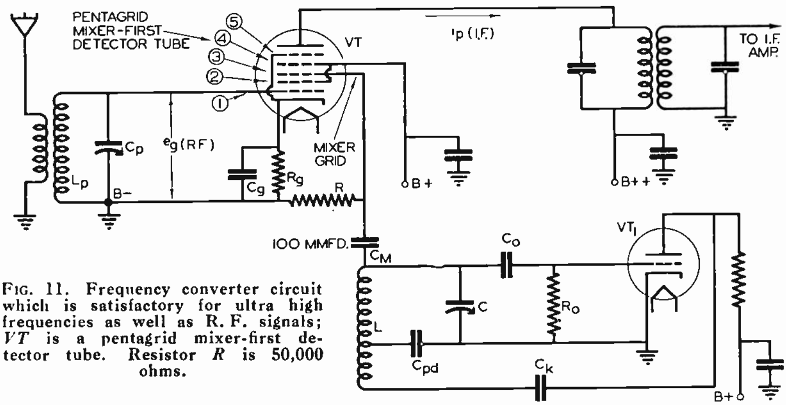

FIG. 11. Frequency converter circuit which is satisfactory for ultra high frequencies as well as R. F. signals; *VT* is a pentagrid mixer-first detector tube. Resistor *R* is 50,000 ohms.

assume that the tuning condensers are set to minimum capacity, that L_p is exactly like L_o, and that C_p is exactly like C_o. Obviously, both circuits will now have the same resonant frequency. Since the oscillator circuit must tune to a higher frequency, the electrical value of either L_o or C_o must be reduced. It is not easy to reduce C_o, its minimum capacity being essentially due to stray capacities between rotor and stator plates, so L_o must be replaced with a coil having enough less turns to make the oscillator tune above the preselector by exactly the I.F. value when both condensers are at *minimum-capacity* positions. But now, when we set both condensers to their *maximum-capacity* values, we find that the oscillator is no longer exactly the I.F. value higher than the preselector (the reason is that at lower frequencies you have to remove more turns from the coil to get a definite frequency difference).

Curves *1* and *2* in Fig. *12B* show how the resonant frequencies of the oscillator and preselector circuits vary as the tuning dial (to which both condensers are ganged) is rotated from 0 to 100 (0 corresponding to the maximum and 100 to the minimum capacity of the tuning condensers); notice how the I.F. beat frequency varies as the dial setting is changed. There is need for an adjustment of some sort which will keep the beat frequency constant. We cannot reduce the number of turns on the oscillator coil, for the coil is correct as it now is for the high frequency setting. Clearly, then, it is necessary to reduce the capacity of C_o for low frequency settings.

A constant beat frequency over the entire tuning range can be obtained by giving the oscillator rotor plates a different shape from those of the preselector. The exact shape required can be figured out by mathematics, but the general shapes will resemble those shown in Fig. *12C*. Notice that as the frequency is lowered (by increasing the capacity), the

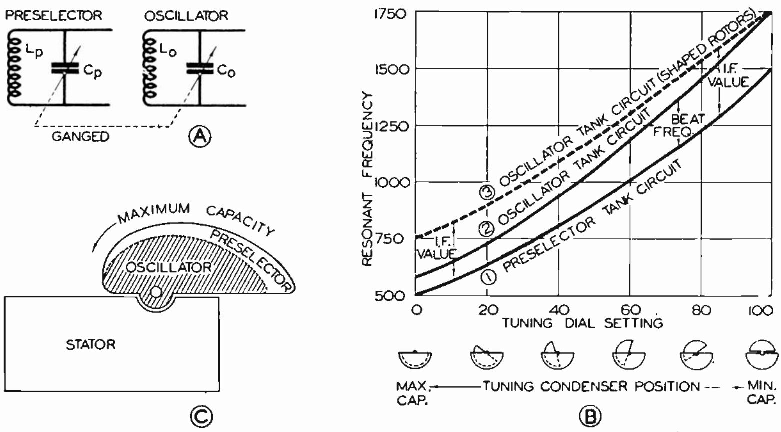

FIG. 12. Preselector-oscillator tracking adjustments are necessary because the resonant frequencies of the two tank circuits (at *A*) do not differ by the same amount (the I.F. value) at each tuning dial setting. The discrepancy is shown by curves *1* and *2* (at *B*); curves *1* and *3* show the ideal relationship, which can be secured if the rotor plates of the tuning condensers are specially shaped as at *C*.

oscillator condenser increases less in capacity than the preselector. Thus we obtain the results represented by curves *1* and *3* in Fig. *12B*.

Condensers having specially cut rotor plates are expensive to build and are good only for one particular model of receiver; they are clearly out of question for all-wave receivers, for here a different shape of rotor would be required for each band. For these reasons modern receivers are being built with ganged tuning condensers having all sections alike, and two trimmer condensers, known as the low frequency padder and the high frequency trimmer, are adjusted to make the preselector and the oscillator track each other. Cut rotor plates are used extensively in auto radio receivers, however, in order to keep down to a minimum the number of trimmer condensers which might get out of adjustment because of vibration.

Low Frequency Padder Condenser. When ganged tuning condensers are used, the oscillator condenser will have too high a capacity when its plates are completely meshed. (Remember that the oscillator coil has less inductance than the preselector coil.) This capacity can be lowered by inserting in the tank circuit, in series with C_o, a trimmer type of variable condenser which is called a *low frequency padder,* a *padder* or sometimes a *lag condenser.* This padding condenser can be adjusted to lower the tank circuit capacity just enough to give perfect alignment at the 0 (lowest frequency) point on the dial. The padding condenser shown as C_{pd} in Fig. *13A* (and also in Figs. *9, 10* and *11*) is considerably higher in capacity than the maximum capacity of C_o, so that its reactance is almost negligible (it acts as a short circuit) at the 100 or high frequency setting of the dial.

High Frequency Trimmer Condenser. We have assumed thus far that the exact I.F. value was produced at the 100 or minimum capacity setting, but this seldom is the case in actual practice because even with mass production methods it is difficult to make coils and condensers with exactly the desired electrical values. Manufacturers of superheterodynes compensate for these errors by placing a small trimmer condenser

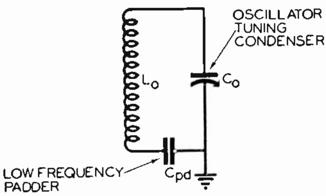

FIG. 13A. The low frequency tracking adjustment is here made by adjusting padder condenser C_{pd}.

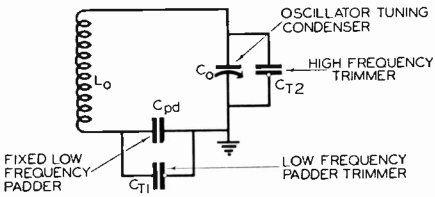

FIG. 13B. Two trimmer condensers are provided here for tracking adjustments; the padder trimmer is shunted by a fixed condenser.

(called the *high frequency trimmer condenser*) in parallel with the oscillator tuning condenser. This, as well as the padder, must be adjusted to make the receiver function properly; let us now consider how these tracking adjustments are made in a modern superheterodyne receiver.

An oscillator tank circuit which is widely used in superheterodyne receivers is given in Fig. *13B*, each condenser being identified. The low frequency padder is here made up of a fixed condenser in parallel with a trimmer condenser; this procedure is quite common in actual practice, for the low frequency padder ordinarily requires only a small variation in a high value of capacity. In order to make this practical oscillator circuit track its preselector, the following adjustments are made:

Assuming that the receiver is to be aligned for the 550-1,500 kc. broadcast band, feed into the preselector input a 1,000 kc. signal (supplied by a signal generator) and set the receiver tuning dial to its 1,000 kc. division. Adjust the low frequency padder (by adjusting low frequency padder trimmer C_{T1}) for maximum receiver output; now you are getting exactly the correct I.F. beat for mid-dial settings. Change the signal input frequency to 1,400 kc., set the receiver dial at 1,400 kc. and now adjust high frequency trimmer C_{T2} for maximum receiver output. If there are two positions of C_{T2} for which maximum output is obtained, choose the one at which C_{T2} has minimum capacity; the other position is a repeat point. Now change the signal input frequency and the dial setting to 600 kc. and readjust the low frequency padder for maximum output. It is often necessary to repeat the adjustments at 1,400 kc. and at 600 kc., since one trimmer has a slight effect upon the other.

These alignment instructions apply to any other frequency band as well. High, medium and low frequencies in each band are selected; the high frequency trimmer and the low frequency padder must then be adjusted to make the preselector and the oscillator track each other. The low frequency padder is always adjusted for the low and mid-scale frequencies, while the high frequency trimmer is adjusted at the high frequency setting. This procedure is called a *three-point track alignment adjustment;* it makes the I.F. value correct for three points, insuring that the I.F. beat will not be off an appreciable amount at other dial settings.

ALL-WAVE SUPERHETERODYNE RECEIVERS

Number of Bands Required. An all-wave superheterodyne receiver differs essentially from a broadcast band superheterodyne receiver only in that the all-wave receiver has one or more extra preselector and oscillator tuning circuits. Since it is difficult to tune a preselector and an oscillator over a range having a frequency ratio greater than about 3.3 to 1, it is necessary to use a new set of coils in the preselector and oscillator circuits for each band of frequencies. If the broadcast band coils for a receiver cover the range from 540 kc. to 1,780 kc. (1,780 being 3.3 times 540), the next band will extend from 1,780 kc. to 5,800 kc. (3.3 x 1,780) and band number 3 will extend from 5,800 kc. to 19,100 kc., these values being approximate. In order to secure this 3.3 to 1 range in each band, the variable condensers must have a low minimum capacity, stray lead connection capacity must be very low, and the coils must have a very low distributed capacity. When these requirements cannot be met because of chassis layout and design problems, or when it is desired to cover all frequencies from 540 kc. to about 22,000 kc., it is necessary to divide the entire frequency range into four bands and use four sets of coils.

Band Changing by Switching Series Coils. Changing the number of coil turns or the number of coils connected together in series is one way of changing the frequency range of a resonant circuit; Fig. *14* illustrates how this is done in one practical four-band superheterodyne receiver. The four preselector coils are connected together in series, as also are the oscillator coils; when the band-change switches (operated by a single control knob) are set to band *1,* only the uppermost coil is in each resonant circuit. Switching to band *2* adds another coil to each resonant circuit, and all four coils are used on band *4* (which ordinarily would be the broadcast band). Notice that a different low frequency padder (x) is used in the oscillator tank circuit for each band. Only one high frequency trimmer is used, this being adjusted for the broadcast band; the preselector circuits must therefore be quite broad to compensate for poor tracking in other bands. Another undesirable feature of this series switching arrangement is the fact that the unused coils may absorb energy, making it necessary to use a special band-change switch which either disconnects or shorts out the unused coils.

Band Changing by Switching Shunt Coils. Band changing can also be accomplished by adding coils in parallel; Fig. *15* shows how this is done for a two-band receiver. Each oscillator coil has its own padder or lag condenser to insure good low frequency tracking; a trimmer condenser

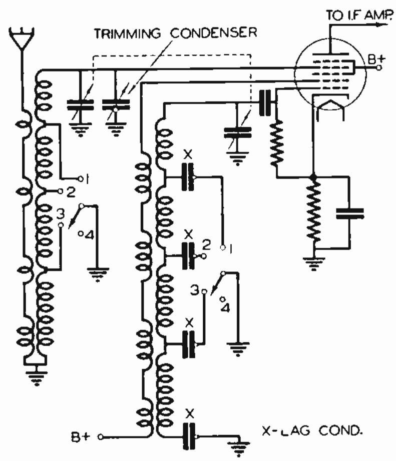

Fig. 14. Preselector and frequency converter circuits of a four-band superheterodyne receiver which employs series coil switching.

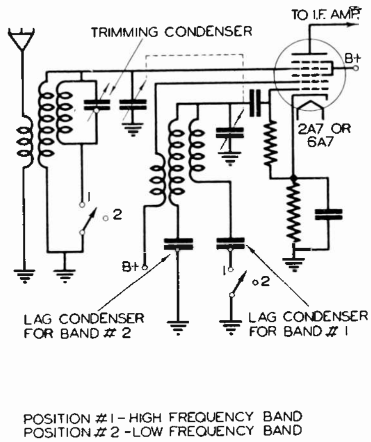

Fig. 15. Preselector and frequency converter circuits of a two band superheterodyne employing shunt coil switching.

is used across one preselector coil to permit changing the minimum frequency of the highest frequency band (band *1*). Unused coils can still absorb energy in this circuit.

Quite often only one oscillator coil is used in two-band receivers, a harmonic of the oscillator being used for the higher frequency band. For example, if the oscillator range for the 550-1,500 kc. broadcast band of a receiver having a 460 kc. I.F. value is 1,010 kc. to 1,960 kc., the second harmonic of the oscillator will vary from 2,020 kc. to 3,920 kc., the correct variation for the 1,560 kc. to 2,460 kc. band. In this case band-changing is accomplished simply by tapping the preselector coil.

Band Changing by Switching Complete Coils. Although the band-changing circuits shown in Figs. *14* and *15* have been used in lower-priced receivers, these systems have a very serious drawback. High frequency trimmer condensers cannot be used in the oscillator circuits (unless a complicated trimmer switching mechanism is provided), for these trimmers would cause even more serious absorption by unused coils and would make it very difficult to align each band independently. A more practical and more widely used circuit is shown in Fig. *16* as applied to a four-band receiver; for each band there is a separate preselector coil with its high frequency trimmer C and a separate oscillator coil with its high frequency trimmer C and low frequency padder X, the change from one band to another being accomplished by a four-section (four-deck), four-point rotary switch. Since image interference is most objectionable in the broadcast band, an extra tuning circuit is inserted between the antenna and the main preselector when the band-change switch is at position *4*. With complete coils being switched, each band is electrically independent of the others and maximum operating efficiency is attained.

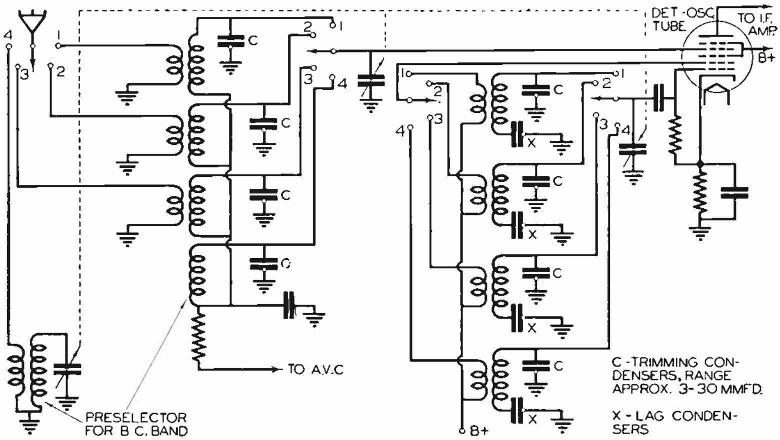

FIG. 16. Preselector and frequency converter circuits of a four-band superheterodyne receiver in which band changing is accomplished by switching complete coils. One extra tuned circuit is used in the broadcast band (band-change switch set to No. 4) to give additional suppression of image interference.

An all-wave receiver circuit containing R.F. amplifier stages in the preselector is shown in Fig. *17;* this arrangement gives better image rejection and improves the signal-to-noise ratio, thus lessening the effects of converter noise. Observe that one R.F. amplifier stage is used for the lower frequency bands (*2*, *3* and *4*) but two stages are used for band *1* to offset the reduction in the sensitivity and selectivity of the receiver at high frequencies.

Thus you can see that all-wave superheterodynes differ from broadcast band superheterodynes only in the sections ahead of the mixer-first detector. All-wave receiver circuits may appear complicated at first glance because of the band-changing switch and the extra parts, but connections are quite easily traced if only one band is considered at a time. Various methods for shorting unused coils will be found; these often seem to complicate preselector circuit diagrams.

THE I.F. AMPLIFIER

Most of the gain in a superheterodyne receiver is furnished by the I.F. amplifier; in fact, the very purpose of frequency conversion is to permit this section of the super to do its work. The *I.F. amplifier* also contributes most of the *adjacent channel selectivity;* that is, if the I.F. amplifier is designed to pass all frequencies (the side-band frequencies) 5 kilocycles above and below the I.F. value, all stations producing I.F. beats which are outside this range will be tuned out or rejected.

Choosing the I.F. Value. The receiver designer considers many things when choosing the I.F. value for a receiver. He knows that low I.F.

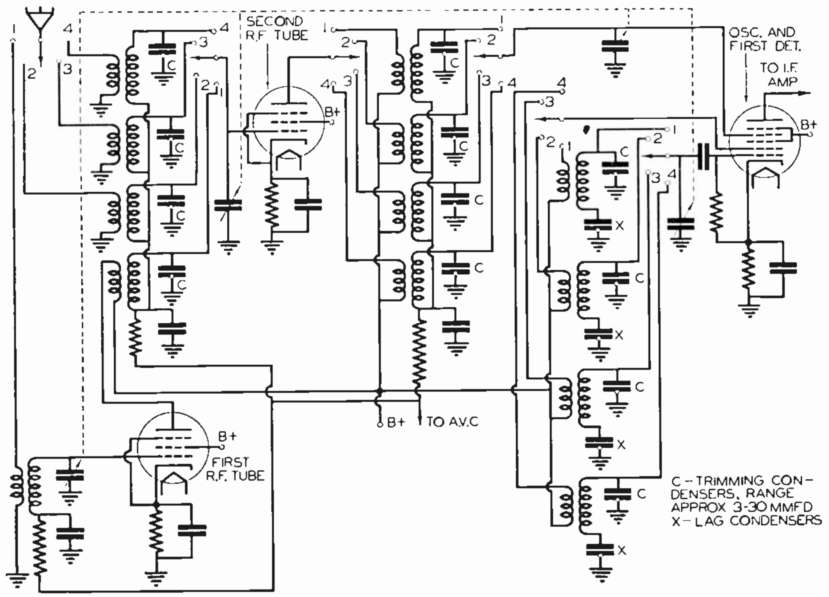

FIG. 17. The preselector in this all-wave superheterodyne circuit uses two stages of R.F. amplification for the highest frequency band (band-change switch set to No. 1) and one stage for all other bands.

values permit high I.F. gain and high selectivity, but require good preselector circuits; likewise he realizes that he can use a simple preselector if the I.F. value is high, and can get reasonable gain by using coils which have the new pulverized iron cores. A high I.F. value is required if a wide band of side frequencies is to be passed; for a 10 kc. band width, the I.F. should be at least 175 kc., and for a 20 kc. band width the I.F. value should be about 460 kc. The 6,000 kc. band width used in television may require an I.F. value of at least 15,000 kc. The I.F. amplifier should always be a little broader than is theoretically required, in order to take care of oscillator frequency drift; this is particularly important in all-wave and television receivers.

For all-wave receivers, therefore, an I.F. value which is at least 50 kc.

off from any of the incoming signals is recommended; I.F. values of about 480 kc. are very widely used in all-wave supers.

Should I.F. Values End in 5? Before the advent of screen grid first detector tubes, it was common practice to choose an I.F. value which ended in 5, such as 175 kc., 265 kc., 465 kc., etc. Harmonics of the I.F. signal, feeding back to the preselector (through the grid-to-plate capacity of the mixer-first detector tube), produce very annoying squeals when stations having the same frequencies as these harmonics are tuned in.*

In the United States most stations in the broadcast band have frequencies ending in 10, such as 960 kc., 1,440 kc., etc.; by making the I.F. value end in 5, only its even harmonics can end in 10 and be equal to a broadcast frequency. For example, the harmonics of a 175 kc. I.F. are 350, 525, 700, 875, 1,050, 1,225, 1,400, etc., of which 700, 1,050 and 1,400 represent station frequencies in the broadcast band; the harmonics of a 180 kc. I.F. are 360, 540, 720, 900, 1,080, 1,260 and 1,440, with all but the first value equal to broadcast station frequencies. An I.F. value ending in 5 thus gives only half as many squeal-producing points on the dial as an I.F. value ending in 10. In the better modern supers, where screen grid tubes eliminate feed-back to the preselector, an I.F. value ending in 5 is preferred (to lessen the effects of any stray feed-back paths) but is not absolutely necessary. The higher the I.F. value, the fewer I.F. harmonics there will be in any one preselector range, especially in the broadcast band.

Typical I.F. Amplifier Circuits. The most widely used I.F. amplifier is the twin resonant circuit shown in Fig. *18A*. When C_1 and C_2, the trimmer condensers, are tuned for maximum receiver output, a highly selective (sharp resonance curve) amplifier is obtained; when C_1 is tuned below and C_2 above the I.F. value, a rounded or even a double peak response characteristic curve is obtained, but the gain is reduced considerably. In the latter case the mutual inductance M must be of the correct value for band-pass results, a job for the designer. Wider band width can be obtained by shunting one of the coils with a 10,000 to 100,000 ohm resistor, but this gives even further reduction in gain.

In any I.F. amplifier, the I.F. transformer in the plate circuit of the mixer-first detector must be extremely selective in order to short circuit the harmonics which are produced by detection and which might other-

* For example, with an I. F. value of 175 kc., the fourth harmonic of the I.F. signal will be 700 kc. When a 700 kc. station is being tuned in, the I.F. signal will be varied from about 174 kc. to 176 kc., in order to locate the correct dial setting, and the fourth harmonic, varying from 696 kc. to 704 kc., will beat with the 700 kc. carrier to produce an audio squeal frequency which will modulate the 700 kc. signal and, after frequency conversion, ride through the I.F. amplifier.

wise react with the detector input. In addition, the coupling between transformer coils must be loose; a copper screen is often placed between the two coils to reduce the coupling.

Where high I.F. gain is desired with a minimum number of circuit parts, a single tuned I.F. circuit like that in Fig. *18B* is used. Trimmer condenser C_1 may be placed across either L_1 or L_2. You will encounter this circuit most often in midget supers.

High Fidelity I.F. Amplifiers. In a high fidelity receiver the resonance curves of the I.F. amplifier must be practically flat over the entire band of frequencies being transmitted, for this section provides most of the gain of the receiver; other sections of the receiver must likewise pass all side frequencies without excessive attenuation (unless defects in one section are compensated for by a correction in another section). Thus, if all frequencies up to 8,500 cycles are desired, the I.F. amplifier must have a band width of 17 kc.

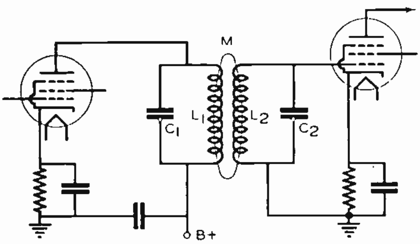

FIG. 18A. Band-pass I.F. amplifier circuit.

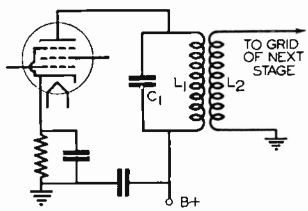

Fig. 18B. Single-tuned I.F. amplifier circuit.

Variable Selectivity I.F. Amplifiers. High fidelity receivers perform beautifully when tuned to strong local stations, but often give squeals and garbled speech (sometimes called "monkey chatter") when tuned to distant stations. This is because the response of the receiver is sufficiently broad that the carrier or side frequencies of an adjacent channel station can interfere with the desired carrier. The remedy obviously is a control which will permit the listener to choose between high selectivity and high fidelity (poor selectivity) characteristics. Three commonly used methods for obtaining variable selectivity in a superheterodyne are given in Fig. *19;* each of these provides a continuously variable control, which allows the listener to reduce the fidelity just enough to stop the interference.

In the circuit of Fig *19A* the selectivity is changed by varying the mutual inductance M of the I.F. transformer, the spacing between coils L_1 and L_2 being varied by mechanical means. With this arrangement the trimmers are adjusted for peak response when M is a minimum (weak coupling) ; now when M is increased, the peak of the response curve flattens out, becoming flat or perhaps even double-humped. Increasing M has the effect of introducing capacity into one circuit while adding inductance to the other, which is exactly what is needed to get double peak response.

Another scheme, which has the effect of shunting each resonant circuit with a resistance, is shown in Fig. *19B;* this employs a third winding shunted by a variable resistor (R). The two resonant circuits are originally adjusted for peak response when R has a maximum resistance; reducing R then widens the response curve, giving high fidelity.

A third method, shown in Fig. *19C,* employs a third winding L_3 which is connected in series with condenser C_3 and rheostat R. Resonant circuits C_1-L_1, C_2-L_2 and C_3-L_3 are tuned for maximum receiver output when R is set to zero resistance; under these conditions circuit C_3-L_3 merely absorbs energy from one circuit and passes it on to the other. As the ohmic value of R is increased, circuit L_3-C_3 absorbs energy; since all three coils are critically coupled, the other circuits are effectively loaded with resistance, reducing the selectivity and gain, and thereby broadening the over-all response.

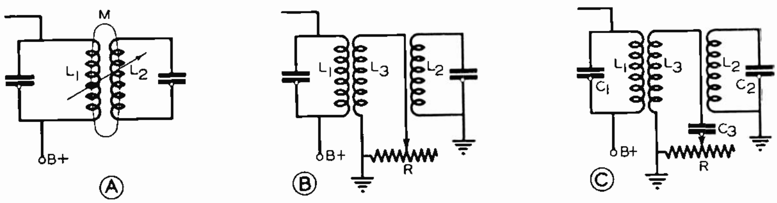

FIG. 19. Three methods of securing continuously variable control of the selectivity of the I.F. stages of a superheterodyne receiver are shown here. Although only one I.F. transformer is shown, each I.F. transformer in a receiver may be identically treated and the selectivity controls ganged together.

High-Low Selectivity Switches. In a variable-selectivity receiver the desired method of controlling selectivity must be incorporated in one or more I.F. circuits. In order to reduce costs, continuously variable selectivity is sometimes replaced with a high-low selectivity (low-high fidelity) change-over switch, as shown in Fig. *20A.* Trimmer condensers C_1 and C_2 are adjusted for single peak response (high selectivity) when the switch is set to point *1.* Moving the switch to point *2* makes coil section L_M common to both resonant circuits; this increases the mutual inductance of the coils, and in effect adds inductance to circuit L_1-C_1, and takes inductance away from circuit L_2-C_2, thereby increasing the band width (giving high fidelity).

Any scheme which will increase the resonant frequency of one circuit while decreasing the resonant frequency of the other circuit by an equal amount may be used to control selectivity. Another method of doing this is shown in Fig. *20B.* When the selectivity switch is at point *1,* normal peak adjustments exist; when at point *2,* condenser C_3 is in series with C_1, increasing the resonant frequency of circuit C_1-L_1, while condenser C_4 is in shunt with condenser C_2, lowering the resonant frequency of circuit L_2-C_2. Condensers C_3 and C_4 are of such capacities as to give the desired band width.

TELEVISION SUPERHETERODYNE RECEIVERS

Aside from the use of a cathode ray tube as an image reproducer, the superheterodyne receiver used to pick up sight (video) and sound (audio) television signals is much like an all-wave sound receiver. You have already studied in your course the basic circuits used in a television receiver, for no radically new principles are involved.

The transmission of a 441-line picture which is repeated completely thirty times each second calls for a video frequency range of no less than 4 mc. Single side-band transmission is used for television purposes in this country, with the lower side frequencies being rejected at the transmitter. Both the sight and sound modulated R.F. carrier signals are radiated by a television transmitter within a frequency channel 6 megacycles wide in the ultra-high-frequency band assigned to television. Seven of these channels in the range from 44 mc. to 108 mc. have been assigned to television.

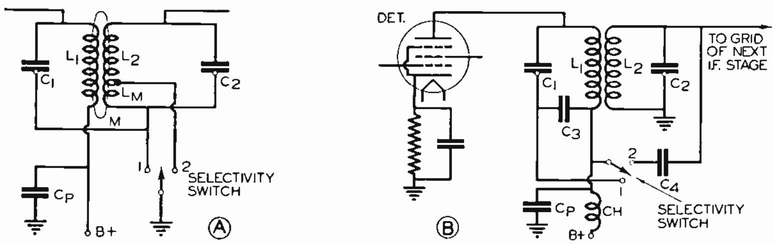

FIG. 20. Two methods for incorporating high-low selectivity switches in a superheterodyne receiver are shown here.

In each television channel, the carrier for the audio signal is .25 mc. below the highest channel frequency. The carrier for the video signal is 4.5 mc. below the audio carrier, with side frequencies extending above and below this value in the manner shown in Fig. *21*.

Both the sight and sound carrier signals are intercepted by a single half-wave antenna, are amplified and tuned by a preselector, and are then passed through a frequency converter stage. A single local oscillator feeding into the frequency converter stage converts both the sight and sound carriers and their associated side frequencies to lower I.F. values at which greater gain can be obtained and satisfactory frequency response can be secured for all desired signal components.

The sight and sound signals thus separate at the output of the frequency converter stage. The sound portion of the television program goes into a sound I.F. channel having a 100-kc. pass band, then to the audio detector, audio amplifier and loudspeaker. The sound channel includes provisions for rejecting picture signals.

The sight carrier and its side frequencies pass into the video I.F. channel, which has a 4-megacycle wide pass band. There are provisions in this channel for rejecting the audio carrier signal. The output of the video I.F. amplifier feeds through the video detector and video frequency amplifier to the television cathode ray tube.

A television picture signal includes impulses which indicate the end of a line and the end of a picture, along with the variations corresponding to detail along each line of the picture. Although the entire signal including the impulses is fed to the television cathode ray tube, only the video components corresponding to detail along a line vary the brightness of the spot on the screen. At some point ahead of the television cathode ray tube, the signal is allowed to act upon a separate stage known as the clipper, which allows only the synchronizing impulses to

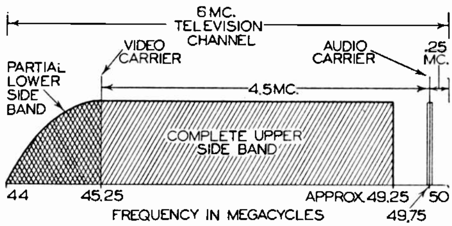

FIG. 21. Relationship between the audio carrier, the video carrier and the side frequencies in a typical 6-megacycle wide television channel. The frequency values specified below the diagram are for the 44-50 megacycle television channel.

pass. After this, the line impulses are separated from the frame impulses. The separated impulses control saw-tooth sweep oscillators which develop the voltages required to sweep the electron beam across the cathode ray tube screen in the proper manner to reproduce the original scene. You have already studied in your course the basic forms of all of these television circuits.

The requirement that R.F. amplifier stages used in the preselector be capable of passing a 6-megacycle wide range of frequencies and that video I.F. amplifier stages be capable of passing a 4-megacycle wide band, coupled with the requirement that video frequency amplifier stages be capable of passing signals ranging from about 10 cycles to about 4,000,000 cycles, has given television receiver design engineers some real problems. These have been solved by using plate load resistances of low ohmic value and circuits having wide pass bands, but this results in low gain per stage. To compensate for this, special tubes having high mutual conductance values were developed for television receivers. These tubes also have low inter-electrode capacities, to minimize attenuation of higher video frequencies.

TEST QUESTIONS

Be sure to number your Answer Sheet 23FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Why must the resonant load in the plate circuit of the first detector be highly selective?

2. What two radio frequency signals in a superheterodyne receiver are combined by the frequency conversion process to produce the I.F. carrier?

3. In addition to giving single-dial tuning, what advantage is secured by ganging the oscillator and preselector tuning condensers?

4. When an interfering signal is heard along with the desired signal, and the frequency of this interfering signal is *above* the frequency of the desired signal *by twice the I.F. value* of the receiver, what type of interference is present?

5. How would you eliminate code interference which is heard at all settings of the tuning dial in a superheterodyne receiver?

6. Why is it desirable to have a stage or two of R.F. amplification ahead of the frequency converter section in a superheterodyne receiver?

7. Give two reasons why the pentagrid mixer-first detector tube, when used with a separate oscillator tube, is a better frequency converter than a single pentagrid converter tube.

8. What two trimmer condensers must be adjusted in order to make the preselector and the oscillator track each other?

9. In what way, essentially, does an all-wave superheterodyne receiver differ from a broadcast band superheterodyne receiver?

10. What section of a superheterodyne receiver provides most of the adjacent channel selectivity?

TONE CONTROL, VOLUME EXPANSION AND NOISE LIMITING CIRCUITS

24FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

HONESTY

That old proverb, "Honesty is the best policy," is just as true today as it ever was. Any organization which depends upon repeat business for its success cannot exist for long without following this policy; any man whose success depends upon dealings with other people likewise cannot afford to disregard this policy.

Strict observance of the law will keep a man out of jail, but that does not necessarily make him an honest man. Honesty goes far beyond the law; it involves a careful regard for the rights of others, a truthfulness and sincerity in dealing with others, a fairness and trustworthiness in matters involving property or business, and a personal honor which is governed by a man's own sense of righteousness.

It is not enough to act so others will think you are honest; you yourself must know, without a shadow of a doubt, that you are playing the game fair and square if you are to enjoy that real satisfaction and peace of mind which is associated with absolute honesty.

Be honest, and your reputation will take care of itself. Let your spoken word, your slightest implied action be as good as your signature on a legal contract, and you will enjoy those things which no amount of money can buy—happiness, success, and the respect of your fellow men.

J. E. SMITH

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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Tone Control, Volume Expansion and Noise Limiting Circuits

Satisfying the Human Ear

THE manufacturers and operators of sound broadcast transmitters have one objective in common with the manufacturers of radio receivers—to make the receiver owner feel that he is listening to the actual studio performance rather than to a loudspeaker. This is by no means a simple task, and as yet has not been completely achieved even in the most expensive radio receivers. Radio engineers are doing everything within their power to improve the faithfulness of reproduction, and each year brings them another step closer towards their goal of perfection.

In this text-book we shall consider the various factors which make it difficult to achieve complete perfection, and study the methods used to satisfy the human ear under different conditions.

Distortion. One important requirement for faithful reproduction is freedom from all types of distortion. All of the sound frequencies which are present in the original performance must be present in the reproduced program and must *seem to have* the same loudness relation to each other as in the original performance; furthermore, there must be no frequencies in the reproduced program which did not originally exist (that is, there must be negligible amplitude distortion and negligible noise originating in the transmitting and receiving apparatus).

Noise. Broadcast transmitters can be, and in most cases are designed to radiate negligible noise. Radio receivers can likewise be so designed that noise originating in them is negligible. It is noise which originates outside of the transmitting and receiving apparatus which requires special attention. Man-made interference noise is the chief offender in this respect; for this reason every serviceman should be familiar with the use of noise-reducing antennas for receivers and the application of noise filters to trouble-making electrical devices, all of which are taken up elsewhere in this Course.

Atmospheric noises, which enter the receiver along with the carrier of the desired station, cannot be entirely eliminated, but their annoying effects can be reduced considerably. You will learn that there are three practical types of circuits used for this purpose: *1, Tone Control circuits,* which cut out high-frequency sound components, thereby eliminating predominating noise signals at a sacrifice of fidelity; *2, noise impulse-silencing circuits,* which temporarily cut out all signals for the duration of sharp noise pulses which are stronger than the program signals; *3, inter-carrier noise suppression circuits,* which cut out all signals, including noise, whenever the station signal is so weak that it is drowned out by noise signals. (Increasing the amount of power radiated by a transmitter, in order that the desired signal can better override noise signals, is a fourth solution, but transmitting power is definitely limited by law in order to prevent interference between stations.) Typical examples of the ingenious circuits which have been developed to accomplish these results will be studied in this lesson.

Peculiarities of the Human Ear. The characteristics of the human ear have a lot to do with radio receiver design. Possibly you have noticed that orchestra music which sounds fine at a moderate distance away seems high-pitched (lacking in low frequencies) when you walk a considerable distance away.

The same phenomenon occurs during the fading of a radio program; this can most readily be noticed when a foreign short-wave program is tuned in. At a normal listening level of loudness the music will sound fine, but as the signal fades out, the music seems to become high-pitched or squeaky; as signal strength comes up to normal again, the music gradually becomes more mellow and pleasing.

The reason for this puzzling effect is simply that our ears hear low frequency or bass notes better at medium and high loudness levels than at low loudness levels. When the volume of a radio program drops because of fading, the bass notes seem to be cut far more than the higher frequencies.

Since radio receivers in homes are ordinarily operated at a loudness level considerably lower than that of the original performance, we have the queer situation that even a perfect radio receiver (one having a flat response over the entire audio range) would sound unsatisfactory whenever its output volume differed from that of the original program.

Characteristic Curves for the Average Human Ear. The peculiar hearing characteristics of the human ear have been carefully investigated. The results of tests on thousands of persons have been combined in the graph in Fig. *1*, which tells how the average ear responds to various frequencies at different loudness levels.

A few words of explanation as to how data for this graph was secured will help you to read its story. First of all, a 1,000-cycle sound was varied in loudness, while various persons listened, until an average loudness level which could just barely be heard was determined. This was called the 0 (zero) db *loudness* level. The actual intensity of this 1,000-cycle sound was then determined with a sound-measuring instrument, and the meter scale on the instrument was made to indicate 0 db *intensity* level for this condition. Now the same test was repeated for other frequencies, and the intensity level in db at which the sound could just barely be heard was measured with the instrument. Thus, at 500 cycles the average meter reading was +6 db; at 100 cycles it read 38 db, and at 30 cycles the reading was +63 db, etc. Each value was plotted on the graph, and a smooth curve was drawn through all the points to give the 0 db loudness level curve, also known as the threshold of hearing curve. This curve shows clearly that intensity levels considerably greater than 0 db are required below 1,000 cycles in order for sound to be heard, and also shows that the human ear hears best at about 4,000 cycles per second.

The intensity level at 1,000 cycles was then raised 10 db to give a loudness level of 10 db at this frequency, and the intensity level at each other frequency which seemed to give this same loudness was determined. This gave data for the 10 db loudness level curve. The same procedure was repeated at 10 db intervals to secure data for the remaining curves in Fig. *1*.

It was found that when the loudness level was made higher than 120 db, the sounds were actually felt by the persons taking the test, the sensation being that of pain in the ears in some instances; the 120 db loudness level curve is therefore known as the *threshold of feeling*.

How to Use the Ear Characteristics Graph. Suppose we want to determine the intensity level required for a certain loudness, say 20 db, at a given frequency such as 200 cycles. We simply locate this frequency on the horizontal scale (point *A*), trace directly upward from it to the point where that frequency line intersects the 20 db loudness curve (point *B*), and then trace horizontally to the vertical reference scale at the left, where we read +40 db (point *C*) as the intensity level required in db for that loudness. In other words, for a 20 db loudness level our ear requires 20 db more sound power at 200 cycles than at 1,000 cycles. At a 90 db loudness level, however, the curve is practically horizontal between these two frequencies, indicating that our ear can hear both frequencies equally well when they are this loud.

Bear in mind that *loudness level* is a human response to sound, and not something which can be measured with instruments. *Intensity level* is the actual measured level of sound as measured by instruments connected to a microphone which picks up all sound frequencies equally well.

We can draw these general conclusions from the curves in Fig. *1*: At *low loudness levels* (from 20 to 40 db), such as those ordinarily produced by a radio receiver loud-speaker in the home, the human ear is most sensitive to sounds in the middle frequency range from 500 cycles to 5,000 cycles, and has difficulty in hearing sounds below and above this frequency range.

As we raise the *loudness level* of sound, such as by turning up the volume control on the receiver, the sensitivity of the ear to low frequencies improves rapidly, so that at a loudness level of 100 db we can readily hear all sound frequencies below 10,000 cycles equally well. The lower the volume control setting on a radio receiver having an ordinary volume control, then, the fewer low or bass notes there will be insofar as our ears are concerned; to a lesser extent this statement also applies to the extreme high frequencies.

To get true high-fidelity reproduction at any desired loudness level, then, it is necessary to compensate for

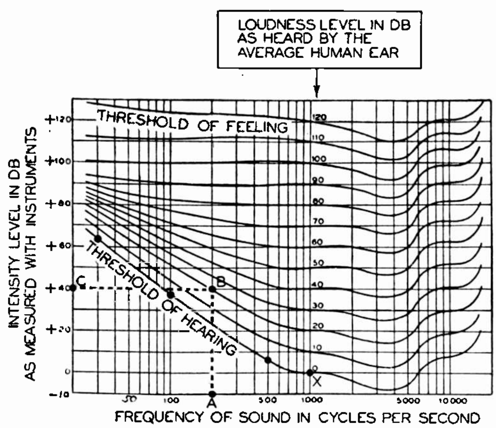

FIG. 1. This standard reference graph gives the average hearing characteristics (frequency response) of the human ear at various loudness levels; in other words, it tells what intensity level will be required for a given loudness level at a given frequency.

the shortcomings of the human ear by boosting the response of a receiver at the low and high frequencies the correct amount *for each loudness level.* Boosting of the lows (raising of the bass notes) is far more important than raising the high-frequency or treble sounds.

Tone Controls. Many receivers are provided with separate bass and treble tone controls, which allow the listener to adjust the response of the receiver to secure faithful reproduction or to suit his particular taste at any desired loudness level. Oftentimes, however, the radio engineer makes these tone controls entirely automatic in operation, so that as volume is reduced, the low and the high frequency notes are automatically strengthened with respect to the middle frequencies. The amount of tone compensation provided at each loudness level is governed by the average reaction of the human ear to sound; receiver design engineers continually refer to the standard curves in Fig. *1* for this purpose. Automatic tone control is particularly appreciated by those listeners who do not have the ability to judge the correct adjustments of the bass and treble controls, or who do not want to take the time required to make these adjustments. Both manual and automatic tone controls will be taken up in this lesson.

Volume Compression. Of course, no radio program is broadcast at a constant volume level from instant to instant. For example, a symphony orchestra may have a variation in intensity of as much as 100 db from the weakest to the strongest passages. If the transmitter were adjusted to handle the loudest passages without overmodulation, then the weakest passages would be completely drowned out by transmitter circuit noise, and the average modulation percentage will be too low for economical operation; on the other hand, if the transmitter is set to keep the lowest passages well above the transmitter circuit noise level, then severe overmodulation and distortion would occur on loud passages. A maximum variation of 40 db is about the most a transmitter can handle, although a range of 30 db seems to be preferred in most transmitters. If the signal level is allowed to rise too high, over-modulation and distortion occur; oftentimes this also results in overloading of the transmitter and opening of circuit breakers, throwing the station temporarily off the air. It is the duty of the studio operator who monitors a broadcast to reduce the audio gain of the transmitter for loud passages and boost the gain for weak passages, thereby compressing the sound into the allowable volume range. Automatic volume limiting systems are also employed for this purpose; these compress just before over-modulation occurs, by cutting down gain.

Volume Expansion. The compression of the original sound into a limited volume range will reduce the quality of the transmitted program. In a number of radio receivers special volume-expanding circuits are used to counteract this compression at high levels and increase the range of volume somewhat. Full expansion is ordinarily not possible because of the inability of the amplifier in the receiver to furnish the power required for the loudest sounds produced in the studio and because only a part (or none) of the compression occurring at the transmitter is automatic, but there is an appreciable improvement in the quality of reproduction when a volume-expanding circuit is incorporated in a receiver.

Sounds are compressed in much the

same way when phonograph records are made, and many of the better phonograph amplifiers have volume-expanding circuits. Because the high level compression usually is automatic in recording studios, the expansion can be made to correspond almost exactly, and very good fidelity can therefore be secured. Several different automatic volume expansion circuits will be studied.

Directional Effects. When we listen to an actual orchestra, our ears are able to determine from which direction each particular sound comes; thus we may note that the drums are to the right of the conductor, while the bass horns are at his left. When all these sounds are reproduced by a single loud-speaker at the receiving point, however, we lose this effect completely, and all of the sounds appear to come from the loudspeaker. With our present system of broadcasting, it is impractical to correct this situation, although it has been done already on an experimental basis.

In one test broadcast, two microphones were located a definite distance apart in the studio, and the sounds picked up by each were independently amplified and broadcast over two separate transmitters. At the receiving location were two separate receivers and loudspeakers, with the loudspeakers located the same distance apart as the microphones in the studio. As a result, the actual directional characteristics of the orchestra were duplicated.

Curiously enough, the lack of directional qualities in a radio program in no way destroys the entertainment value of the program for the average listener. We have become accustomed to radio transmission as it is, and consequently the tremendous expense involved in complete duplicate transmitting and receiving systems for each broadcast is unwarranted at the present time.

Simple Tone Controls

Any device which, when introduced into a radio receiving circuit, serves to reduce or remove the higher-frequency sound signals will have the apparent effect of boosting the low and medium frequencies. A condenser is one simple device for doing this, and is therefore widely used in simple tone controls. It is customary to make the insertion of one or more condensers in the circuit for tone control purposes optional, so the listener can select the most satisfactory tone control position for each loudness level.

When a tone control condenser is connected between the grid and the cathode or chassis of an audio amplifier stage or between the plate and the cathode or chassis, the high reactance of this condenser at low frequencies results in negligible by-passing of the signal, but at medium and high frequencies the reactance of the condenser is so low that there is appreciable signal by-passing. A simple condenser tone control gives an apparent boost in bass or low-frequency signals because the signal which it feeds to the next stage has a higher proportion of bass notes (with respect to medium and treble notes) than the signal fed into the tone control.

Simple Four-Position Tone Control. One simple and widely used tone control arrangement is that shown in Fig. *2A*, where selector switch *SW* serves as the tone control. When this switch is set at point *1*, no shunting or by-passing of the signal occurs, and hence all frequencies in the sound signal are fed to C_K without attenuation. As the switch is set to points *2*, *3* and *4*, increasingly greater capacities are placed between the plate and ground, and increasing amounts of the middle and high frequencies are shunted to ground without passing through the load resistor R_L for transfer to the following stage.

In inexpensive receivers there are generally only two positions of the tone control, and only one condenser; in the first position of the tone control switch, which might be labeled "BRIGHT," no condenser is in the circuit and all frequencies are passed uniformly. In the second position of the switch, often labeled "MELLOW," the condenser is in the circuit and the medium and higher frequencies are cut down, giving a bass-boosting effect. Receivers with three-position tone controls, labeled "B R I L L I A N T," "BRIGHT" and "MELLOW," would use two condensers.

What Is the Best Tone Control Setting? It is incorrect to say that highest fidelity is always obtained at one particular position of the tone control. When the receiver is turned to maximum volume, giving a high level of loudness, that position in which there is no condenser in the circuit to by-pass the higher frequencies will give the best fidelity if the receiver normally has a flat response. On the other hand, when the receiver volume is turned down, it may be necessary to place the highest-capacity tone control condenser in the circuit in order to reduce the highest frequency signals enough so that they will not sound any louder to the human ear than the low and medium frequency signals. It must be remembered that the curves in Fig. *1* were secured by averaging the hearing characteristics of a great many persons. Individuals may therefore deviate considerably from these curves.

Continuously Variable Tone Control. In the circuit of Fig. *2A*, the tone control must be adjusted in steps, with the result that proper correction of tone will not be possible at certain loudness levels in between these steps. For this reason many people prefer a continuously variable tone control like that shown in Fig. *2B*. Here a variable resistor is placed in series with a single tone control condenser. When this resistor is set at zero resistance, only the condenser is connected between the plate of the tube and ground, and we have maximum reduction of the high frequencies (the low and medium frequencies will then come through considerably stronger than the high frequencies). Increasing the resistance increases the net impedance of this tone control path to ground, thus reducing the by-passing effects on the high frequencies. When the maximum tone control resistance of 100,000 ohms is in the circuit, practically no signal frequencies take the path through the tone control circuit and there is no cutting of high frequencies.

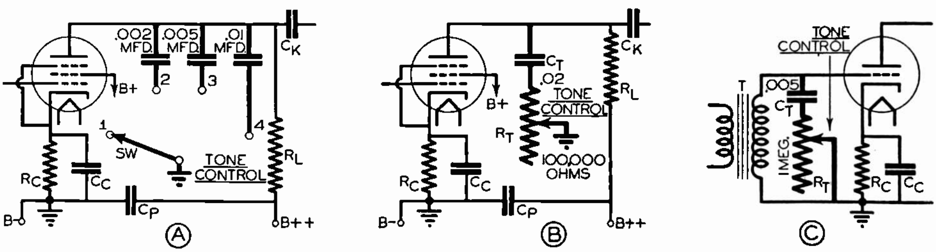

FIG. 2. Simple manual tone control circuits which utilize the signal by-passing action of a condenser.

A similar continuously variable tone

control arrangement is shown in Fig. *2C* as it would be connected between the grid and chassis of an audio amplified stage. The action of this circuit is identical to that in Fig. *2B;* a lower value of capacity and a higher value of resistance are required for the grid connection, as you can see by comparing the values specified in Fig. *2C* with those in Fig. *2B*. It is important to realize that an appreciable amount of attenuation or cutting of high frequencies can be achieved only if the impedance of the tone control circuit is considerably lower than the impedance of the load which it shunts. Since the grid-cathode path of the tube in Fig. *2C* is a high-impedance load for the secondary winding, C_T and R_T have high ohmic values.

How Tone Controls Reduce Noise. Simple tone controls are widely used in all-wave receivers, and are especially valuable when listening to short-wave programs coming from far distant transmitters. The signals from these distant stations are generally accompanied by a great deal of noise; this is because they are received at such low levels that receiver gain must be increased considerably, and noise then becomes more noticeable. It is a known fact that in these noise signals the higher sound frequencies predominate; when the tone control is set to cut down high frequencies, the received signal becomes considerably less noisy. You can easily verify this for yourself by trying the tone control on an all-wave receiver while tuned to a European station; note how the noise is reduced when the tone control is set for MELLOW or BASS reception.

Tone Controls May Be Connected Anywhere in the A.F. Amplifier. There appears to be no one preferred position for the tone control in an audio amplifier. Sometimes this control is connected in the output circuit of a diode detector, right at the input of the audio amplifier, as shown in Fig. *3*. Potentiometer R_3 serves as the volume control, with the setting of its movable arm determining the amount of A.F. voltage which is fed through blocking condenser C_4 to the grid of the first audio stage. Tone control potentiometer R_2 is shunted across R_3, and the movable contact of R_2 is grounded through condenser C_3. Moving the tone control from position *1* to position *2* gradually increases the shunting effect of C_3, and therefore increases the cutting or by-passing of high-frequency signals.

A similar tone control arrangement could be used in Fig. *2B* by replacing

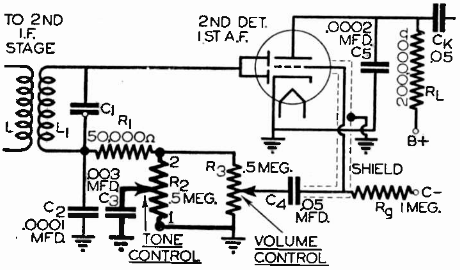

FIG. 3. Simple manual tone control circuit acting on the load of a diode second detector; the parts values are those used in the Silvertone Model 1825A superheterodyne receiver.

resistor R_L with a potentiometer and connecting the movable tap of the potentiometer to the chassis through a .02 mfd. condenser; R_T and C_T would then be removed. Likewise in Fig. *2C* the secondary of the audio transformer could be shunted with a .5 to 1 megohm potentiometer, with its movable contact grounded through a condenser, in place of the R_T-C_T tone control arrangement shown.

How Tone Controls Affect A.F. Response Curves. The effect of a typical four-position tone control upon the over-all audio frequency response of a radio receiver is clearly shown by the graph in Fig. *4*. Curve *1* is for the tone control setting where there is no shunt capacity to cut down the higher frequencies; this curve therefore represents the normal frequency response of the receiver, indicating the relative output intensity level at each sound frequency. Curves *2*, *3* and *4* show how this response is changed as increasingly greater shunt capacity is inserted in the circuit. These curves show clearly how a tone control cuts down the medium and high frequencies in the audio range without affecting the low or bass notes. With variable tone controls like those in Figs. *2B*, *2C*

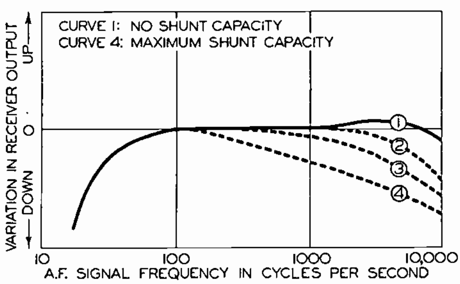

FIG. 4. This graph shows the effect of a four-position tone control upon the over-all frequency response of a typical radio receiver.

and *3*, we could have any number of different response curves between *1* and *4*, depending upon the control setting.

If the volume level of a receiver is raised to a high value when the tone control setting corresponds to curve *4* in Fig. *4*, bass notes will be amplified excessively for the requirements of the human ear, and the over-correction will be readily noticed by the listener as a boomy effect. Some people actually prefer a very strong bass response and will purposely set the tone control for this result, even though they thus destroy the fidelity or quality of reception.

Special Bass and Treble Tone Controls

In the more expensive radio receivers you will often find two separate tone controls, one for changing the low frequency or bass response and the other for changing the high frequency or treble response. Let us first consider bass controls.

Parallel Resonant Bass Control Circuit. Resonant circuits are widely used to control the bass response of a receiver; a typical example is that in Fig. *5A*, where condenser *C* and iron-core inductance *L* form a parallel resonant circuit which has a resonant frequency of about 50 cycles (*C* will ordinarily be about .1 mfd., and *L* about 100 henrys). At resonance this circuit acts as a high resistance which, being in series with resistor *R* (about 10,000 ohms), will result in a high plate load impedance. The amplification of the stage is therefore increased in the low frequency or bass range around 50 cycles.

This parallel resonant circuit acts like a reactance of low ohmic value at frequencies higher than 50 cycles, under which condition resistor *R* governs the plate load impedance. The greater the resistance of the resonant circuit at resonance, the greater will be the boost in low frequency response; this resonant resistance can be varied over a wide range by adjusting the setting of potentiometer R_B. When all of R_B is in the circuit, the resonant resistance is quite low and there is little or no boosting of bass response. Maximum bass boosting is secured when all of R_B is shorted out.

Audio Input-Shunting Bass Control Circuit. Another widely used bass tone control circuit is shown in Fig. *5B*. Inductance *L*, potentiometer *R* and condenser *C* form the bass tone control circuit, which in this case is not a resonant circuit.

We can neglect the effect of C_K, as its reactance will be small in comparison to the reactance of L at any frequency or in comparison to the resistance of R. Assume for the moment that C is omitted; clearly we now have a voltage divider consisting of R and L, with the reactance between point P and ground determining the voltage output. Since the reactance of L at low frequencies is quite small in comparison to the resistance of R, the bass voltage will be developed essentially across R (between points *1* and *2*). As potentiometer contact P is moved from point *2* to *1*, less and less of this bass voltage is fed to the grid of the next tube. Since the audio system is intentionally made to have a high bass response, position *2* of the movable tap is for high bass response and position *1* is for low bass response.

Although moving contact P from point *2* to point *1* decreases the amount of bass forwarded to the following tube, it also decreases to some extent the medium and treble frequencies. Condenser C in Fig. *5B* is used to bypass medium and high frequency signal components around the upper section of R, and consequently the medium and treble notes are passed by the tone control circuit without appreciable attenuation regardless of the setting of P. This bass control is definitely not a volume control when condenser C is used; if C is omitted, however, volume control action will be present along with bass control.

Treble Controls. The resonant tone control circuit in Fig. *5A* can also be made to serve as a treble control if the values of L and C are chosen to provide resonance at a high audio frequency value. With this arrangement, varying the setting of potentiometer R_B will vary the high frequency response from its normal value to a value considerably above normal.

Use of a Conventional Tone Control as Treble Control. A more widely used procedure for securing treble control is that wherein the audio amplifier is designed to have a sharp rise in response at the higher frequencies, and one of the conventional tone control circuits shown in Figs. *2A, 2B, 2C* and *3* is used to cut down this high frequency or treble response as desired.

Automatic Tone Controls

The purpose of a tone control, as you already know, is to produce the effect of boosting the extreme low and extreme high-frequency response of the receiver to compensate for the inability of the human ear to hear these frequencies as good as the medium frequencies at low levels of loudness. The same results can of course be accomplished by reducing the level of the middle frequencies more than that of the extreme frequencies when reducing the volume. It is possible to secure this action automatically as the volume control is adjusted by the listener.

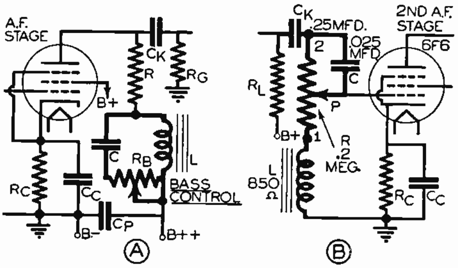

FIG. 5. Typical bass control circuits; that at *A* can also be made to serve as a treble control, by making L-C resonate at a high audio frequency. That at *B* is used in a General Electric all-wave receiver.

Engineers differ as to the extent to which automatic tone control should correct for the shortcomings of the human ear at low levels of loudness. Some feel that only the bass should be reenforced (automatic bass compensation), while others prefer to reenforce both the treble and the bass (automatic tone compensation) to secure more nearly perfect compensation for the drop in sensitivity of the human ear under the conditions in question.

Automatic bass compensation (often abbreviated as A.B.C.) could be secured with a tone control of the type shown in Fig. *3* if we mounted this tone control potentiometer on the same shaft as the volume control, so that when volume was reduced, the medium and high frequencies would be cut down proportionately in order to satisfy the human ear. While this could be made to work perfectly satisfactorily, there is a much simpler way of accomplishing the same results.

Condenser-Type A.B.C. Circuit. A practical automatic bass compensation circuit is shown in Fig. *6A;* although quite simple, it is entirely effective. The two terminals of this circuit, x and y, are connected either across the diode load resistor or across the output of some audio stage in the receiver. Volume control potentiometer R_1 is tapped at point *2*, which need not necessarily be its mid-point. Condenser C in series with resistor R between points *2* and *3* serves to attenuate (cut down) the middle and high frequencies at low-volume settings of the control, thus providing automatic bass compensation. Whenever you encounter a circuit like this, where the volume control has a fixed tap which is connected to ground through a condenser and a resistor, you can immediately identify it as an *automatic bass compensation circuit.*

Consider the circuit in Fig. *6A* from the viewpoint of a voltage divider. If C and R were not present, the voltage E at any frequency would depend solely upon the position of contact arm P. With C and R connected as shown, and with the reactance of C decreasing with increases in frequency, the impedance between points *2* and *3* decreases as the frequency increases. The lower this impedance becomes, the more A.F. voltage there will be across section *1-2* of the voltage divider; in fact, at very high audio frequencies almost all of the available signal voltage is developed across points *1* and *2*.

When P is at point *1*, all of the A.F. voltage developed across the voltage divider is fed to the grid of the next stage regardless of its frequency. If P is placed at point *2*, only the voltage developed between points *2* and *3* is fed to the grid of the next stage; the reactance between these points decreases at the higher frequencies and consequently there are fewer high-frequency components than normal in the output voltage E when P is at *2*. We thus have the bass-boosting effect required for automatic bass compensation. At any position of P between points *1* and *2*, the output voltage E depends upon the ratio of the impedance between P and *3* to the total impedance between points *1* and *3*, and the amount of automatic bass compensation increases from zero (when P is at *1*) to its maximum value when P is at *2*. When P is moved below *2* (towards *3*), the amount of bass compensation remains the same as for point *2* and all frequency components are reduced uniformly as in normal volume control action.

Occasionally you may find an additional condenser and resistor connected in series between point *4* and the chassis, and another condenser and resistor between point *5* and the chassis; this is done to provide increasingly greater bass compensation as contact arm *P* is moved from *2* to *3*.

Series-Resonant A.B.C. Circuit. Even greater attenuation or cutting of the high and middle frequencies for automatic bass compensation purposes is possible with a series resonant circuit arrangement as shown in Fig. *6B*. Coil *L* and condenser *C* in series are adjusted to be broadly resonant to the middle and high frequencies; as a result, the effects of their reactances cancel at these frequencies, leaving only resistance *R* and the coil resistance in shunt with section *2-3* of

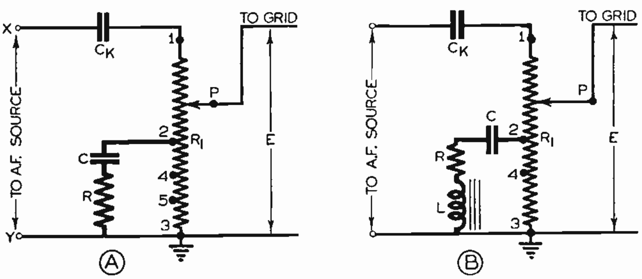

Fig. 6. Two practical automatic bass compensation circuits.

potentiometer R_1; resistance *R* prevents complete cutting of signals at the resonant frequency. At low frequencies, however, the reactance of *C* is so high that the shunting effect of the series resonant circuit can be neglected. As contact arm *P* is moved from point *1* to point *2*, lowering the volume, the amount of cutting of medium and high frequencies gradually increases to a maximum value when *P* is at *2*. Further reductions in volume (by moving *P* below point *2*) give no further increase in bass compensation unless an additional series resonant circuit or condenser-resistor circuit is connected between point *4* and ground. Very often resistor *R* is omitted and a coil which has a sufficiently high resistance to give the desired broad tuning over the middle and high frequency range is used. If the *L-C* circuit is broadly resonant only for the medium frequencies, only these medium frequencies will cut down at low volume control settings, and automatic tone control (bass and treble compensation) is secured.

Unique Tone Control Circuits

Separate Bass and Treble Channels. Some manufacturers of radio receivers provide one path in the audio amplifier for low-frequency signals and another entirely separate path for high-frequency signals; this permits amplification of these signals independently and gives a definite control over their relation to each other.

A simple circuit of this nature is shown in Fig. 7. The audio signal output of the first A.F. amplifier tube (VT_1) divides at point *1;* the middle and high frequency signals in the audio range take the path through the .001 mfd. condenser C_3 to audio amplifier tube VT_3, but the reactance of this condenser is so high at low frequencies that very few low frequency signals get through. The other path for signals from point *1* is through .5 mfd. condenser C_2 and through 100,000-ohm resistor *R* to audio amplifier tube VT_2. Both low and high frequencies can pass through this condenser and resistor, but the high frequencies take the .05 mfd. shunt path (C_4) around the .5 megohm potentiometer (R_3) to ground and consequently do not act upon the grid of VT_2. Only the low frequency components and a portion of the medium frequencies are amplified by VT_2. Resistor R prevents C_2-R-C_4 from being a complete short for high frequencies, for that would leave none for the treble tube VT_3. The potentiometers in the grid circuits of VT_2 and VT_3 can be adjusted to provide any desired relationship between the bass, medium and treble frequencies. The outputs of the bass and treble amplifier tubes are combined at point *2* accentuate the bass and treble frequencies, thus giving high-fidelity reproduction of music at normal low sound levels.

The circuit diagram of a typical Motorola tone control system is shown in Fig. *8*. The tone control switch is shown at position V (VOICE). Under this condition the A.F. signal is developed across load resistor R_1, all R.F. components accompanying this signal being by-passed to ground by the .0002 mfd. shunting condenser C_2. This audio signal voltage is then applied to .5 megohm resistor R_2 through blocking condenser C_3 and by-pass conden-

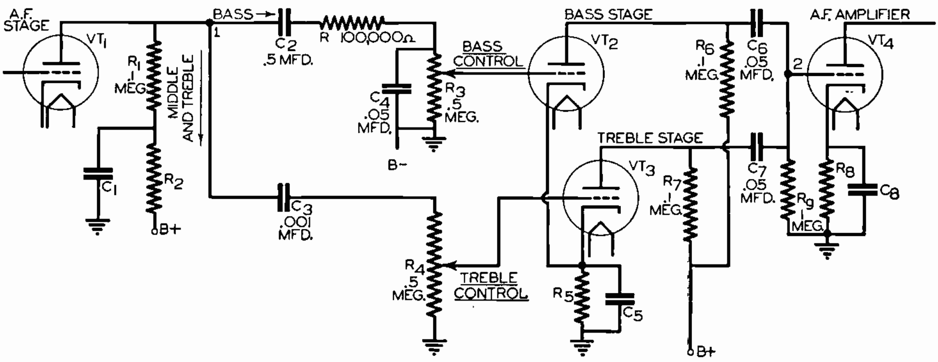

FIG. 7. Special tone control circuit which uses separate channels for amplification of bass and treble frequencies, with independent controls for each channel.

and fed from there to the grid of audio amplifier tube VT_4.

The Motorola Acoustinator. A rather unique bass and treble tone control is employed in some Motorola radio receivers. The audio systems in these receivers are designed to have a peak response at the medium frequencies, this being considered a highly desirable condition for clear voice reproduction. Means are provided for cutting down the medium frequencies and to some extent the treble frequencies when bass compensation is desired, such as at low levels of loudness. Means are also provided for cutting down the medium frequency response so as to ser C_4. Since R_4 and R_5 offer no paths to ground, the entire signal voltage across R_2 is applied to the control grid of the second A.F. tube through the R_4-R_5-C_5 combination. The output of this tube feeds into the primary of an audio transformer across which is connected .007 mfd. condenser C_9. This condenser shunts some of the high-frequency audio signals around the primary, and therefore serves to cut down the high-frequency response. The audio amplifier normally has reduced bass response. As a result, when the tone control is in position V, the audio amplifier system has a response which is peaked in the middle frequencies.

Since the majority of voice frequencies are in this middle region, we have a condition which many people consider ideal for the reproduction of voice.

With the tone control in position *M* (MUSIC), the middle frequencies are cut down considerably and bass and treble frequencies therefore predominate. Position *M* is therefore used chiefly for reception of music at a low level of loudness. In this position of the tone control the bass signal currents take the path through resistor R_4 and condenser C_7 to ground, for C_5 is essentially an open circuit at low frequencies. The reactance of C_7 at bass reactance of C_5 is also quite low in relation to the ohmic values of R_4 and R_5 so at high frequencies we can consider R_4 and R_5 as being in parallel. The tone control input and output voltages will thus be the same at high frequencies, but this voltage will be reduced because R_4 and R_5 load the detector circuit. High and low-frequency voltages are about normal, while medium frequency voltages are cut considerably. The final effect is therefore a boosting of lows and highs.

With the tone control in position *B*, two condensers (C_6 and C_8) are connected to ground by the switch. C_6

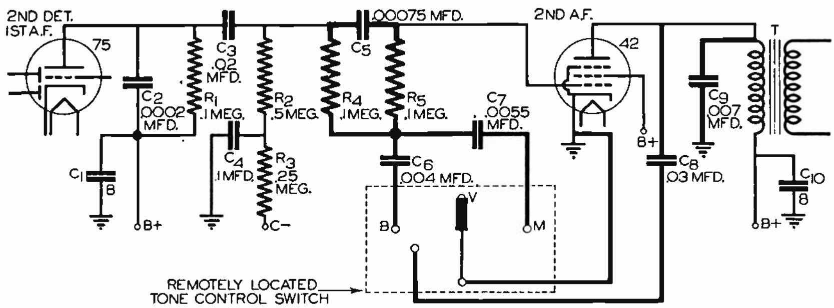

FIG. 8. Heavy lines indicate the circuit of the Acoustinator tone control system as used on the Motorola Model 70 and on many other Motorola receivers.

frequencies (about 50 cycles) is approximately .6 megohm or six times the resistance of R_4, and consequently nearly all of the bass signal voltage is developed across C_7 and is impressed upon the grid of the type 42 tube through R_5. The middle frequencies, taking the same path as the bass signals, find a considerably lower reactance at the .0055 mfd. condenser; most of the available medium frequency signal voltage is wasted across R_4, and only that small portion which is developed across C_7 affects the grid of the type 42 tube. At high frequencies, the reactance of C_7 is so low that it can be considered a short-circuit path. The acts in much the same way as C_7 in cutting down the response at medium frequencies, while C_8 acts like C_9 in cutting the highs. As a result, position B (BASS) gives a high bass response; this reduces static and interference noises to a minimum, and gives a soft mellowness to music.

The General Electric Tone Monitor. When an audio signal is fed from the output of an audio amplifier back into the input of an audio stage in such a way that the feed-back voltage is 180 degrees out of phase with the normal input signal for that stage, degeneration (reduction in output) will occur. In the tone control system shown in

Fig. *9*, used in General Electric model F-77 and other G.E. receivers, degeneration is purposely introduced in this way to provide a control over tone.

First let us analyze circuit conditions when the tone monitor switch (a type which connects together two adjacent contacts), is in the *S* or speech position. Observe that the switch now shorts R_{16} and C_{15}, so that feed-back current from point *1* on the secondary winding of the output transformer flows through the switch, through resistor R_6 to point *2* on the volume control, and then through section *2-G* of the volume control to ground, developing across this section an out-of-phase voltage which is applied to the grid of the first A.F. stage through section *2-P* of this control. The higher the feed-back current, the more degeneration or reduction in signal there will be. Since there is no reactance in the feed-back current path (only the 22,000-ohm resistance of R_6), the amount of feed-back current which causes degeneration will be constant over the entire frequency range. This will lower the gain over the entire frequency range, but will not change the shape of the frequency response curve for the amplifier.

The audio frequency response curve for the amplifier circuit in Fig. *9* is that represented by curve *S* in Fig. *10* (the heavy solid-line curve); this will also be the response curve when the tone monitor is in the *S* position, for the shape of the curve is not affected by uniform reduction of gain over the entire frequency range. Note that there is a peak in the high-frequency region from 3,000 to 6,000 cycles; this occurs because the primary leakage reactance of output transformer primary T_5 acts with Condenser C_{20} to form a resonant circuit at these frequencies, and maximum power is fed to the input of T_5. The peak response in this range, along with uniform response down to 100 cycles, provides a pleasing reproduction of speech at normal room volume.

When the tone monitor switch is placed at position *F*, the foreign-reception position, R_{16} and C_{15} still remain shorted. Condenser C_{19} is now in parallel with resistor R_6; at low frequencies the reactance of this condenser is quite high, with the result that feed-back current will take the path through R_6. Normal amplifier response can therefore be expected at low frequencies, for feed-back current is

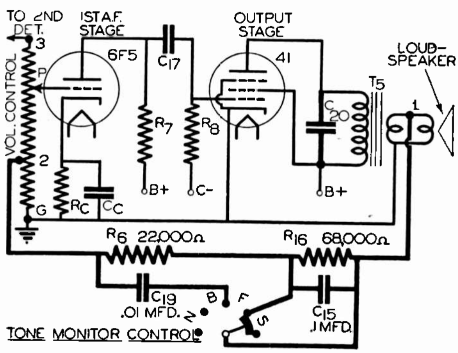

FIG. 9. The G. E. Tone Monitor Control circuit is shown here in heavy lines, as applied to the General Electric Model F-77 receiver (the amplifier circuit is shown here in simplified form).

still at the value determined by R_6. At higher frequencies the reactance of C_{19} is naturally less; since this condenser shunts R_6, more feed-back current flows at higher frequencies than would ordinarily be passed by R_6 alone, increasing the degeneration and thus cutting down the high frequency response. The shape of the response curve for this foreign-reception setting is represented by curve *F* in Fig. *10;* this differs from the normal response curve only at frequencies above about 1,000 cycles. The attenuation or cutting of the high-frequency components serves to remove objectionable noise signals which ordinarily accompany programs received from foreign countries.

When the tone monitor switch is in the *N* or normal-reception position, feed-back current flows through the parallel combination of R_{16} and C_{15}, and then flows through R_6 to point *2* on the volume control. At low frequencies the reactance of C_{15} is high, and R_{16} acts in series with R_6 to reduce the feed-back current practically to zero. As a result, peak bass response is secured. At medium and high frequencies the reactance of C_{15} becomes so low that it shorts out R_{16}, and only R_6 is effective in limiting feed-back current. This means that in the *N* position of the tone monitor switch we will have the normal treble peak in the response curve as well as a peak in the bass or low frequency region, as indicated by curve *N* in Fig. *10;* this is a desirable condition for listening to music at the low loudness levels usually preferred in the home.

Setting the tone monitor switch at position *B*, the bass position, places condenser C_{19} across both R_6 and R_{16}, and inserts the R_{16}-C_{15} combination in series with R_6. At low frequencies the reactances of these two condensers are so high that we can neglect them; this leaves R_{16} and R_6 acting in series and reducing feed-back current almost to zero. Degeneration is thus almost entirely eliminated at low frequencies, and bass response goes up.

At medium frequencies the reactance of C_{15} is low enough to provide a shunt path around R_{16}, but C_{19} is still out of the picture. The 22,000-ohm resistance of R_6 now controls feed-back current, and so we have essentially the same medium frequency response as was secured at positions *S*, *F* and *N*.

At high frequencies C_{15} shorts out R_{16}, and C_{19} provides a low-reactance shunt path around R_6. Feed-back current thus increases considerably, cutting down the high-frequency response quite rapidly as frequency increases. At position *B*, then, curve *B* in Fig. *10* will be the response curve of the receiver; it clearly indicates a boosting of bass frequencies.

Naturally each setting of the tone monitor control will sound different to the human ear at each setting of the volume control, because of the changing characteristics of the human ear with loudness. Automatic compensation for the variations in sensitivity of the ear with loudness is secured by

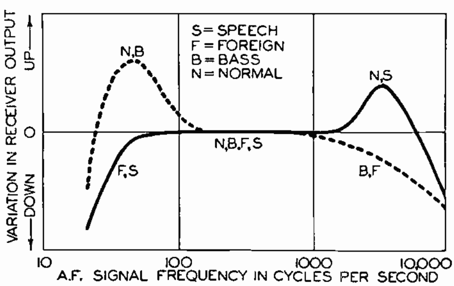

FIG. 10. This graph shows how the G. E. Tone Monitor Control (Fig. *9*) changes the audio frequency response of the receiver in which it is used. The graph represents full-volume conditions, when *P* is at point *3*; there is then no automatic tone compensation.

making the tone control connection to a tap at point *2* on the volume control potentiometer. Varying the volume control setting thus gives an automatic balance between the normal response of the amplifier and the special response introduced by the tone monitor circuit.

Volume Expansion Circuits

The comparison of sound level is of extreme importance in the practical operation of radio transmitters, for otherwise over-modulation and an excessively low signal-to-noise ratio would exist. Compression of sound level is just as important in the production of disc recordings of musical numbers, for excessive volume results in over-cutting of the grooves. Volume compression, of course, destroys the fidelity or faithfulness of a program, for it cuts down the volume of high-level passages. In order to counteract this volume compression, it is necessary to introduce some form of volume expansion in the reproducing device.

Although automatic volume expansion can be applied to both radio receivers and electric phonographs, it is far more satisfactory when the original compression is performed automatically, as is now being done on most recordings. In radio transmitters the compression is done manually by the studio operator, and obviously no automatic circuit in the receiver can exactly compensate for an action which depends for its accuracy upon human alertness and skill.

The most widely used system for automatic volume expansion depends upon the fact that *the gain of a variable mu or super-control pentode tube varies with the negative C bias voltage which is applied.* By applying to a variable mu pentode amplifier tube, in series with its normal negative C bias, a positive D.C. voltage which increases with sound level, the gain of the tube can be made to increase as sound level or volume increases. The necessary D.C. or A.V.E. (automatic volume expansion) control voltage is secured by rectifying the audio voltage and filtering out the A.C. component of the resulting pulsating voltage. This D.C. voltage must of course be time-delayed, for if the A.V.E. control voltage varies too rapidly with fluctuations in sound level, the reproduced music will sound "choppy" and have a "gurgling" effect; likewise if the A.V.E. control voltage is too greatly time-delayed, the benefit of automatic volume expansion will be lost.

RCA A.V.E. Circuit. A typical automatic volume expansion circuit based upon this principle and used in a phonograph amplifier is shown in Fig. *11*. The phonograph pick-up at the upper left in the diagram feeds an audio signal into step-up transformer T_1, across the secondary of which is shunted a 625,000-ohm volume control potentiometer R_4. Notice that this potentiometer is in an automatic tone compensating circuit, there being two taps on the potentiometer for this purpose. Series resonant circuit L_2-C_2, connected to the first or uppermost tap, serves to attenuate the middle frequencies and thereby has the effect of raising the bass and treble response at medium and low volume levels. Resistor R_2 broadens the resonant response of L_2-C_2 and limits the amount of attenuation at medium frequencies. R_3 and C_3, connected between the lower tap on the potentiometer and ground, provide an additional boosting effect for the bass response at still lower volume levels. Series resonant circuit L_1-C_1, also connected across the secondary of T_1, resonates at about 700 cycles and serves to cut down the response of the audio amplifier in this region. Resistor R_1 prevents complete cut-off at resonance.

After passing through the volume and tone control circuits, the audio signal is fed through D.C. blocking condenser C_4 into vacuum tube VT_1, which is ordinarily operated at a high negative C bias and thus normally has low gain. At the same time the audio signal developed across the secondary of transformer T_1 is fed into vacuum tube VT_2, a triode amplifier; this audio signal has not been acted upon by the automatic tone and volume control circuits. The output of VT_2 is rectified by VT_3 and then filtered to give a D.C.

voltage whose value is dependent only upon the signal level at the secondary of T_1. This varying D.C. voltage is applied to one of the grids of pentode tube VT_1 in such a way as to increase the gain of the tube in proportion to the level of the original sound. Now let us trace the circuit in greater detail.

Potentiometer R_8 controls the amount of signal voltage applied to triode amplifier VT_2, and thus provides a control over the amount of volume expansion. R_9 and C_9 together provide automatic C bias for this tube, and plate voltage is obtained by a connection through resistor R_{12} to the B+ terminal of the receiver power supply circuit. The A.C. plate current of VT_2 flows through C_{10}, R_{10} and C_{11} to the chassis, with most of the voltage being dropped across R_{10}. Observe that the plate and cathode of VT_3 are connected together; this tube therefore acts as a diode rectifier with its grid (acting as anode) connected to one side of R_{10} and its cathode connected through R_{11} to the other side of R_{10}.

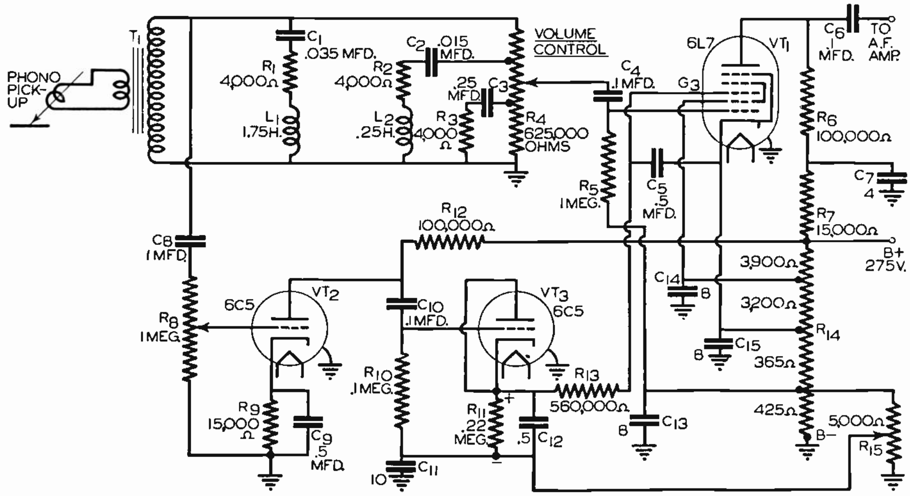

FIG. 11. Automatic volume expander circuit as used in a number of RCA electric phonographs.

Since VT_3 permits electron flow only in the direction from cathode to grid, the A.F. voltage existing across R_{10} sends through R_{11} a pulsating current which develops across this .22-megohm resistor a pulsating D.C. voltage, with polarity as indicated. Condenser C_{12} smooths out the A.F. variations, and the resulting D.C. voltage is applied to the third grid (G_3) of VT_1 through filter R_{13}-C_5, which provides the necessary time delay in the application of the A.V.E. control voltage. The negative terminal of R_{11} connects to ground through potentiometer R_{15}, which is connected across a part of voltage divider R_{14} in such a way as to provide an adjustable negative C bias which will act in series with the positive bias across R_{11}. Potentiometer R_{15} need be adjusted only when a new tube is inserted in the volume expander circuit.

At low volume levels practically no D.C. voltage is developed across R_{11}, and grid G_3 of VT_1 then receives the full negative C bias voltage developed by R_{15}. As the volume level increases, the positive voltage drop across R_{11} increases and counteracts the negative C bias, with the result that the third grid becomes less negative and the gain of tube VT_1 increases.

The action of an automatic volume expander circuit of the type shown in Fig. *11* is illustrated by the graph in Fig. *12*. The lower curve tells how the output level varies with the input level when there is no automatic volume expansion, and the upper curve gives the same information for a circuit having automatic volume expansion. Notice that as the input signal level is increased, automatic volume expansion makes the output level increasingly greater than would be obtained without A.V.E. With proper circuit design, an exact reproduction of the original program can be secured even though the volume level is condensed during the recording process in the case of a phonograph record or during the transmitting and receiving process in the case of a radio system.

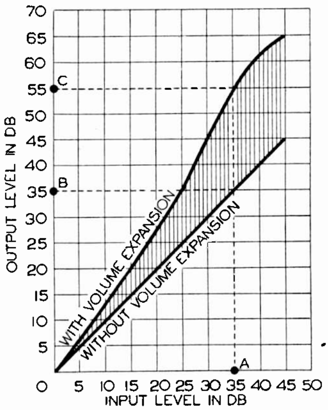

FIG. 12. Automatic volume expansion action of the phonograph amplifier circuit in Fig. *11*. In preparing this graph, a definite low input signal level was assumed and called 0 db input level, and the output level under this condition was called the 0 db output level. These curves tell that if the receiver is being fed with a signal of 35 db (point *A*), the output level without A.V.E. will also be 35 db (point *B*); with A.V.E., however, the output level will be 20 db higher, or 55 db (point *C*).

Crosley Auto-Expressionator. Another interesting automatic volume expansion circuit, which in addition provides automatic bass compensation at low sound levels, is that shown in Fig. *13*; as you can see, this is a special form of filter (some engineers call it a differential bridge) connected between the output transformer of the receiver and the loudspeaker. It is used in a number of Crosley receivers, where it is known as an *auto-expressionator*.

All four switches in Fig. *13* are operated by a single control which permits instant change-over from normal operation to A.V.E. and A.B.C. Normal operation is secured when switches SW_3 and SW_4 are open, and switches SW_1 and SW_2 are closed; a study of the circuit will show that under these conditions a direct connection exists between the loudspeaker and the output transformer, with no parts in series or shunted across the loudspeaker.

With the control switch in the A.V.E. position, switches SW_1 and SW_2 will be open and switches SW_3 and SW_4 will be closed, as indicated on the circuit diagram. We will assume for the moment that the loudspeaker is disconnected. Audio frequency current flowing from the output transformer to point A will have two paths to point B; *1*, through X_1 (a ballast resistor), resonant circuit L_1-C_1 and R_1; *2*, through R_2, resonant circuit L_2-C_2 and ballast resistor X_2. At point B the currents from the two paths combine again and return to the output transformer. Resistors R_1 and R_2 are equal in value; ballast resistors X_1 and X_2, whose resistance increase with current, are likewise the same size; resonant circuits L_1-C_1 and L_2-C_2 are also identical in characteristics, and thus the same current would flow over each path when the loudspeaker is disconnected.

When the loudspeaker is connected between points C and D, the loudspeaker current will depend upon the voltage existing between these points, and this voltage will be the difference between the voltage drops for A-C and the voltage drop for A-D. The ballast resistors used in this circuit are of special design, increasing in ohmic value as the current through them increases. This means that as the output current of the receiver increases, the resistances of X_1 and X_2 increase, causing the impedance of branch A-C to be greater than that of branch A-D and causing the impedance of branch B-D to be greater than that of B-C. Even when cold, the ohmic values of the ballast resistors are slightly greater than the ohmic values of R_1 and R_2. As a result, the circuit is in an unbalanced condition at all times, with some signal voltage always being applied to the loudspeaker. The unbalance becomes greater as the receiver output current increases and sends more current through the ballast resistors. At low values of power output, when the circuit is most nearly balanced, only a small amount of the total output power is supplied to the loudspeaker.

As the power output of the receiver increases, the circuit becomes farther out of balance and more and more of the receiver output power is applied to the loudspeaker. This increases the intensity of the louder passages, expanding the volume range. The time lag in the heating and cooling of each ballast resistor filament is an important factor in the proper operation of this circuit, for it determines the speed of A.V.E. action.

Now let us see how this circuit works as a bass compensator. Since each resonant circuit resonates at about 40 cycles, we can see immediately that for the medium and high audio frequencies, the reactances of condensers C_1 and C_2 become quite low, and the resonant circuits thus do not create an unbalance at these higher frequencies. At low or bass frequencies, however, the resonant resistance of each resonant circuit becomes quite high, causing a greater-than-normal unbalance and thus sending more current through the loudspeaker. The result is a boosting of the bass notes at low sound levels. At high sound levels, however, the resistance of X_1 increases to the point where it makes the resonant resistance of each resonant circuit practically negligible in so far as unbalance is concerned; this means that bass compensation occurs only at low sound levels.

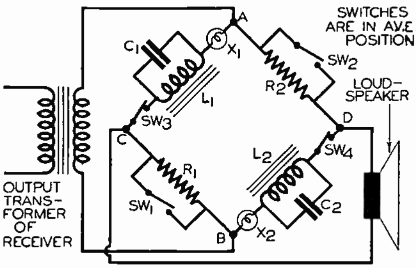

FIG. 13. Crosley Auto-Expressionator circuit, a combination automatic volume expansion and automatic bass compensation arrangement.

The Noise Problem

Signal-to-Noise Ratio. One of the most perplexing problems with which the radio engineer has to deal is that of noise. Regardless of whether this noise originates in the receiver or outside the receiver, it is reproduced along with the desired signal and is oftentimes strong enough to be annoying. Recognizing that it is impossible to eliminate noise entirely, the engineer endeavors to use apparatus which will make it negligible with respect to the desired code, sound or picture signal

This is why he continually refers to the signal-to-noise ratio (the signal voltage or current divided by the noise signal voltage or current).

Even the average radio listener unknowingly recognizes the importance of a high signal-to-noise ratio, for he invariably tunes to a local station when he desires to enjoy a high-quality musical program with a minimum of noise. This local station, being close to the receiving location and having reasonably high power, can produce at the receiving antenna a high enough signal strength to give the desired *high signal-to-noise ratio.*

Man-Made Interference Noises. Noise originating outside of the receiver is usually caused by electrical apparatus such as motors, sign flashers and other devices in which sparks occur when electrical circuits are broken. This type of noise is commonly referred to as man-made interference and is most common in industrial cities and towns, where it will predominate over atmospheric noises except perhaps on stormy days. Much of this interference can be reduced by the use of special noise-reducing antennas (considered elsewhere in the Course), but the ideal remedy is elimination of the interference at its source by the use of noise filters.

Radio stations have aided materially in reducing the effects of noise by increasing the power of their transmitters. In extremely noisy locations in cities, owners of radio receivers should be told to tune to the high-power local stations in order to secure a high signal-to-noise ratio at their receivers.

The wave form of a typical noise signal is shown in Fig. *14;* notice that there is a general noise level, existing practically all of the time, which is ordinarily not objectionable except when low-power or distant stations are tuned in; in addition, there are sharp pulses of noise or static at irregular intervals, which usually are objectionable. As a rule these pulses are of very short duration, less than .001 second.

Receiver Noise. Inside the radio receiver, thermal agitation and tube shot effect, particularly in the first R.F. stages of a receiver, result in unavoidable circuit noises. Fortunately these circuit noises can be reduced to a level less than that produced by a one-microvolt input signal (by proper selection of circuits and tubes), and the signals of most stations can override this noise level. The mixer-first detector in a superheterodyne receiver can give excessive noise, but a properly

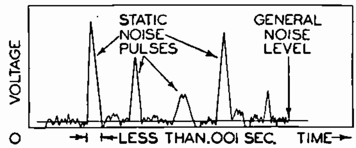

Fig. 14. Wave forms of typical rectified noise signals as they may exist in the detector stage of a radio receiver.

operated stage preceded by R.F. amplification will not have this trouble.

We shall now consider in turn the use of tone control circuits, noise impulse-silencing circuits and inter-carrier noise suppression circuits for noise-reducing purposes.

Noise-Reducing Tone Controls

An analysis of noise signals will reveal that they contain practically all audio signal frequencies, with the higher frequencies, above 3,000 cycles, predominating. It is for this reason that a tone control which suppresses or attenuates the high audio frequencies is also effective in reducing the amount of noise. Of course, this suppression of the high audio frequencies destroys the faithfulness of reproduction, and consequently tone controls are far from being a satisfactory solution to the noise problem.

Noise Impulse-Silencing Circuits

The Lamb Noise Silencer. The circuit shown in Fig. *15*, developed by J. J. Lamb, serves to eliminate noise pulses by silencing the receiver for the duration of each pulse. This circuit has been found quite valuable in commercial and communication receivers which are used for code signal reception. It has not been entirely satisfactory for broadcast receivers, however, for the action of the noise-silencing circuit has the effect of partially destroying the peaks of modulation in the received carrier, thereby creating the more serious problem of amplitude distortion.

The Lamb noise-silencing circuit is generally inserted between the I.F. amplifier and the second detector of a superheterodyne receiver, as indicated in Fig. *15*.

The signal voltage developed by the second I.F. transformer between point *A* and ground is made up of an I.F. carrier modulated by noise signals and by desired intelligence signals. This voltage is applied directly to the control grid of the 6J7 noise amplifier tube, and also to the control grid of the 6L7 second I.F. amplifier tube. The amplified output of the second I.F. tube feeds through tuned primary transformer T_3 to the 6H6 full-wave diode second detector, which through rectification provides the desired A.F. signal voltage and a D.C. voltage for A.V.C. purposes. The amplified output of the noise amplifier tube, on the other hand, feeds through tuned primary

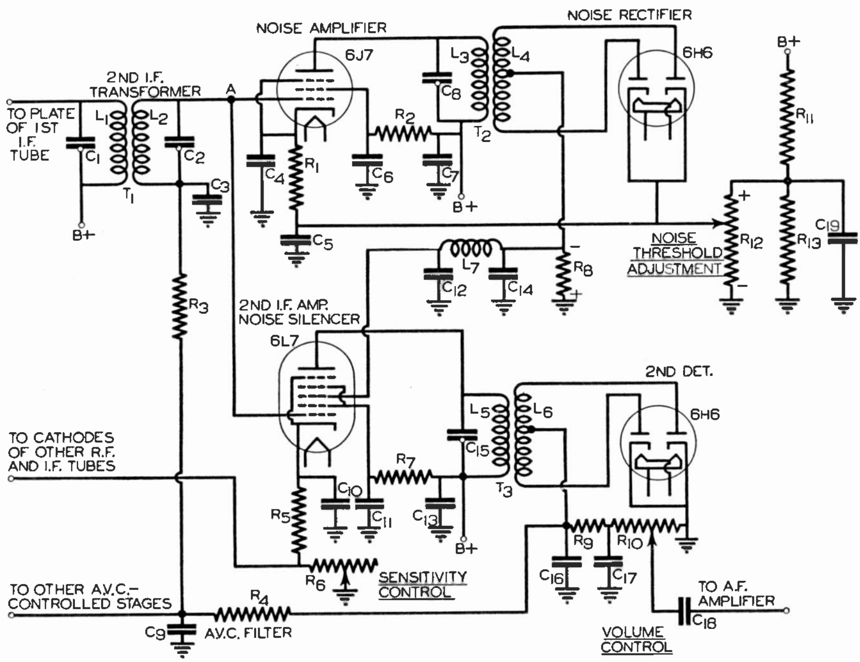

FIG. 15. The Lamb noise silencer, which silences the receiver for the duration of each strong noise pulse, is shown here incorporated in a superheterodyne receiver.

transformer T_2 (tuned to the I.F. value) to another 6H6 double-diode tube which serves as a full-wave noise rectifier. The cathodes of both the noise amplifier and noise rectifier tubes are connected to the movable contact of noise threshold adjustment potentiometer R_{12}, and the setting of this control determines the value of the negative bias which is applied to the control grid of the noise amplifier and to the diode sections of the noise rectifier. This bias on the diodes acts much like a delay voltage, in that it determines the minimum signal strength required to swing the diode plates positive and start rectification; the bias is normally set so that rectification occurs only for noise peaks extending above the desired signal level. Note that the noise amplifier tube also receives a bias from the A.V.C. circuit of the receiver through A.V.C. filter R_3-C_3; this serves to maintain the proper noise threshold level despite normal variations in desired signal level due to fading.

The rectified noise voltage, which is developed across noise rectifier load resistor R_8 when strong noise peaks are present, is made up of I.F., A.F. and D.C. components. Filter combination C_{14}-L_7-C_{12} removes the I.F. and A.F. components; the remaining D.C. voltage is applied to the third grid of the second I.F. amplifier-noise silencer tube, driving this grid more negative with respect to ground and thus blocking plate current flow for the duration of each strong noise pulse.

When no noise pulses are present, the noise rectifier plates are negative with respect to their cathodes; no current passes, no D.C. voltage exists across R_8, and consequently the third grid of the 6L7 second I.F. tube has only the normal negative C bias determined by R_5 and R_6. Desired signals are therefore amplified and detected in a normal manner by the two lower tubes in Fig. *15*.

When a strong noise pulse enters the receiver along with the desired signals, it instantly drives the noise rectifier plates positive, and the D.C. voltage developed across R_8 by the resulting rectified current flow is applied without delay to the third grid of the second I.F. amplifier-noise silencer tube, blocking plate current flow completely. Under this condition no desired or noise signals whatsoever reach the second detector, and consequently the noise is not heard. The instant the noise pulse drops below normal signal level, the noise rectifier stops conducting, the blocking voltage is removed from the third grid of the 6L7 tube, and normal receiver operation is restored.

Naturally there must be no time delay betwen the arrival of a noise pulse at the noise amplifier and the application of the D.C. silencing voltage to the third grid of the noise-silencer tube if the silencing action is to be instantaneous and is to last only for the duration of each strong noise pulse. Under this condition the receiver is silenced for such a short interval at a time that the action can scarcely be noticed by the human ear.

Diode Noise Limiter. If the load of a diode detector is instantly shunted with a large condenser when a noise pulse comes through, the audio voltage developed across this load, as well as the noise pulse, will be greatly reduced for the duration of the pulse. A practical noise-limiting circuit based upon this principle is shown in Fig. *16*. This circuit uses a type 6H6 double-diode tube, with section D_1 serving as second detector (resistors R_2 and R_3 form its load) and section D_2 serving as an automatic noise-limiter switch places a large condenser across R_3, a part of the detector load, during the time of a noise pulse (the two sections are shown as separate tubes to simplify your study of the circuit, but remember that they are actually in the same vacuum tube envelope). The D.C. voltage developed across the detector load resistors is used for A.V.C. purposes, with C_F and R_F serving as the A.V.C. filter. Condenser C is an R.F. by-pass condenser which keeps I.F. signals out of the detector load. Switch *SW* is a panel control, and must be in the closed position when noise-limiting operation is desired.

When no strong noise pulses are present, the normal rectified electron flow is from point *1* to point *3* through the detector load, and point *1* is therefore more negative than points *2* and *3*. The D.C. voltage developed between points *1* and *3* charges condenser C_1 through resistor R_1, which is of high ohmic value. Once this condenser is charged, no additional current flows through R_1, and points *1* and *4* are then at the same negative potential with respect to ground (point *3*). Diode section D_2 now acts as a high resistance, for its anode (point *4*) is more negative than its cathode (point *2*).

Now suppose that a strong noise pulse is rectified by diode section D_1 along with the desired modulated carrier. The flow of rectified current through the detector load increases instantly, and the D.C. voltage between points *1* and *3* will likewise increase instantly. C_1 will begin drawing current through R_1 in order to become charged to the new voltage value. The time constant of the R_1-C_1 combination is quite high, however (ordinarily it is from 1/10 to 1 second), and consequently C_1 cannot be charged instantly to the new voltage. Since the average noise pulse lasts about 1/1000 of a second, which is considerably less than the time constant, point *4* remains essentially at the previous low negative potential for the duration of the noise pulse, while point *2* goes instantly to the new higher negative potential. This means that the plate of diode section D_2 becomes positive with respect to its cathode for the duration of the noise pulse; current then flows through D_2 and its resistance drops to a quite low value. Since this tube is in series with high-capacity condenser C_1 across R_3, the net impedance between points *2*

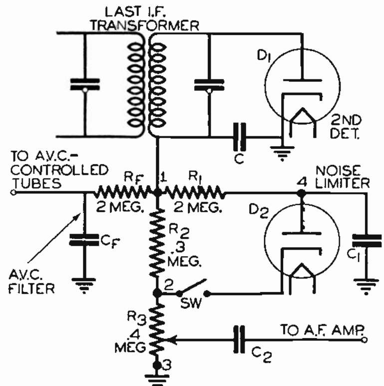

FIG. 16. Diode noise-limiter circuit, which shunts all audio signals to ground through a condenser for the duration of each strong noise pulse when switch *SW* is in the closed or noise-reducing position.

and *3* is lowered, and the A.F. voltage across R_3 is therefore lowered. As a result, the A.F. voltage fed to the first audio stage drops considerably for the duration of each noise pulse, and the A.F. output voltage of the receiver is correspondingly lowered. The instant the noise drops below normal signal level again, point *2* returns to its original potential, current flow through D_2 stops, and the D_2-C_1 shunt path across R_3 is no longer effective in limiting the audio amplifier input voltage.

Inter-Carrier Noise Suppression Circuits

In receivers having A.V.C., the noise which is heard when tuning between stations may be objectionable to some listeners. This inter-station or inter-carrier noise occurs *because automatic volume control raises the gain of the R.F. system to the point where normal external and internal noises become objectionable.* Some receivers have an inter-station noise-suppression circuit which works in conjunction with A.V.C. to silence the receiver when no station is tuned in. This inter-carrier noise suppression system is often known as quiet automatic volume control, abbreviated Q.A.V.C.; since it stops or squelches noise it is also known as a noise-squelching circuit. In some circuits the detector action is delayed for weak signals; in other circuits the I.F. or A.F. amplifier is blocked until the station signal reaches a level which is high enough to override noise which may be present, thus preventing reception of stations having less than the minimum satisfactory signal-to-noise ratio. To be sure, this has the effect of reducing the apparent sensitivity of the receiver; a switch is therefore provided to cut out this noise-suppressing action when maximum sensitivity is required regardless of noise.

The diode noise-limiter circuit shown in Fig. *16* also serves to a certain extent as an inter-carrier noise suppressor. Suppose that the receiver is tuned off a station. Diode section D_1 of course receives no input voltage under this condition, and no current flows through R_2 and R_3. Points *1* and *2* immediately assume ground potential, and point *4* will likewise be at ground potential after the time-delay interval (less than one second), during which condenser C_1 discharges to ground through R_1, R_2 and R_3, has elapsed. Noise or static signals which enter the receiver under this condition will, of course, be rectified by diode section D_1, making point *2* negative with respect to ground. Point *4* remains at ground potential because of time-delay action, making the plate of D_2 positive with respect to its cathode. Noise signals reaching point *1* will therefore take the low-impedance path through R_2, D_2 and C_1 to ground. Noise is thus diverted from the input of the A.F. amplifier and will not be reproduced by the loudspeaker when tuning slowly from station to station. Of course, the noise-reducing action of this circuit ceases as soon as the time-delay interval has elapsed.

In the more conventional types of inter-carrier noise suppression circuits, the receiver is made inoperative for weak signals on the assumption that the noise signals heard between stations will be weaker than any of the desired strong carrier signals. Three types of inter-carrier noise suppression circuits are used for this purpose: *1, biased demodulator circuits,* which place a bias or delay voltage on the diode detector so that only carrier signals above a certain level will be demodulated; *2, A.F. amplifier blocking circuits,* which block or prevent operation of the A.F. amplifier until the carrier signal exceeds a definite minimum value; *3, I.F. and R.F. amplifier blocking circuits,* which prevent operation of these amplifiers until the carrier level becomes appreciably higher than the noise level. Let us consider one example of each of these inter-carrier noise suppression methods.

Biased Demodulator Circuit. As you know, delayed A.V.C. action can be obtained by inserting in the separate A.V.C. diode rectifier circuit a delay voltage which must be exceeded by the carrier signal before the rectification required for the production of an A.V.C. voltage can take place. Usually, a separate diode rectifier is then required for demodulation purposes.

If we introduce this delay voltage directly into the diode rectifier circuit used for demodulation, so that only signals above a certain minimum level will be rectified, we have one form of inter-carrier noise suppression. Weak carrier and noise signals cannot overcome this delay voltage, and hence are not reproduced by the loudspeaker as the receiver is tuned from one station to another. With this arrangement, however, the receiver must be tuned to fairly strong carriers in order to secure satisfactory reproduction, for medium-strength signals will undergo a certain amount of amplitude distortion.

A circuit incorporating this biased demodulator type of inter-carrier noise suppression is shown in Fig. *17*. In the *D* (distance) position of switch *SW*, the two diode sections of the 6B7 tube together serve for demodulation and A.V.C. purposes, and there is no delay voltage in the diode circuit. Under this condition all signals, including noise, are detected in the usual manner.

When the switch is placed in the *L* (local) position, the voltage drop across cathode bias resistor R_C acts in series with the diode circuit. This delay voltage must be exceeded by the signal before A.V.C. action and demodulation can take place, and the carrier signal must be reasonably larger than this delay voltage before complete demodulation can occur. If R_C (which acts also as C bias resistor for the amplifier section of the 6B7 tube) is replaced with a potentiometer and the movable arm is connected to the *L* terminal of the switch, the amount of delay voltage in the rectifier circuit can be varied.

A.F. Amplifier Blocking Circuit. In Fig. *18* is a well-known example of a circuit which employs quiet automatic volume control (Q.A.V.C.) action to block or cut off the input signal to the A.F. amplifier whenever the carrier level becomes so low that noise will be objectionable. As you can see, a special Q.A.V.C. tube is inserted between the detector and the first A.F. stage, with a switch in the cathode lead to make this tube inoperative when ordinary receiver action is desired.

Observe that the plate-cathode resistance of the Q.A.V.C. tube acts in series with a 1-megohm resistor (part

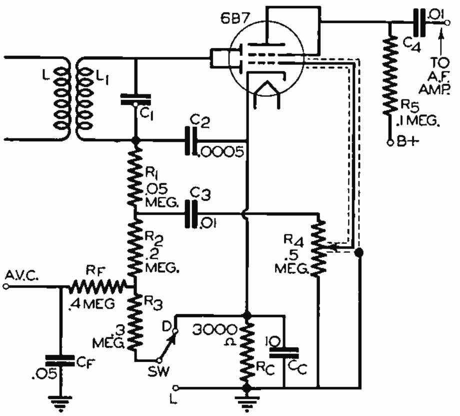

FIG. 17. Biased demodulator type of inter-carrier noise suppression circuit, as used in the Silvertone Model 7149 receiver. This circuit reduces the noise ordinarily heard in an A.V.C.-controlled receiver when tuning between strong stations.

72) between $B+$ and ground G, with the screen grid of the type 77 A.F. amplifier tube connected to point X as indicated. We thus have a voltage divider, with the screen grid voltage of the type 77 tube being determined by the plate-to-cathode resistance of the Q.A.V.C. tube. The lower this resistance, the lower will be the positive voltage developed across the Q.A.V.C. tube and applied to the screen grid of the A.F. tube, and the lower will be the gain of this type 77 tube.

Now let us see how weak signals lower this plate-cathode resistance and thereby block the first A.F. tube so as to suppress inter-carrier noises. Notice that the control grid of the Q.A.V.C. tube connects to the diode second detector load through a 4-megohm resistor. Under a no-carrier-signal condition, the only D.C. voltage across diode load resistor *55* will be a very low D.C. voltage produced by noise signals; condenser *52* and resistor *53* remove all A.C. component which might otherwise reach the Q.A.V.C. tube. The Q.A.V.C. tube thus gets a small negative C bias, under which condition *its plate current is high* and *its plate-to-cathode resistance quite low.* This makes the screen grid voltage of the type 77 tube low enough to prevent amplification of any noise signals which are fed to the control grid of this tube through D.C. blocking condenser *57*. Potentiometer *82* controls the screen grid voltage on the Q.A.V.C. tube and thus determines the amount of plate current which will flow during this low negative C bias condition. This potentiometer can be adjusted so that signals below any desired level will be blocked.

When a desired strong carrier signal reaches the detector, the resulting D.C. voltage across detector load resistor *55* increases the negative bias on the control grid of the Q.A.V.C. tube, increasing the plate-to-cathode resistance of this tube and thereby increasing the screen grid voltage on the 77 tube enough to permit amplification of the desired signals in the usual manner.

In the circuit just described, blocking action was secured by varying the screen grid voltage of the first A.F. amplifier tube; the same results can be secured by applying the blocking voltage to the control grid of this tube, as is done in the inter-carrier noise suppression circuit in Fig. *19*. No extra tube is required here, for the triode section of double-diode-triode tube VT_1 is used to produce the required blocking voltage. A desired carrier signal is rectified by the combined diode sections of the tube in the usual manner, developing a D.C. voltage across detector load resistor R_2. The audio voltage which also exists across this resistor is fed through D.C. blocking condenser C_5 to the control grid of the pentode first A.F. amplifier tube VT_2, while the D.C. voltage is fed through resistor R_3 to the control grid of the triode section of tube VT_1. Plate current for this triode section flows through resistor R_4, producing across it a voltage drop which acts with the drop across voltage divider resistor R_9 to provide C bias for VT_2. You can readily see that when the current through R_4 is small, the C bias on the

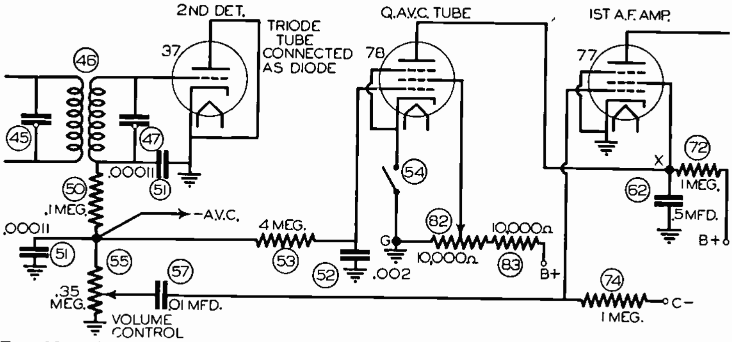

FIG. 18. This quiet A.V.C. circuit, used in the Philco Model 16-122 receiver, acts upon the screen grid of the first A.F. tube, blocking the amplifier whenever the receiver is tuned between strong stations. It thus serves to suppress inter-carrier noise.

pentode tube will essentially equal the voltage drop across R_9 which is ordinarily about 2 volts. This is the C bias required for normal A.F. amplification of a desired signal.

When no carrier signal is being rectified by the diode section, the D.C. voltage across R_2 is essentially zero, which means that the triode section of VT_1 will be operating at zero bias. This makes the plate current of this section high, and this large current flowing through R_4 increases the negative C bias considerably on the control grid of VT_2. As a result, the pentode cannot amplify any weak signals or noise signals which may appear across R_2 as the receiver is tuned between stations.

When a desired strong carrier signal is tuned in, the D.C. voltage developed across R_2 drives the grid of the triode highly negative, reducing the plate current of VT_1 and restoring the C bias of VT_2 to its normal value.

I.F. and R.F. Amplifier Blocking Circuit. Noise signals and weak carrier signals which are ordinarily heard when tuning between stations can be suppressed by applying to the I.F. and R.F. sections the same principle as that just described in connection with the A.F. amplifier blocking circuit. In Fig. *20* is shown a circuit which, when switch *SW* is closed, will accomplish the desired results, driving all of the control grids in the R.F. and I.F. sections highly negative for weak signals and placing a negative bias on the second detector diode sections to prevent rectification of weak signals. Normal bias is restored immediately when the carrier signal becomes greater than the minimum desired level.

An analysis of this circuit starts with resistor R_{13}, across which the second detector develops the desired audio voltage and the D.C. voltage for A.V.C. purposes; the plate current of the whisper control tube also flows through R_{13}, developing across it an additional voltage for blocking purposes. When no carrier signal is present, the only voltage across R_{13} is that due to plate current of the whisper control tube, and the magnitude of this voltage is determined by the setting of movable arm *P* on potentiometer R_{18} and by the negative bias on the control grid of this tube. Point *1* will be negative with respect to the chassis during this no-carrier-signal condition.

Now observe that the output of the I.F. amplifier is fed to the upper diode

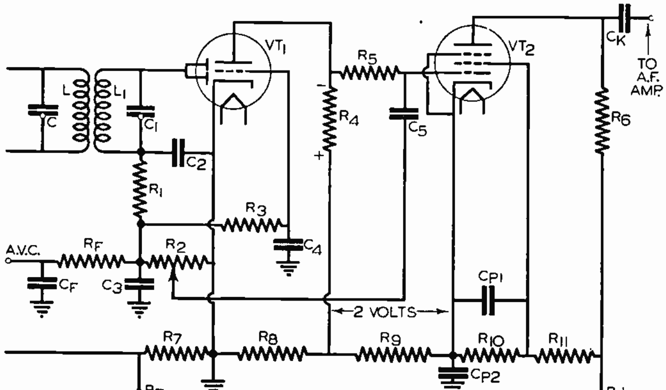

FIG. 19. Another form of quiet A.V.C. circuit, which acts upon the control grid of the first A.F. tube rather than on the screen grid.

of the whisper control tube through C_{19}. When no carrier signal is present, there will be no rectified current flow, and point X and the control grid of the whisper control tube will therefore be at cathode potential; as a result a large plate current flows through the triode section of this tube, then through SW, R_{13}, R_{16}, R_{17}, R_{18} up to P and back to the cathode. This develops a large negative voltage across R_{13} and since this voltage is applied to the A.V.C.-controlled tubes through the usual A.V.C. feed system, it blocks these tubes.

When weak intelligence and noise signals are present in the output of the I.F. amplifier, such as when tuning between powerful local stations, these pass through C_{19} to the upper diode section of the whisper control tube, where they undergo rectification and produce D.C. voltage drops across resistors R_4, R_{29} and R_7. The direction of electron flow is such that point X on R_7 will be negative with respect to the cathode of the tube; since the control grid of the triode section of the whisper control tube is also connected to this point, it gets a negative C bias. Plate current flow is thereby reduced, and the voltage drop produced by this plate current is correspondingly reduced. This reduces the negative bias applied to the R.F. and I.F. sections through the A.V.C. system, but the negative bias on the second detector diode sections is still high enough to prevent signal rectification.

When a sufficiently strong carrier signal is tuned in, the diode sections of the whisper control tube will pass enough current to block plate current flow through the triode section (by increasing the voltage drop across R_7), and practically no current will be drawn through R_{13} by the whisper control tube. This completely releases the delay action of the whisper control tube upon the A.V.C. circuit, restoring normal high sensitivity of the receiver. A.V.C. action remains normal with further increases in carrier level. The setting of potentiometer R_{18} determines the minimum carrier level at which the delay action is released and normal A.V.C. action begins.

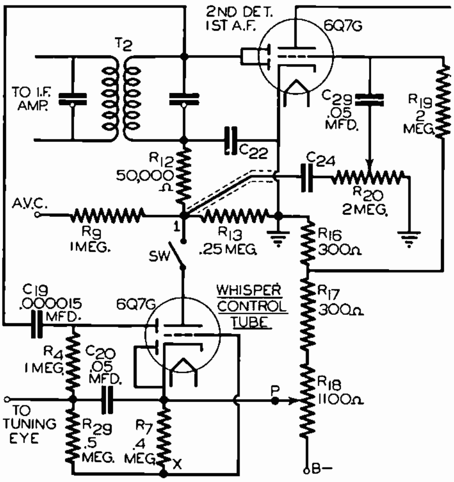

FIG. 20. This inter-carrier noise suppression circuit, used in the Silvertone Model 4666 receiver where it is called a "whisper tuning control," serves to block the R.F. and I.F. amplifiers through the A.V.C. system, and at the same time provides delayed A.V.C. action.

The circuit in Fig. *20* thus provides a combination of inter-carrier noise suppression and delayed A.V.C. action. The listener is able to tune from one station to another even at low sound levels or whisper levels without hearing inter-station noise, and thus this circuit has been called a whisper control circuit. Opening switch SW removes the delay action, allowing reception of weak signals along with noise. Observe that the opening of this switch does not stop the functioning of the diode section of the whisper control tube; this is essential because the diode also provides a D.C. control grid voltage for the electron ray indicator tube or tuning eye.

TEST QUESTIONS

Be sure to number your Answer Sheet 24FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What three types of circuits are used for reducing the annoying effects of atmospheric noises which enter a radio receiver?

2. At low loudness levels, is the human ear more sensitive to medium-frequency sounds (500 cycles to 5,000 cycles) than to low-frequency sounds (below 500 cycles)?

3. Why does a simple condenser tone control give an apparent boost in bass signals?

4. How can a conventional tone control provide treble control?

5. What type of circuit is present when the volume control has a fixed tap which is connected to ground through a condenser and a resistor?

6. Why is degeneration intentionally introduced in the General Electric Model F-77 receiver circuit shown in Fig. *9*?

7. Upon what fact does the operation of the most widely used automatic volume expansion system depend?

8. Why should a receiver be tuned to a local station when a minimum of noise is desired?

9. Why is inter-carrier noise heard in receivers having A.V.C.?

10. Name the three conventional types of inter-carrier noise suppression circuits.

LIGHT-SENSITIVE CELLS FOR CONTROL CIRCUITS

25FR-2

PIONEER HOME STUDY RADIO SCHOOL

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NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

ACTION SPEAKS FOR ITSELF

"Be sure you are right, then go ahead"—this has been the motto of many of the world's great men.

In most cases you know instinctively what is right, your decision being based upon your past training, your experience, your common sense and your conscience. In these cases, *act!* Waste no valuable time arguing with others who know less than you; waste no time trying to "pound" your ideas into a cynical world—take the initiative yourself.

It is a thousand times better to *do things* and let your deeds speak for themselves than to spend your time explaining why your proposed course of action is right. Too many friends can hinder your success if you take time to justify your actions to each one of them.

If you need advice—if you are not exactly certain you are right, then go to men who are capable of giving authoritative answers to your questions. You'll find that leaders of men, authorities in a particular field, are glad to answer serious, well-planned questions. Analyze their advice in connection with your own experiences, make your decision, then act!

Give this plan a tryout; you will accomplish a great deal more work, and I am sure you will be a lot happier.

J. E. Smith.

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Light-Sensitive Cells for Control Circuits

THE ELECTRIC EYE

UNDOUBTEDLY you have read about the magic *electric eye,* a seemingly mysterious device which causes doors to open as you walk toward them, turns on roadside signs in the country as an automobile approaches, sounds alarms when anyone walks over a forbidden area, prevents workers from placing their hands in dangerous machines such as punch presses, and does thousands of other equally amazing and practical feats. In this lesson you will learn about the many different types of electric eyes, which are called either photoelectric or *light-sensitive cells* by technical men. You will learn how each type of cell is constructed, how it functions, and how it can be made to replace man's eyes.

Thousands of light-sensitive cells are in use today in every corner of the world, responding to beams of light which may be perfectly invisible to the human eye, detecting every change in illumination from the sun or from other sources of light; these cells change their *electrical characteristics* with variations in the light which they "see." These light-sensitive cells start and stop heavy machinery, count objects moving past at a mile-a-minute speed, guard against fire, smoke, water, and burglars, and even "read" books for blind persons. Cigars, beans, eggs, fruit and other products are being graded as to color or shade by light-sensitive cells, faster and more accurately than by the human eye.

Although the field of photoelectricity is not new, its development into commercial practicality has taken place within the last few years. Scientists have known for more than one hundred years that certain electrical effects could be obtained by exposing chemical elements and compounds to light, but the lack of suitable apparatus to make use of this electrical effect, and the poor sensitivity of the light-sensitive cells then available, prevented the commercial utilization of this photoelectric action.

Recent developments in the field of television and electronics resulted in a great demand for photoelectric devices, and today the electric eye is looked upon as a dependable and invaluable device for industrial and commercial applications. As men in industry and business realize the value of electronic control, more applications will find their way into everyday use. Only the imagination of man stands in the way of accomplishing deeds which are best called *magic*.

As a sideline for the radio man, the field of photoelectric control offers great opportunities, for in this branch of electronics are many simple, basic applications requiring only standard equipment now available at reasonable prices, a knowledge of the fundamentals of photoelectricity and a goodly amount of mechanical ingenuity and common sense.

A COMPLETE PHOTOELECTRIC INSTALLATION

Before taking up the different types of light-sensitive cells I want to describe briefly a complete photoelectric installation, in order that you can better understand the important part which is played by the light-sensitive devices which you will study. The six important basic parts of a complete photoelectric control installation are as follows:

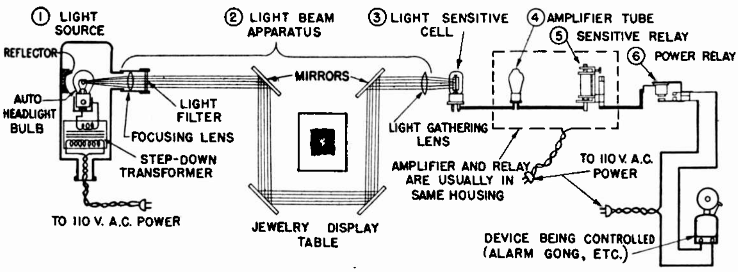
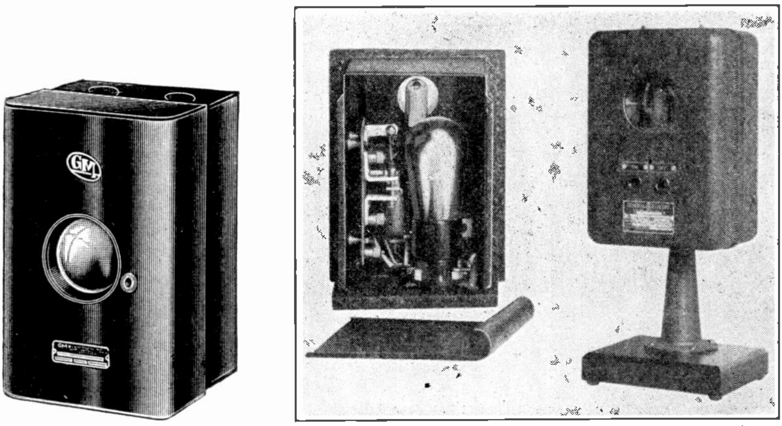


FIG. 1. Simplified diagram of a complete photoelectric installation such as might be used to protect valuable jewelry on a display table. The infra-red light filter on the light source makes the light beam practically invisible.

1. *The source of light.* The light which is directed upon the electric eye may be the natural light from the sun or artificial light from an incandescent lamp, gas flame, arc light, etc.
2. *Light beam apparatus.* On some photoelectric installations it is necessary to concentrate the light into a narrow beam in order to make it travel over a definite path before reaching the light-sensitive cell; lenses and curved mirrors are used at the light source to accomplish this. Again, it may be necessary to change the direction of the beam of light by means of a mirror, or to make the light beam invisible to the human eye by using filters which absorb the visible light rays. Where insufficient light reaches the light-sensitive cell it may be necessary to use a collecting lens which gathers light and concentrates it upon the relatively small area of the light-sensitive cell.

3. *The light-sensitive cell.* The electric eye or light-sensitive cell changes its electrical characteristics in response to changes in illumination.
4. *The photoelectric amplifier.* With certain types of light-sensitive cells it is necessary to build up the strength of the variations in current or voltage from the light-sensitive cell by means of a vacuum tube amplifier, which may contain one or more ordinary radio amplifier tubes or gaseous tubes.
5. *The super-sensitive and sensitive relay.* When the relay is connected directly to the output of the light-sensitive cell, a super-



Courtesy G-M-Labs. Inc. *Courtesy J. T. Rhamstine* *Courtesy General Electric Co.*

FIG. 2. Typical commercial photoelectric apparatus. Each unit contains a gas type photoelectric cell, an amplifier tube, and a sensitive relay. The G-M Phototube Relay (left) has a 3" diameter light-collecting lens mounted in front of the photocell. Center: Rear view of the Rhamstine Photoelectric Relay, with cover removed to show tubes and relay. Right: G-E Photoelectric Relay for indoor illumination control.

sensitive relay is needed; when connected into the plate circuit of the amplifier tube, an ordinary sensitive relay is satisfactory. The contacts of the sensitive relay start and stop the electrical equipment which is to be controlled, or control the current to the operating coil of a heavy duty relay. Relays which operate on currents of less than 250 microamperes are classed as *super-sensitive;* those which require from ¼ to 10 milliamperes are classed as *sensitive* relays.

6. *The heavy duty or load-controlling relay.* This additional relay, used after the sensitive relay, is necessary in installations where the preceding relay is not capable of handling the cur-

rent required by the device being controlled. In some very large installations two or even more power relays, one operating the other, are required. Relays which require more than 10 milliamperes are considered the *heavy duty* type.

The simplified diagram in Fig. *1* gives you the relations between the various parts in a typical photoelectric installation (the alarm gong sounds when light beam is intercepted at any point along its path). Fig. *2* shows a few typical commercial photoelectric units having several of the basic parts mounted in one housing.

By properly choosing circuits and relays, you can make a change in cell illumination produce any desired control operation, choose the degree of light intensity at which the relays will operate, and speed up or slow down the action of your controls as much as you desire. The only actual limitations to a photoelectric control system are the sensitivity of the light-sensitive cell with its associated apparatus and the ingenuity of the control engineer.

As an example of how this photoelectric equipment operates, I will describe a typical installation, that where a photoelectric eye is used to open the doors of a garage when a car enters the driveway. The light source can be mounted on a post on one side of the driveway; this source throws a beam of light across the driveway at such a height that the beam will be intercepted by a car coming in or going out. The beam of light is directed on a light-sensitive cell mounted on the opposite side of the driveway. The apparatus is so connected that nothing happens while the beam of light illuminates the light-sensitive cell. When an automobile approaches, the light beam is interrupted; the light-sensitive cell detects this immediately and causes the value of the current in the plate circuit of the amplifier tube to change. This operates the sensitive relay; its contacts close and send current through the heavy duty or power relay. The contacts of the power relay close, sending current through the electric motor which operates the door opening mechanism. All this happens so quickly that the garage doors are completely open by the time the car reaches them.

WHAT IS LIGHT?

The importance of light in any photoelectric installation should be quite obvious from what I have said up to this time. I think you will find this Lesson more interesting if you first learn a little about light itself; that is why I am including a brief discussion of light and how it is measured.

The greatest source of light is the sun; it sends out waves which are very similar to those which we use in radio communication except that they are a great deal shorter in wave length. Light waves which can be seen by the human eye vary in length from 40 to 70 millionths of a centimeter. The wave length of light can for convenience be expressed in millimicrons, units of length equal to one-thousandth of one-millionth of a meter or one ten-millionth of a centimeter; the human eye therefore responds to a light between 400 and 700 millimicrons, as shown in Fig. *3*. Radio waves, which range from .01 to 25,000 meters in length are therefore more than one million times as long as light waves. Study Fig. *3* carefully, noting how the human eye responds to the different colors in the visible spectrum.

The electric eye, in addition to "seeing" those frequencies of light which can be detected by the human eye, will also respond to ultra-vio-

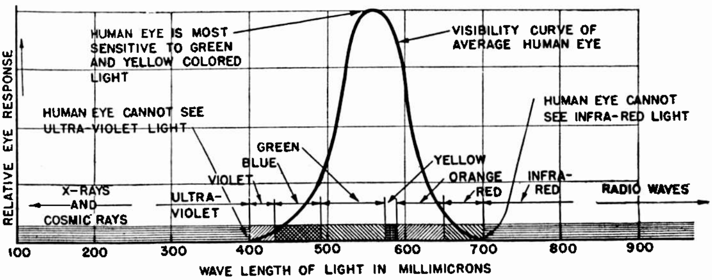


FIG. 3. **The relative sensitivity of the average human eye to light of various colors (various wavelengths) is given by this curve.**

let light and infra-red light, both of which are invisible to the human eye. It is this characteristic of the electric eye which makes it possible to use invisible light beams to control machinery or to operate burglar alarms.

Light-sensitive cells respond to various types of artificial light as well as to natural light. The ordinary incandescent electric lamp is the most common of artificial sources of light for photoelectric equipment. Here the filament, a very fine wire of high resistance, is heated by a current of electricity until it becomes incandescent and gives off light. Electric lamps designed for automobile headlights are ideal for photoelectric work because the source of light is concentrated into a very small space, approximating a point source of light. The smaller the source of light, the easier it is to focus that light into a beam.

Other artificial sources of light include natural gas lights, coal gas lights, the carbon arc lamp, the mercury vapor lamp, and gaseous conduction tubes (better known as neon tubes).

How Light Is Measured. As you know, the wax or tallow candle was one of the first artificial sources of light. When new light sources began to take the place of the candle, it was natural that their power should be expressed in terms of the old and familiar candle. Eventually a candle made according to certain specifications and burned under certain conditions was selected as the unit of light intensity, and the light given off by this candle was said to have an intensity of *one candlepower.* If an electric bulb was found to be 40 times as strong as this candle, it was said to have a candlepower rating of 40. The average electric lamp used in the home has an intensity of about one candlepower per watt of power used.

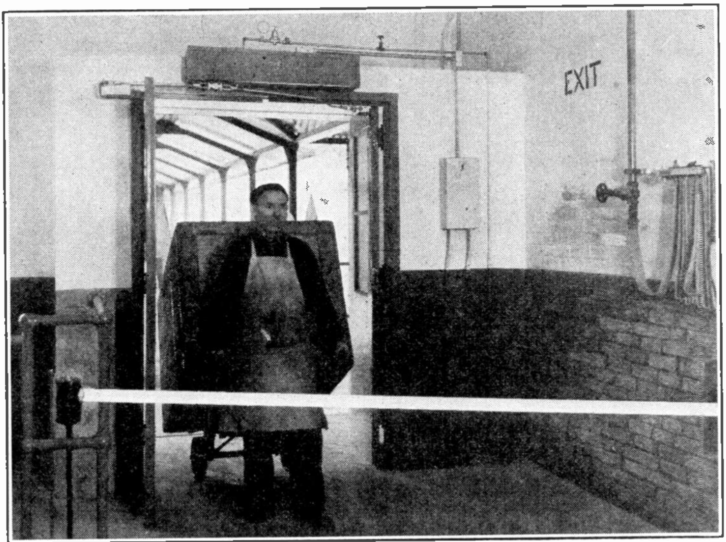
Undoubtedly you have noticed that the strength of the light on a certain object, such as a book, decreases very rapidly as the book is moved away from the source of light. Actually the intensity of the illumination produced by a source of light varies *inversely as the square of the distance* from the source of light. In other words, if the illumination at a point two feet from the source is a certain value, the illumination at a point four feet from the source (twice as far away) will be one-fourth of that at the first point.

The practical unit of illumination is the *foot-candle.* This is the amount of light received on a surface which is directly facing and one foot away from a light source which has an intensity of one candlepower. For example, the correct illumination for general reading purposes is about 15 foot-candles; this means that the illumination on the printed page should be equivalent to that which would be produced by 15 standard candles located one foot above the page.

Another unit of illumination, the *lumen,* represents the *amount* of light (or light flux) falling on a surface one square foot in area, every point of which is one foot from a point source of light having a strength of one candlepower. Practically, however, to determine the amount of light (number of lumens) falling on a uniformly-illuminated surface of limited area, you multiply the area of the surface (in square feet) by the intensity of the illumination at the surface (in foot-candles); the answer will be in lumens. To determine the number of lumens of light emitted by a lamp, multiply the candlepower rating of the lamp by the number 12.6.

The foot-candle is a measure of the *intensity* of light at a *certain point,* such as at the face of a light-sensitive cell; the lumen is a measure of the *amount* of light falling on a *given area,* such as the sensitive surface of a light-sensitive cell. *Light intensity at the cell (in foot-candles) multiplied by effective area of the cell (in square feet) gives the number of lumens of light on the cell.*

Brightness is another factor which must be considered by the photoelectric engineer, for he will often direct a light on a certain surface and use an electric eye to pick up the light reflected from that surface. Brightness can be expressed in *candles per unit area;* this means that brightness is a measure of the ability of an illuminated surface to act as a source of light. For example, a surface has a brightness of 10



Courtesy The Stanley Works

Installation of photoelectrically controlled door opener in a factory. Light source is at left, and photocell cabinet at right. One light beam is directed across each side of doorway; interrupting first beam causes pneumatic door operator to open doors, and interruption of second beam, after person has passed through doorway, causes doors to close again. Interlocking relays prevent improper operation.

candles per square foot when each square foot of this surface reflects as much light in a given direction as would 10 candles.

Light Sources. In photoelectric work it is generally very desirable to have a definite beam of light directed on the electric eye. Naturally, it is desirable to use as small a light source as possible, in order to economize on power and make a compact unit. Most commercial light sources for photoelectric work use the small but powerful 32-candlepower automobile headlight bulb, getting the required low voltage from a step-down transformer which is connected to a 110-volt A.C. line, and concentrating the light into a beam with a lens. Since only that light which falls on the lens is useful in producing the beam, reflectors are generally used back of the bulb to reflect light back to the lens. Some light is absorbed at each reflection and each passage through a lens, so it is usually necessary to make adjustments of the light source and the relay apparatus until satisfactory operation is secured.

TYPES OF LIGHT-SENSITIVE CELLS

Although photoelectric or light-sensitive cells of various types are being manufactured today by many different firms, all of these can be divided into three basic classes. These three classes of light-sensitive cells are:

1. *Photoemissive cells.* Electrons, emitted from the cathode of the cell by the action of light, are collected by an anode which is at a positive potential. Photoemissive cells are better known as *photocells;* some technicians prefer to call them phototubes, since they are always built into glass envelopes like glass type radio tubes. In many technical books and articles you will find all types of light-sensitive cells referred to as photocells, but you can generally determine which type of cell is meant from the nature of the article. Remember that when we speak of photocells in this book we are referring specifically to *photoemissive cells.*
2. *Photoconductive cells.* In these cells the resistance (or conductivity) of a material changes under the action of light. Selenium is the most common resistance material used in these cells; you will find that photoconductive cells which use selenium are often referred to as *selenium cells.*
3. *Photovoltaic cells.* These cells develop their own voltage under the action of light. They are likewise often referred to as photoelectric cells, but photovoltaic cells or self-generating cells are the terms which will be used in this Course. The term photoelectric cell, as used in this Course, will refer to light-sensitive cells in general, regardless of their type.

Each light-sensitive cell has its own characteristics, and naturally transfers these characteristics to the associated photoelectric apparatus. The successful photoelectric technician must be familiar with each type of cell, in order that he can choose the best cell, the best circuit, and the best apparatus for each particular job. Knowing how the different cells behave, he can compare the advantages and disadvantages of the various types of photoelectric units on the market and can understand the specifications and ratings for each unit. Some cells are more dependable than others; some require external sources of voltage which may fail; some cells have a comparatively short life; all these factors must be taken into consideration where failure of the photoelectric control would in any way endanger human life or damage valuable equipment. For these reasons I am giving you, in the following pages, detailed descriptions of each type of cell, telling how they are constructed, how they operate, and basically how they are used.

PHOTOEMISSIVE CELLS

The photoemissive cell can be compared to a diode or two element tube, for both contain two electrodes mounted in a glass envelope. In the radio tube, the electrons which make up the current through the tube are secured by heating the cathode (filament), but in the photoemissive cell the rays or "bullets" of light activate the sensitized surface of the cathode and cause electrons to be emitted. The other electrode, called the anode, attracts the emitted electrons, as it is positively charged with respect to the cathode. The photoemissive cell acts like a variable resistance whose ohmic value changes with light; the more light there is shining on the cell, the greater is the current passed and the less is the resistance of the cell.

The construction of a typical photocell is shown at *A* in Fig. *4*. Here the cathode is a semicircular cylinder of metal (usually oxidized silver) supported inside the glass envelope by stiff wire leads made of nickel. The anode is simply a nickel rod or wire mounted in the axis of this cathode cylinder. The anode is untreated, but on that surface of the cathode which faces the anode is a thin film made up of caesium oxide, sodium, potassium, or lithium. I suggest that you consider the cathode film as simply a layer of light-sensitive chemical compound.

Soda-lime glass is used as the envelope for most of the photocells made today, it being easy to form into the desired shape. Higher priced cells use either pyrex glass or fused quartz, for these have lower light losses and allow more ultra-violet rays to pass. Lead glass is never used for photocells, because it combines chemically with the materials used on the cathode, discoloring the envelope, and because lead glass is a poor transmitter of light (it absorbs a high percentage of the rays).

The modern photocell is made by automatic machinery in much the same way as radio tubes are made. The proper chemical is sprayed on the cathode, the two electrodes are mounted in the glass stem, and this stem is then sealed to the glass envelope. The bulb is evacuated by vacuum pumps, then given a special treatment in a high frequency electrical furnace to complete the processing of the coating on the cathode.

Note that the anode in a photocell is the *smallest* electrode; this is necessary so the anode will not cast too large a shadow on the cathode and reduce the efficiency of the cell. In regular radio tubes the opposite holds true, for the plate or anode of a radio tube is the *largest* electrode.

Two types of photocells are in common use, these differing only in that one contains a gas while the other has a "hard" or high vacuum. Gas is introduced to give an increased current output for a given amount of light. The inherent sensitivity of a photoemissive cell is controlled by the cathode materials; the introduction of a gas reduces the effect of the space charge and permits greater sensitivity to be attained.

Photoemissive cells are always used in conjunction with one or more amplifier tubes, for the current passed by the cells is too small to operate even a supersensitive relay. A typical circuit which can be used with either gas or vacuum type photocells is given in Fig. *4B*. An ordinary radio tube such as the 30 or the 12A serves as amplifier tube; the relay is of the sensitive type, with its contacts connected into the power supply leads of the device being controlled. In this basic circuit the grid of the amplifier tube has a negative bias, and therefore draws no current. The relay resistance (usually somewhere between 1,000 and 10,000 ohms), is comparatively low with respect to the circuit resistance, so consider the photocell and resistor *R* to be in series across points *A* and *B* of the batteries. When the photocell is dark (no light on it), its resistance is very high and no current flows through it and *R;* the resistance drop (IR drop) in *R* is very low, then, and the grid of the tube can be considered as having almost the same negative potential as point *A*. With a highly negative grid, little or no electron current passes from cathode to plate in the amplifier tube and the relay armature is not attracted to the relay core.

When light falls on the photocell, reducing its resistance, a larger current flows through *R* and the photocell (resistors in series add; reducing the resistance of the cell reduces the resistance of the combination and allows more current to flow) and the IR drop in *R* becomes greater. Electron flow is from *A* through *R,* through the photocell and through the relay to *B;* point *C* is more positive than point *A*. The grid thus becomes more positive than point *A* when light falls on the photocell; with a lowered negative bias on the grid, plate current flows through the relay, causing the armature to be attracted to the relay core. In a practical circuit the grid bias would be controlled by a potentiometer connected across the grid bias battery, in order to adjust the circuit for maximum response to changes in light.

It is only necessary to reverse the positions of *R* and the photocell in this circuit in order to make the relay operate when the cell, originally illuminated, is darkened (as when some object interrupts a light beam directed on the cell).

VACUUM TYPE PHOTOCELLS

In the vacuum type of photocell the total tube current is made up of electrons which are emitted by the cathode (see Fig. *4C*). This cell

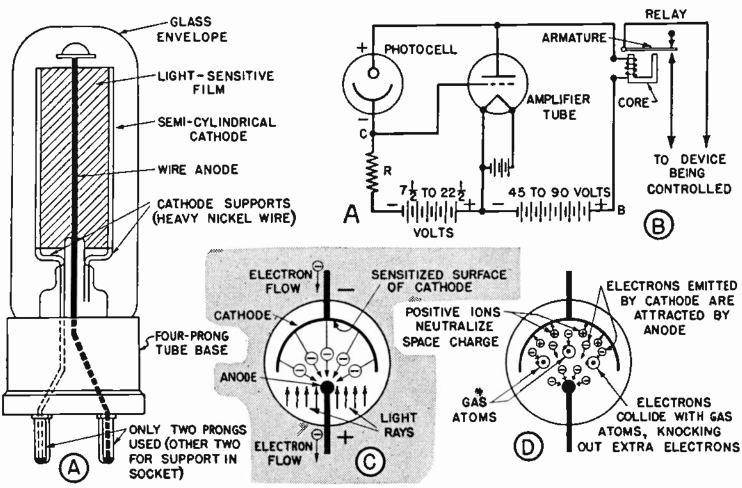


FIG. 4. The construction, the schematic symbol, the theory of electron flow in both gas and vacuum type tubes, and the diagram of an amplifier circuit for a typical photoemissive cell are given here.

will respond to light variations of almost any frequency, which means that it is ideal for use with television apparatus and for the fastest of counting jobs. The capacity between the anode and cathode is the only important limitation to the highest light variation frequency to which this cell will respond.

Just as curves are used to illustrate the characteristics of the vacuum tubes which you have studied, so too can curves be used to illustrate photocell characteristics. The stronger the light the greater will be the current flow, but does this relation hold at all times? Is the current affected by the voltage applied to the cell? These are important questions which can be answered easily by making some simple tests.

Current-Illumination Curve. This important photocell characteristic curve is obtained by applying a fixed voltage (say 40 volts) to a cell and measuring (with a micro-ammeter) the current passed by the cell at different intensities of illumination. With a vacuum type photocell the results obtained will give a curve like that in Fig. *5A*, showing that the current output is directly proportional to the amount of light falling on the cell. Here the cell current doubles when the light flux is doubled.

With a vacuum type photocell, light varying in intensity at frequencies as high as 1,000,000 cycles (encountered in television systems) can be accurately converted into electrical variations, for the straight line characteristic shown in Fig. *5A* holds true at all frequencies encountered in practical television service.

Current-Voltage Curve. If a vacuum type photocell, illuminated by a constant light intensity of about .5 lumen, were connected to a variable source of D.C. voltage, and measurements were made of the current passed by the cell for each value of voltage, the curve obtained would be like that shown in Fig. *5B*. Notice that once the voltage reaches a certain value (above the knee of the curve) the cell current increases very little as the voltage is further increased. At this point, called the *saturation value* of current, practically all of the electrons emitted by the cathode under the action of the fixed light are drawn to the anode. Clearly, then, there is little to be gained by increasing the voltage above this value. A small size vacuum cell can safely withstand up to 500 volts; oftentimes such a high value must be applied to the cell because of circuit conditions.

A standard incandescent electric lamp, whose voltage is adjusted to operate the filament at a constant and fixed temperature, is used in securing characteristic curves for all types of light-emissive cells; the illumination on the cell is varied by changing the distance between lamp and cell rather than by varying the light source.

The curve in Fig. *5B* can be made to show the relation between the sensitivity of the cell and the cell voltage simply by dividing the current values by the number of lumens of light on the cell. The vertical scale at the right in Fig. *5B* was obtained in this way, by dividing each value of current in the scale at the left by .5, the number of lumens of light on the cell. Now it is easy to see that a vacuum type cell should be operated at a voltage corresponding to a point *above the knee* of the curve if greatest sensitivity is to be obtained.

Color Response Curve. Another very important photocell characteristic is its response to light of different colors (wave-lengths). The curve in Fig. *5C* gives this information for a typical vacuum type photocell; in general the color response of a photocell differs considerably from that of the human eye (shown by dash-dash curve). Since this particular cell has a maximum response very near the infra-red light region, it is ideal for use with invisible light beams. Various light-sensitive materials are used on the cathode to get a certain desired color characteristic. Quartz must be used for the envelope where a tube is to be highly sensitive to ultra-violet light, since ordinary glass does not transmit ultra-violet rays.

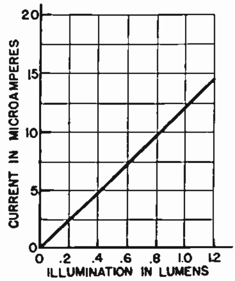


FIG. 5A. Current-Illumination Curve for a typical vacuum type photocell (Westinghouse SR-50 phototube).

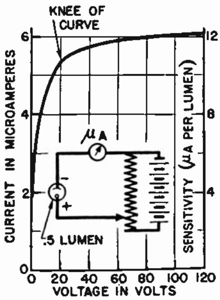


FIG. 5B. Current-Voltage Curve for Westinghouse SR-50 phototube, obtained with constant illumination of .5 lumen.

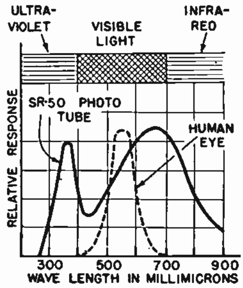


FIG. 5C. Color Response Curve for Westinghouse SR-50 phototube, with response of human eye shown for comparison.

GAS TYPE PHOTOCELLS

The gas type photocell differs from the vacuum type only in that after evacuating a small quantity of an inert (inactive) gas such as argon, helium or neon is admitted before sealing off the tube. In this gas type cell the electrons emitted by the cathode, traveling at high speed towards the anode, have sufficient force to knock out electrons from gas atoms into which they collide, thus splitting up the atoms into positive ions and free electrons; this process is known as *ionization.* The electrons resulting from these collisions are attracted to the anode along with the emitted electrons, and serve to build up the photocell current. The positive ions (atoms from which electrons have been knocked out) move to the space cloud near the cathode, neutralizing the electrons there and allowing more of the electrons from the cathode to find a free path to the anode. If the ionization is made too strong by excessive anode voltage, causing a glow discharge, the gas ions bombard the cathode, destroying the tube.

This "ionization by collision" process is shown in Fig. *4D*. The original tube current can be increased as much as ten times by the ionization of the gas; the amount of ionization increases rapidly as the voltage is increased, but the voltage must be kept below a critical value in order to prevent a glow discharge (similar to that in neon sign tubing) from destroying the tube. With too-high voltages the gas type tube will pass current even when no light is falling on the cathode. Resistors are often placed in series with a gas type tube in order to limit this discharge current to a safe value in case the voltage becomes too high. The operating voltages vary between 25 and 100 volts for the average gas photoemissive tubes, depending upon their construction; under no conditions should this voltage be exceeded.

Characteristic curves for a typical gas type photocell, the General Electric PJ-23 phototube, are given in Figs. *6A*, *6B* and *6C*. The current passed by the gas type cell increases practically in direct proportion to the *illumination,* just as in the vacuum type cell (Fig. *5A*).

The curves in Fig. *6B* give you a very good idea of the characteristics of a gas type photocell; at voltages below 20 volts this cell behaves almost exactly like a vacuum type cell (Fig. *5B*), for at these low voltages the emitted electrons do not reach a sufficiently high speed to knock electrons out of the atoms of gas inside the photocell. At some voltage above about 20 volts (above the knee of the curve) ionization starts, and further increases in voltage give much greater increases in current than would be obtained with a vacuum type cell. The dotted lines (Fig. *6B*) show how the current would vary at higher voltages if there were no gas in the tube.

The voltage and current rating specified by manufacturers for gas type tubes must be carefully followed if the tube is to be in operation for long periods of time. Voltages slightly higher than rated values shorten tube life considerably, and very high voltages cause a glow discharge which destroys the tube. In general, the maximum safe operating voltage of the average gas type photoemissive cell is about 100 volts. The operating voltage can sometimes be increased for low values of illumination (see the curve for .1 lumen illumination in Fig. *6B;* here the current is far below the maximum rated value of 20 ma. at maximum rated voltage) provided that the maximum rated value of current is not exceeded; it is a good idea to place a resistor in series with the tube to limit current to a safe value in case the illumination is accidentally increased.

Gas Ratio. The ratio of the current passed by a gas photocell at its maximum safe operating voltage to the current passed just before ionization and gas amplification begins is known as the *gas ratio* of the tube. For example, the gas ratio of the General Electric PJ-23 tube (Fig. *6B*) is about 7; this value was obtained by dividing the current at 90 volts by the current at 25 volts, the illumination being held constant at a value which limits the current at 90 volts to a safe value. Maximum values are generally specified for gas ratios, since the ratio becomes less as illumination on the cell is decreased.

Color Sensitivity. The color response of a gas type photocell depends upon the kind of glass used for the envelope and upon the nature of the light-sensitive material used on the cathode. The curve in Fig.

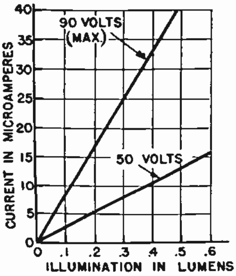


FIG. 6A. Current-Illumination Curves for a typical gas type photocell (General Electric PJ-23 Phototube).

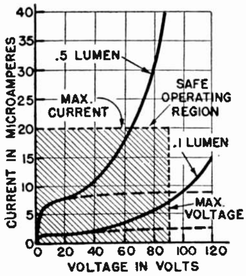


FIG. 6B. Current-Voltage Curve for General Electric PJ-23 phototube, for two different values of illumination.

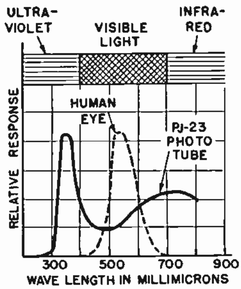


FIG. 6C. Color Response Curve for General Electric PJ-23 phototube. Note peak in ultra-violet region.

6C is therefore just one of many color characteristics associated with gas photocells. This particular tube has high sensitivity to ultra-violet and infra-red, but comparatively low sensitivity to visible light.

Gas and Vacuum Photocell Ratings. Just as radio tubes have certain definite ratings which must not be exceeded, so do photocells have maximum voltage and current values which cannot be exceeded in ordinary practice.

The *maximum anode current* is the maximum value of current which can be safely passed by the tube. For A.C. this is the peak value of current.

The *maximum anode voltage* is the maximum value of voltage which can safely be applied to the tube. For A.C. this is the peak value of voltage.

The *maximum illumination* is more important in connection with gas type cells than with vacuum type cells. At high values of illumination, the voltage applied to a gas type photocell must be considerably lower than the rated value in order to keep the current down to a safe value (in the safe operating range shown in Fig. *6B*). Vacuum type cells are ordinarily not designed to withstand direct exposure to sunlight for long periods of time; at high values of illumination the voltage should be kept at the minimum value which gives satisfactory operation.

The *sensitivity* of a photocell is generally expressed as the current passed in microamperes per lumen of light flux; this is usually measured at a light intensity of either .1 or .5 lumen, in order that sensitivity ratings of various tubes can be compared. The sensitivity of vacuum type cells varies from about 5 to 35 microamperes per lumen (the sensitivity of the vacuum type cell in Fig. *5A* is about 15 μa per lumen), while for gas cells, rated sensitivity values may be as high as 300 microamperes per lumen (the average sensitivity rating of the gas type cell in Fig. *6A* at an anode voltage of 90 volts is 50 microamperes per lumen).

Figure 7 shows a number of typical photoemissive cells. Gas and vacuum type photocells look the same, since the gas used is invisible.

PHOTOCONDUCTIVE CELLS

The operating principle of this cell is the change in electrical resistance (change in ohmic value) of a material when exposed to varying intensities of illumination. The photoconductive cell is essentially a high resistance whose ohmic value varies with the light falling upon the cell. The stronger the light falling on the cell, the lower becomes the resistance. Since this type of cell does not generate its own voltage, it requires an external potential and will pass some current even when in the dark.

The photoconductive effect was first noticed by an engineer named Willoughby Smith, who, while stationed in the Azores Islands in 1871, noticed that the selenium resistors he was using changed their resistance when exposed to sunlight. Reporting the discovery to a group of scientists, he announced: "By the aid of the telephone I heard a ray of light fall on a bar of metal!"

Photoconductive cells are being made almost exclusively from selenium, although certain other compounds, one of which is thallium oxysulphide, show appreciable photoconductive effects. Many different forms of selenium cells are on the market today.

The term "cell" is somewhat misleading when used in connection with photoconductive cells and photoemissive cells, for these do not generate their own voltage and are therefore not to be compared to a battery. The word *cell,* is, nevertheless, commonly used among technical men for all three classes of light-sensitive devices, and is therefore used in this lesson. You will always be able to tell what is meant

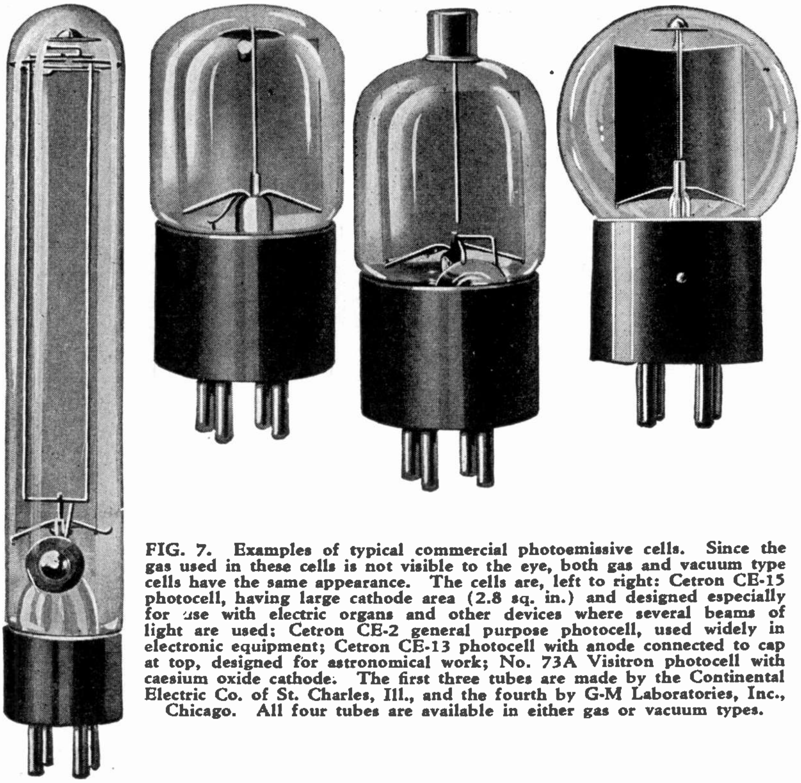


FIG. 7. Examples of typical commercial photoemissive cells. Since the gas used in these cells is not visible to the eye, both gas and vacuum type cells have the same appearance. The cells are, left to right: Cetron CE-15 photocell, having large cathode area (2.8 sq. in.) and designed especially for use with electric organs and other devices where several beams of light are used; Cetron CE-2 general purpose photocell, used widely in electronic equipment; Cetron CE-13 photocell with anode connected to cap at top, designed for astronomical work; No. 73A Visitron photocell with caesium oxide cathode. The first three tubes are made by the Continental Electric Co. of St. Charles, Ill., and the fourth by G-M Laboratories, Inc., Chicago. All four tubes are available in either gas or vacuum types.

by referring to the circuit diagram, for the symbols for light-sensitive cells are quite different from the symbols for batteries.

A selenium cell consists essentially of two electrodes between which is deposited a thin film of selenium. The electrodes, which can be either of copper, iron, nickel, aluminum, silver, gold, platinum, metal alloys, lead, graphite or carbon, are mounted on some insulating block such as quartz, glass, clay compounds, porcelain, slate, mica or bakelite.

The construction of a simple selenium cell is pictured in Fig. *8A*. Two pieces of metal foil are cut out as shown and cemented to the flat base, after which a thin layer of molten selenium is spread evenly over the foil plates and all gaps between the foil. Sometimes the selenium in powder form is sprinkled over the plates, then heated and spread out, or selenium is heated to its boiling point and the vapors allowed to condense on the plates. In any event, the cell must be annealed by heating carefully until the selenium changes from its pitch black form to the gray crystalline form which is highly sensitive to light, then cooled slowly.

Commercial selenium cells are made in a number of different ways. One type of cell has two wires wound over an insulating slab, with a thin layer of selenium deposited between the wires. Each wire serves as a terminal of the finished cell, the resistance between the two wires being determined by the resistance of the selenium layer. A flat piece of slate is sometimes coated with a film of graphite which is polished with a chamois skin, then divided into two interlacing sections with a sharp tool and selenium deposited over the entire surface.

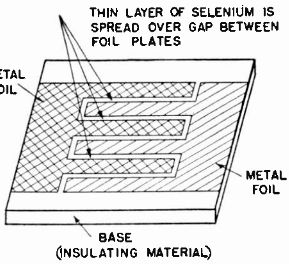


FIG. 8A. The basic construction of a simple selenium cell is illustrated in this sketch.

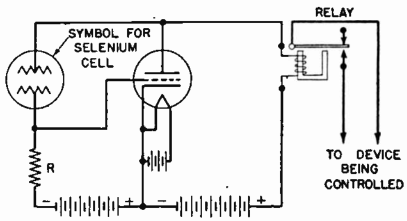


FIG. 8B. Basic circuit for a selenium (photoconductive) cell. Note symbol used to represent this cell.

In other types of selenium cells a thin film of platinum, gold or silver is fused into the surface of a block of glass or quartz. This thin metal film is then divided into two sections by a zigzag or comb-like line made with a precision instrument known as a "dividing engine." There may be as many as one hundred lines or scratches per inch on the cell. When the metal film has been divided into two separate electrodes in this manner, a thin layer of selenium is placed over the entire unit, this selenium serving to bridge the gaps between the two electrodes. This method gives a very small separation between the two plates and a long gap covered with selenium.

The Acousto-Lite Type 50A2 cell, characteristics of which are given in Fig. *9*, belongs in this last class; it is highly sensitive to changes in illumination but is not recommended for operating voltages higher than 80 volts or light intensities of more than 20 foot-candles. As a precaution against breakdown due to excess voltage or excess current, a one-megohm resistor is usually connected in series with the cell.

Looking first at the Current-Illumination curve (Fig. *9A*), you can see that the current passed increases with illumination, but the effect of the light (the increase in current) is less at the higher values of illumination. Notice that the current does not drop to zero when the cell is dark (the applied voltage being held constant); selenium cells have a definite "dark" resistance, so current can drop only to the dark level when light is cut off from the cell. The resistance of this particular cell is about 10 megohms in the dark and about 2 megohms

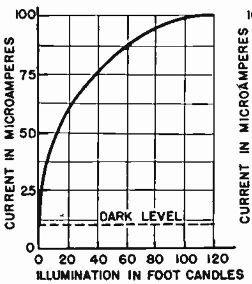


FIG. 9A. Current-Illumination Curve for Acousto-Lite Laboratories Type 50A2 selenium cell.

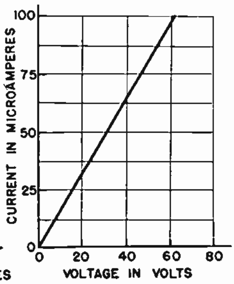


FIG. 9B. Current-Voltage Curve for Type 50A2 selenium cell (with constant illumination).

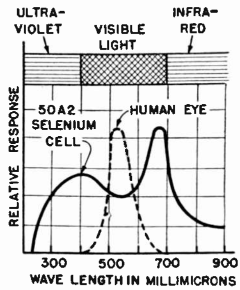


FIG. 9C. Color Response Curve of Acousto-Lite Laboratories Type 50A2 selenium cell.

at an illumination of 10 foot-candles, hence this cell has what is called a dark-to-light resistance ratio of 5.

When illumination is held constant on a selenium cell and the voltage varied, the current varies exactly as it would for an ordinary fixed resistance. You know that the current passed by a resistor varies directly with the voltage applied; that is why the curve in Fig. *9B* is a straight line.

You will find that most selenium cells have a maximum sensitivity to red or infra-red light, with a lower peak (in some instances) in the ultra-violet region (Fig. *9C*).

Photoconductive cells are generally used with vacuum tube amplifiers, just as are photoemissive cells, but it is possible to make them with a resistance sufficiently low to permit direct operation of a sensitive relay. A battery delivering somewhere between 15 and 45 volts must then be connected in series with the cell and relay, for photoconductive cells do not generate a voltage. The current passed by the cell under constant illumination depends only on the voltage applied to the cell; the maximum current is determined by the maximum voltage which can be applied without causing breakdown of the selenium in the gap between the plates.

The amplifying circuits required for selenium cells are very similar to those used with photoemissive cells. A fundamental selenium cell circuit is given in Fig. *8B*. Light falling on the selenium cell changes its resistance, thereby changing the bias voltage on the grid of the tube. In the circuit shown, increases in light make the grid of the tube less negative (more positive), thereby causing the plate current to increase and operate the relay. With this circuit, therefore, the device being controlled by the relay operates whenever a strong light falls on the cell. If the positions of the selenium cell and the resistor *R* are reversed, the relay will be closed when the cell is dark but will open just as soon as sufficient light falls on the cell.

Selenium cells are generally sealed in moisture-proof cases, for they are quite sensitive to changes in humidity. The stability of the cells is in general quite poor; those cells which have a very high sensitivity to changes in light usually have a short life, and their sensitivity changes with use. Mounting in moisture-proof cases also improves cell stability, but with many cells the current passed varies slightly even with constant illumination. Their power output is limited by the maximum voltage which can be impressed without causing breakdown across the electrodes and by the amount of heat developed in the cell (excess heat changes the selenium to an insensitive form).

Selenium cells ordinarily have a time lag and are rather slow to respond to changes in light, but with certain types of construction they can be made to respond satisfactorily to light frequencies of up to 6,000 cycles, as in sound picture work. The use of selenium cells for audio frequency work is, however, the exception rather than the rule. It takes several minutes after an increase in light before an ordinary selenium cell will allow maximum current to flow, but fortunately for control use, the current reaches 95 per cent of its final value in about .03 second. Selenium cells, however, are unsuited for use in television systems and in any other circuits where very rapid response is required.

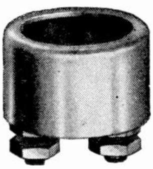
Advantages of Selenium Cells. Some selenium cells are very sensitive to infra-red light, and these are especially valuable where control is to be secured with an invisible light beam. Selenium cells can be made to have a low sensitivity to changes in light and a high current output, or a high sensitivity with low current output, just as is desired. Their output is in general considerably greater than that of photoemissive cells. Typical selenium cells are shown in Fig. *10.*

Precautions in Using Selenium Cells:

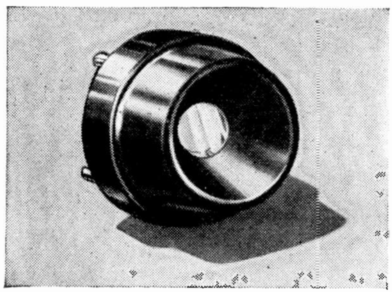
1. Keep cells cool. The heating effect resulting from too large currents through the cell, from exposure to an intense light source or by using the cell in locations where temperature is excessive, will cause the selenium in the cell to become soft and possibly melt, thus rendering it unfit for photoelectric use.

2. Keep cell dry. When not in use, place in a dark box containing a few pieces of calcium chloride in order to absorb moisture near the cell.

3. High potentials should be avoided. Use the lowest possible voltage which will give the desired results. Choose high resistance relays



Courtesy Acousto-Lite Labs.



Courtesy Hugh H. Eby, Inc.

FIG. 10. Examples of typical selenium cells. At the left is the Acousto-Lite Type 50A2 cell, curves for which are given in Fig. 9. The Eby Electric Eye (right) has its light-sensitive element sealed in moulded bakelite; it will operate on voltages up to 250 volts and at frequencies up to 9,000 cycles. The response of the Eby cell is not sufficiently linear, however, to make it suitable for use with sound-on-film movie projectors.

or place a limiting resistance in series with the cell for protective purposes. In general, 4 milliamperes is more than ample for relay work.

4. Exposure to intense lights for long periods of time should be avoided, for this causes "fatigue" which makes the cell temporarily, and in many cases permanently, insensitive to light.

5. When not in use, cells should be kept in the dark, but they may be exposed to light regularly, for short periods of time, to aid in retaining their sensitivity.

6. If the resistance of a cell drops greatly, it can be raised, at least temporarily, by applying pulsating or alternating currents.

PHOTOVOLTAIC CELLS

Photovoltaic cells are really small batteries or sources of direct current, since they generate a current which varies with the intensity of the light falling on the cell; more correctly, they transform the radiant energy of light directly into electrical energy. Although the voltage output of these cells is quite low, the current delivered is sufficient to operate an indicating meter or a *super-sensitive* relay without using any batteries or auxiliary apparatus.

Types of Photovoltaic Cells. There are two general types of photovoltaic cells: the *dry* or electronic type, which is today the most common, and the *wet* or electrolytic type. These differ only in the methods of construction and in general characteristics, for each generates its own voltage.

Dry Type Photovoltaic Cells. This type of cell consists essentially of a metal disc, perhaps one-sixteenth inch thick, on one side of which is a film of light-sensitive material; this basic construction is illustrated at *A* in Fig. *11*. The metal disc forms the positive terminal of the cell, and a thin metal film deposited on part or all of the sensitized surface forms the negative terminal. The action of light forces electrons to the surface of the sensitized layer, where they are collected by the thin metal film which serves as the negative terminal of the cell. The metal disc is the positive terminal, for it must make up for the electrons drawn out of the sensitized layer by the action of light. A voltage therefore exists across these terminals when the cell is illuminated, and electron flow will be in the direction indicated at *B* in Fig. *11*.

Photovoltaic cell circuits are quite simple, the cell being connected directly to the coil terminals of some type of super-sensitive relay, as in Fig. *11C*. Since the contacts of this relay ordinarily cannot handle the current required by the device to be controlled, a sensitive relay is generally used. The contacts of the super-sensitive (meter type) relay then control the current to the coil of the sensitive relay, which in some cases may operate a heavy duty relay.

Although the dry type of photovoltaic cell can be made in a number of different ways, the following is a typical manufacturing procedure. An iron disc about 2 inches in diameter and one-sixteenth inch thick is first thoroughly cleaned, then covered on one side with ordinary solder. A thin layer of selenium is deposited over this layer of solder, and this layer is annealed or heated under pressure. When the cell has cooled, a thin film of either gold, silver or platinum is deposited on the selenium surface, this film being thin enough to allow light to pass through. This film can be applied as a very thin sheet of the metal (called "gold beater's metal") or can be sprayed on the selenium in molten form from a special spray gun. In some cases the translucent metal film is deposited on the selenium by a process called "cathode sputtering," which is carried out in a vacuum chamber. The cell is completed by making contact to the iron disc and to the translucent metal film with thin metal washers of the same diameter as the iron disc. Naturally the cells must be handled very carefully, for the translucent metal film will rub off very readily. A glass window is customarily set into the cell housing to protect the light-sensitive layer.

Photronic Cell. The Weston Photronic cell, one of the first commercial selenium iron type cells to be developed in the United States, is constructed in much the same manner as was described above; this is today one of the best known of all photovoltaic cells in this country.

The component parts of a Photronic cell are shown in Fig. *12;* at *A* is the thin disc made of iron, on one side of which is the layer of light-sensitive selenium. The cell is assembled as follows: The glass

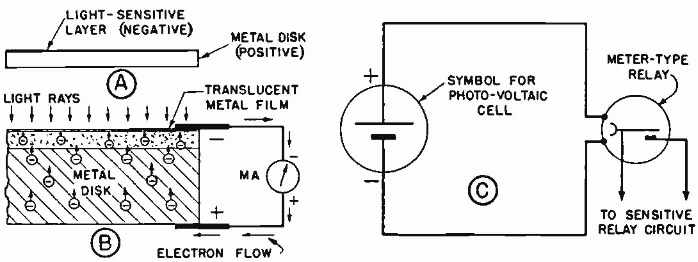
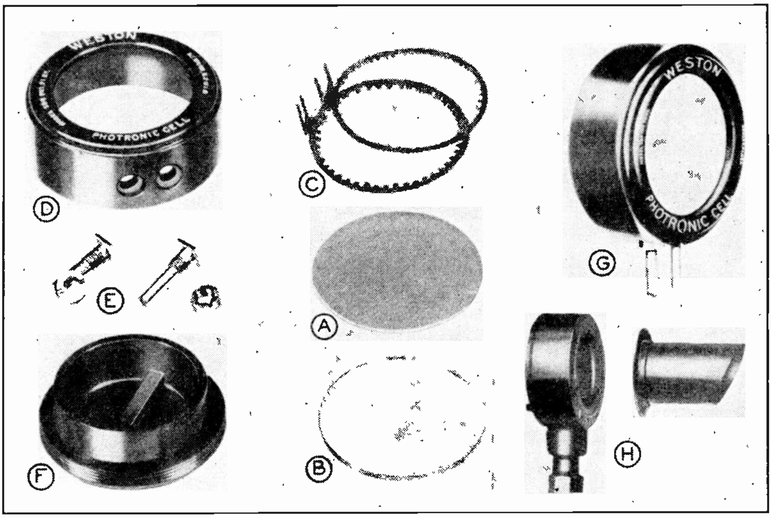


FIG. 11. Basic construction of and basic circuit for the dry photovoltaic (self-generating) cell.

window is placed in the bakelite housing; the iron disc, with one of the metal contact rings on each side, is placed in the housing next, with the sensitive side against the glass; the contact rings are turned so each terminal lug is over one of the holes in the side of the housing, and the terminal bolts are set into place, heads inside the housing; finally the bakelite cap is screwed into the housing. The projecting ends of the bolts are of the same diameter as radio tube prongs, and fit into an ordinary four-prong tube socket.

Characteristic curves for the Weston Photronic cell are given in Fig. *13.* The current output varies with the external resistance connected to the cell as well as with the illumination, the output being linear (proportional to illumination) for low values of external resistance. This linear relation for low resistances holds true even when the cell is in direct sunlight (about 175 lumens of illumination) ; the maximum current in direct sunlight, for a 3-ohm external resistance, will be about 20,000 microamperes or 20 ma. In using meters or relays with Photronic cells, therefore, it is necessary to consider their resistance. Low resistance meters are used where it is necessary that the current produced be directly proportional to the light intensity; for low values of illumination (below .1 lumen or below 10 foot-candles), sufficiently linear response can be obtained with instruments having 1000-ohm or higher resistances, for the curves are practically straight in this region (see Fig. *13A*).

The voltage output of the Photronic cell for varying intensities of illumination, measured by a method which involved no flow of current



Courtesy Weston Electrical Instrument Co.

FIG. 12. View of component parts of the Weston Photronic cell, a dry type photovoltaic cell. A—sensitized iron disc; B—glass window; C—metal contact rings; D—bakelite housing; E—terminal bolts; F—bakelite cap; G—assembled cell; H—Photronic cell in weatherproof housing, with visor to keep out unwanted light.

through the cell, is shown in Fig. *13B*. The curve is not linear, and the values of voltage are quite low; this cell, together with all other photovoltaic cells, is in general not used with vacuum tube amplifiers, which require large changes in grid voltage to get useful changes in plate current in a single amplifier tube.

The relative color response curve for the Photronic cell, given in Fig. *13C*, shows that the cell and the human eye have a maximum response to about the same color, yellow-green. The manner in which a glass window absorbs ultra-violet light can be seen; a much higher response to ultra-violet light is obtained with a quartz window in the cell. Filters (panes of colored glass) which give the Photronic cell almost exactly the same color response as the human eye can be obtained from the manufacturer; these filters are necessary whenever the cell is to replace the human eye in making measurements of light. The Weston illumination meter, where the cell is connected directly to an indicating current instrument reading in foot-candles, is an example of this use.

Photronic cells should be used as current sources rather than voltage sources, for the current output of the cell varies directly with the light falling on the cell. In order to obtain a constant voltage from this type of cell, it is necessary to connect a resistance across the cell and take off the voltage across the resistor. This voltage will then be proportional to the light falling on the cell.

It is possible to connect two or more Photronic cells *in parallel* to

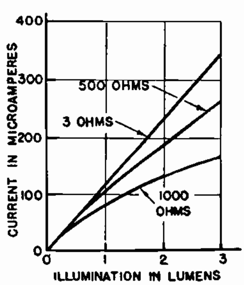


FIG. 13A. Current-Illumination Curve for Weston Photronic cell.

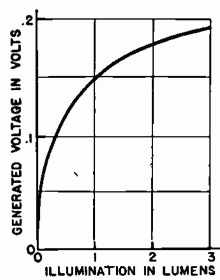


FIG. 13B. Voltage-Illumination Curve for Weston Photronic cell.

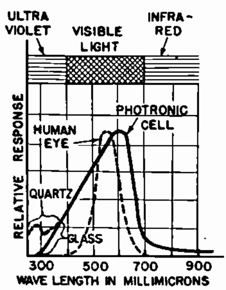


FIG. 13C. Color Response Curve for Weston Photronic Cell.

obtain a greater current output for a given intensity of illumination; connections are exactly the same as for dry cells, minus to minus and plus to plus. The dark resistance of these units is quite high, which means that a number of cells at different points can be connected together in parallel without the possibility of one cell feeding current into the others. The total current delivered by a system made up of a number of dry photovoltaic cells will be proportional to the total light falling on all of the cells; for instance, if three cells in parallel furnish 100 microamperes when illuminated by light sources of equal intensity, the combination of cells would give exactly 67 microamperes if one cell were completely darkened. Individual cells have this same characteristic; practically the same current response is obtained when light is concentrated on one part of the cell as when the *same amount* of light is spread uniformly over the entire active surface.

The Electrocell, a dry disc type of self-generating cell imported from Germany, consists of a light-sensitive layer of selenium deposited on the surface of an iron disc, contact being made to the layer with a transparent conducting film of silver. Transparent lacquer sprayed over the greater part of the cell protects it from rough handling. The sensitivity of this cell is 480 microamperes per lumen; in direct sunlight the 1¾-inch diameter cell will deliver as much as 20 ma. It is claimed that the Electrocell, in the larger sizes, delivers enough current to operate a sensitive relay directly, thus eliminating the need for an expensive super-sensitive relay. The smallest Electrocells, ⅜-inch in diameter, have a sufficiently low capacity to be used at frequencies up to 8000 cycles.

Another type of dry photovoltaic cell which is now on the market, the Westinghouse Photox cell, consists of a disc of copper on which has been formed a thin film of cuprous oxide. Contact is made to the copper and to the oxide layer in much the same way as was done with the selenium iron type cell. Gold is the material used as the translucent film on this cell.

The Lange cell, of German manufacture, is quite similar in construction to the above-mentioned photovoltaic cells; according to data furnished by the manufacturer, it has a very good current output.

The General Electric Company's selenium-on-iron type photovoltaic cell is mounted in a bakelite case and provided with prongs which permit mounting it in an ordinary four-prong radio socket. This cell and two types of multiple Photronic cell units appear in Fig. *14*.

General Characteristics of Dry Photovoltaic Cells. Dry photovoltaic cells are generally connected directly to super-sensitive relays, these being built much like a milliammeter or microammeter, but with contacts on the moving pointer and fixed contacts on the meter scale. These relays respond to currents of the order of microamperes, and are therefore quite costly.

For all practical purposes, the response of a dry photovoltaic cell to changes in light can be considered to be practically instantaneous. Actually these cells are fast enough to detect the passage of a rifle bullet through a beam of light. Because of the high parallel capacity of the cell, however, (about .5 mfd.) dry photovoltaic cells are not suitable for use in audio frequency apparatus, such as for responding to a light beam which has been modulated at audio frequencies. Photoemissive cells are more generally used for this purpose.

The output of a photovoltaic cell can be increased considerably by connecting a small potential, not over 6 volts, in series with the cell. Too high voltages may permanently change the characteristics of the cell; in fact, the manufacturers of the Photronic cell recommend that no external voltages be used if maximum cell life is to be obtained. A photovoltaic cell behaves much like a photoconductive cell when an external potential is used in series with the cell.

Dry photovoltaic cells are believed to have an unlimited life; that is, they will retain their characteristics for long periods of time if kept at temperatures below about 120° Fahrenheit. The cells must be

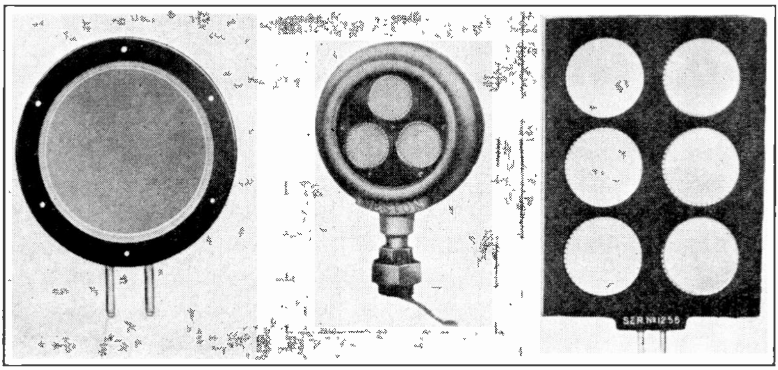


FIG. 14. Typical photovoltaic cells. Above, left to right: Blocking layer cell, a type of photovoltaic cell made by General Electric Co.; a Weston unit consisting of three Photronic cells in a weatherproof housing; Weston unit consisting of six Photronic cells in parallel, made by the Weston Electric Instrument Co. for use in measuring very low intensities of illumination. At right: Visitron F-2 cell, made by G-M Laboratories, Inc. All photovoltaic cells shown here are capable of generating sufficient current to operate super-sensitive relays directly.

tightly sealed in their cases, for they are critically affected by chemical vapors and by dampness.

Wet Photovoltaic Cells. The photovoltaic cell in wet form is now almost 100 years old, for its principle, known as the Becquerel effect, was discovered by Edmund Becquerel in 1839. While experimenting with the ordinary type of voltaic cell known in that day, he noticed that his cell gave out a much greater output in direct sunlight than in the subdued light of his laboratory.

In its simplest form, the wet photovoltaic cell consists essentially of two metals which are immersed in an electrolyte, one of these metals or electrodes being exposed to a source of light. Research workers have developed two types of these wet photovoltaic cells, one in which the electrodes themselves are light-sensitive, and another in which the electrolyte is light-sensitive, but neither type is believed to be of great commercial importance at the present time.

Wet photovoltaic cells can be constructed with a number of different electrode materials and electrolytes. One form of this cell has two copper electrodes, on one of which is a film of cuprous oxide. Another type uses one copper electrode on which is the film of cuprous oxide, and one lead plate; the electrolyte in this case is a dilute solution of lead nitrate.

The wet type of photovoltaic cell has a number of drawbacks. In some types destructive gases were formed in the cell while it was standing idle. Industry in general hesitates to adopt equipment like this, in which there is a possibility of leakage of liquid.

Naturally polarity must be considered when connecting photovoltaic cells of all types into a circuit, for the cells are really small voltaic cells. In the wet type of cell, the electrode having the oxide layer is always *positive.*

Choosing Light-Sensitive Cells. The electronic control engineer seldom finds it necessary to make a choice between the different types of light-sensitive cells for a particular application, as manufactured equipment which already includes the light-sensitive cell is now available in many different forms. The information on light-sensitive cells which has been given in this lesson will, however, help you to understand the operation of photoelectric apparatus, for only by a thorough knowledge of the fundamental principles of photoelectricity can you use available equipment to the best advantage. Leave experimenting and research with light-sensitive cells up to the factory engineers who have the necessary equipment and training to do this type of work.

TEST QUESTIONS

Be sure to number your Answer Sheet 25FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What is the general effect of variations in light on a light-sensitive cell?

2. Name the six basic parts of a complete photoelectric control installation.

3. What kinds of light are invisible to the human eye, yet can be "seen" by the electric eye?

4. Name the practical unit of illumination.

5. Name the three classes of light-sensitive cells.

6. What is the maximum safe operating voltage of the average gas type photoemissive cell?

7. Do selenium cells respond instantly to changes in light?

8. What type of light-sensitive cell will operate a super-sensitive relay without auxiliary apparatus?

9. What device is used with the Photronic cell to make it have exactly the same color response as the human eye?

10. How would you connect two or more Photronic cells to secure a greater current output for a given intensity of illumination?

LOUDSPEAKERS AND HOW THEY OPERATE

PART 1

26FR-1

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Loudspeakers and How They Operate

Part 1

Introduction

IN RADIO receivers and in public address systems the loudspeaker serves to convert audio frequency currents into sounds which can be heard by the human ear. The A.F. currents in the last stage of the audio amplifier are made to set in motion an electro-mechanical system, and this in turn causes the air in the vicinity of the loudspeaker to vibrate in accordance with the variations in the audio signal, thus producing sound having all the characteristics of the original sound.

A Complete Loudspeaker has Three Sections. From what you have already studied in this Course and from your own actual experience, you can readily see that a complete sound reproducer or loudspeaker consists of three essential sections: *1,* an electro-mechanical *driving unit,* often called a *motor,* which converts A.F. currents into vibratory motion; *2,* the *diaphragm* or *cone,* which when driven by the motor sets the surrounding air into motion; *3,* the *air coupling system,* consisting essentially of a horn or baffle, which improves the efficiency of the loudspeaker by setting a larger amount of air into vibration and by preventing the reproduced sound components from cancelling each other.

The "Weakest Link" in Radio. Perfection in radio transmitter and receiver design is of little value unless the loudspeaker, the final link in the radio system, is capable of reproducing the entire range of audio signals with true fidelity and is capable of operating at the required maximum loudness level without distorting the reproduced sound. Contrary to general impressions, *the loudspeaker is the weakest link in the entire radio system.* The design of high-fidelity loudspeakers is an intricate and involved task even for the engineer who specializes in this particular branch of radio engineering. Even today, after years and years of research on the subject, engineers are still striving for the perfect loudspeaker.

What You Will Study. Although as a Radiotrician and Teletrician you are not particularly interested in the exact details of loudspeaker design technique, a general discussion of some of the problems encountered in building loudspeakers and a study of the various solutions which have been developed for these problems will serve to make you realize the limitations of loudspeakers. Furthermore, a familiarity with the constructional features of various types of loudspeakers and with their performance under various conditions will be of value to you in any branch of radio. Only the more widely used loudspeakers, which you will be likely to encounter in your practical work, will be considered. Basic principles of loudspeaker construction will be stressed, but enough actual examples of commercial loudspeakers will be taken up to illustrate how these principles apply to all loudspeakers.

Types of Loudspeakers

Although some loudspeaker manufacturers have assigned trade names to their various types of loudspeakers, you will find that technical men in general prefer to describe loudspeakers according to their construction or operation.

Loudspeakers can be divided into four general groups according to the type of motor or driving unit which they employ: *1, magnetic loudspeakers,* in which the moving element is made of iron; *2, dynamic or moving coil loudspeakers,* in which the moving element is a coil of wire; *3, condenser loudspeakers,* in which one plate of a large two-plate condenser is the moving element; *4, crystal loudspeakers,* in which a crystal is the moving element.

Magnetic Loudspeakers. That type of magnetic loudspeaker which depends for its operation upon the attraction of a bi-polar driving unit for an iron diaphragm has long since been superseded by the other types to be discussed. The bi-polar driving unit is still used almost universally in headphones, however, and will therefore be taken up in this lesson. Magnetic loudspeakers in use today are of the *balanced armature type;* when a balanced armature unit is made to drive a diaphragm, we have a *diaphragm type magnetic loudspeaker.* On the other hand, if a balanced armature unit drives a cone, we have a *magnetic cone loudspeaker.*

Dynamic Loudspeakers. When the fixed magnetic field for a dynamic or moving coil loudspeaker is furnished by an electromagnet, we have what is known as an *electrodynamic loudspeaker.* When this fixed magnetic field is provided by a permanent magnet, we have a *permanent magnet dynamic loudspeaker,* often abbreviated as *P.M. dynamic loudspeaker.* Either of these dynamic or moving coil units can be used to drive a small cone, a large cone or a diaphragm. With a small cone or diaphragm, the air coupling unit is usually a horn; with large cones, of the size commonly found in radio receivers employing dynamic loudspeakers, a baffle ordinarily serves as the air coupling system.

Condenser Loudspeakers. These are also known as *electrostatic loudspeakers,* for they depend for their operation upon the forces of attraction and repulsion existing between two charged plates. The moving plate is ordinarily about one foot square, so no cone or diaphragm is required. Condenser speakers are used so seldom today that only the fundamental operating principles will be taken up in this lesson.

Crystal Loudspeakers. The driving units of crystal loudspeakers are all essentially the same, but they may be made to drive either a diaphragm or a cone, and may be used with either a baffle or horn.

Once you become familiar with loudspeaker construction and operation, you will find that practically all of the loudspeaker names or designations which you encounter will be self-explanatory.

Bi-polar Magnetic Driving Units

No discussion of sound-reproducing units would be complete without a consideration of the headphone unit. Aside from the fact that this bi-polar magnetic driving unit was the essential part of all early loudspeakers, headphones are still widely used today by commercial radio operators, by radio amateurs, by experimenters, and by those who are hard-of-hearing.

Headphone Construction. The constructional details of a typical headphone unit are shown in Fig. *1*, the important parts being clearly identified. The operating principle of this bi-polar magnetic driving unit can be more clearly understood by referring to the simplified diagram shown in Fig. *2A*. The permanent magnet *PM*, semicircular in shape and made of hard steel, produces a fixed magnetic flux which flows through the two soft iron pole pieces *P*, and then through two air gaps to the thin iron diaphragm *D* (about .003 inch thick), which is firmly clamped around its edges to the housing and which is accurately spaced away from the pole pieces. The diaphragm is attracted toward the pole pieces; one explanation is that the magnetic circuit always adjusts itself to have the least reluctance (opposition to the flow of magnetic flux), while another is that the north (*N*) pole piece makes the section of the diaphragm directly above it a south (*S*) pole, and the south pole piece makes the diaphragm section above it a north pole. Since opposite poles always attract, the diaphragm is bent toward the pole pieces.

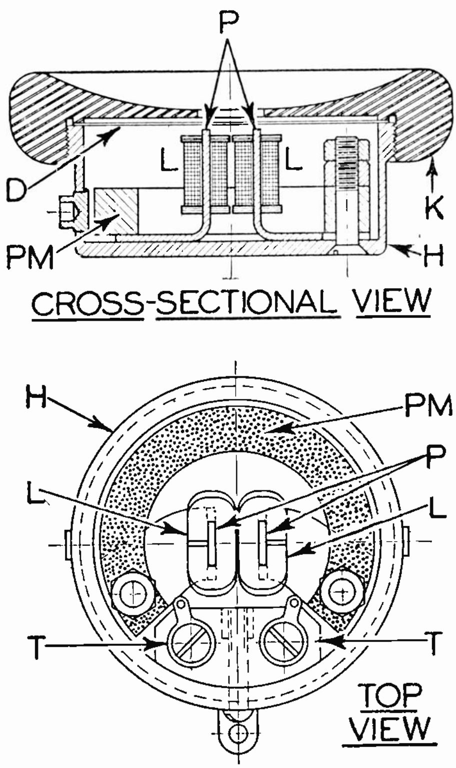


FIG. 1. These two diagrams show the important constructional details of a typical bi-polar magnetic driving unit as used in a headphone. The parts are: *PM*—hard steel permanent magnet; *L*—coils; *P*—soft iron pole pieces; *D*—soft iron diaphragm; *H*—metal housing; *K*—ear cap; *T*—headphone terminals, connected directly to the coils.

The diaphragm is made stiff enough and is originally separated far enough from the pole pieces so that it cannot actually touch the pole pieces under any normal conditions of operation.

How a Headphone Works. Observe that around each of the pole pieces in Fig. *2A* is a coil of wire, with the two coils connected together in series in such a way that the magnetic flux due to each will be in the same direction through the permanent magnet. When a current is sent through these coils, it will produce an additional magnetomotive force which either aids or opposes the magnetomotive force of the permanent magnet (depending upon the direction of current flow) and therefore either increases or decreases the amount of magnetic flux flowing through the magnetic circuit of the headphone. Any change in this total magnetic flux naturally changes the attraction of the pole pieces for the diaphragm; when the current flowing through the coil is varying at an audio frequency, the diaphragm will move toward and away from the pole pieces at the same frequency. With proper design of the entire headphone unit, the movement or displacement of this diaphragm will correspond exactly to the variations in the audio frequency currents,

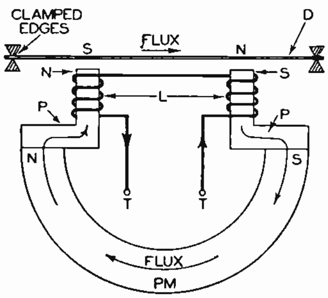


FIG. 2A. Simplified diagram of a bi-polar magnetic headphone unit, showing coil connections and flux paths.

and this diaphragm will produce sound waves which correspond in wave form to that of the A.F. signals.

Why Strong Permanent Magnets are Necessary. One of the most important factors affecting the performance of a magnetic loudspeaker is the permanent magnetic field. Let us see what would happen if this field were not used. Assume that we are sending a pure sine wave alternating current through the coil of the bi-polar driving unit in Fig. *2A*, with permanent magnet *PM* temporarily replaced by a soft iron piece of similar shape. When this alternating current is zero there will be no magnetic field and no pull on the diaphragm. As the current swings positive, the two poles will become magnetized with opposite polarity, and the diaphragm will be pulled toward the pole pieces. This attraction will continue until the current again reduces to zero. As the current reverses for the negative half of the cycle, the polarity of each pole will reverse, but the poles will again attract the diaphragm. As a result, the diaphragm will vibrate at twice the frequency of the current passing through the coil. Clearly this is an undesirable condition for sound reproduction.

The use of a strong permanent magnetic field eliminates this undesirable frequency-doubling effect in a bipolar headphone unit, for the permanent field provides a continuous attraction for the diaphragm which is merely varied by the alternating current. The change in the attraction of the pole pieces for the diaphragm depends upon the original magnetization and upon the change in flux caused by the signal current flowing through the coils (the change in attraction actually depends upon the product of these two factors). Increasing the strength of the permanent magnet and increasing the strength of the signal currents are thus possible ways of increasing the sensitivity of a headphone unit.

Modern headphone units have permanent magnets made of chrome or tungsten steel, which produce a strong permanent flux and thereby give a highly sensitive unit with a minimum of frequency doubling. Permanent magnets made of Alnico produce even greater magnetomotive forces, and this recently developed alloy may therefore be found in new high-quality headphones. Placing the diaphragm as close as possible to the pole pieces increases the amount of permanent flux and thus increases the sensitivity of the unit, but at the same time this procedure reduces the maximum available volume; the practical headphone unit is therefore based upon a compromise between sensitivity and volume.

If the coil current in a bi-polar magnetic driving unit is to produce a large A.C. magnetic flux, many turns of wire are needed on the coils, and the A.C. magnetomotive force produced by these turns must develop a large A.C. flux. You know that in a magnetic circuit the amount of flux produced for a given magnetomotive force depends upon the reluctance of the flux path, just as the current for a given voltage depends upon the resistance of the path for current in an electrical circuit. The first essential of a low-reluctance flux path is a small air gap between each pole piece and the diaphragm, but on the other hand, the air gap must be long enough to permit the diaphragm movements which are necessary for maximum required volume. With the arrangement shown in Fig. *2A,* however, the A.C. flux produced by the coils must flow through the permanent magnet; unfortunately this has a high reluctance because it is made from a hard, tempered steel or steel alloy rather than from soft iron.

A simple solution to this difficulty is shown in Fig. *2B;* it involves placing a short-cut path for A.C. magnetic flux across the bottoms of the pole pieces. The air gap *R* which is placed in this path has a low enough reluctance to make the *alternating* magnetic flux prefer it to the path through the permanent magnet, but at the same time this air gap offers considerably more reluctance to the *permanent* magnetic flux than does the desired path through the pole pieces and the diaphragm.

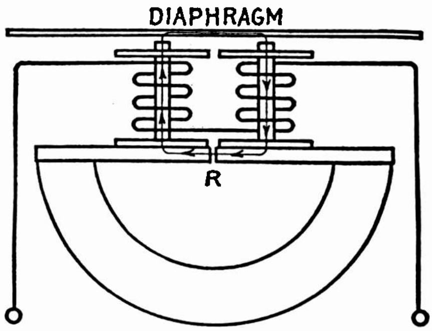


FIG. 2B. Simplified diagram of a special type of bi-polar magnetic headphone unit in which a leakage reactance path *R* for magnetic flux is purposely introduced to improve performance.

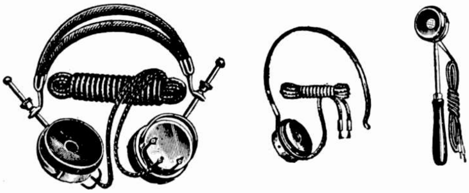
Headphone Ratings. Headphones are commonly rated according to their D.C. resistance, even though the impedance value gives a far better indication of operating characteristics. For a given type of headphone construction, having a given size of bobbin for each coil, we can use a large number of turns of very small wire, thereby securing a high D.C. resistance and a high impedance, or we can use a small number of turns of larger wire to secure a low D.C. resistance and low impedance. Since headphones ordinarily serve as plate loads in amplifier stages, it is the impedance value (generally measured at the average voice frequency of 1,000 cycles) which is of importance; the designer will choose a headphone impedance value which best matches the required plate load of the amplifier tube. In general, the impedance of a headphone unit at 1,000 cycles will be from five to ten times its ohmic value for direct current.

When headphones are being used primarily to convert low intensity signals into audible sounds, they should be rated on the basis of how much A.F. power in milliwatts is required to produce a just audible sound; as yet, however, very few manufacturers supply this information.

Analysis of Vibrating Systems

A complete study of the mechanically vibrating parts used in loudspeakers involves a number of new fundamental ideas which you should understand before proceeding farther with your study of loudspeakers. A mechanical vibrating system has certain properties which compare with those of an electrical vibrating or oscillating system; for instance, you will learn that an inductance (coil) in an electrical oscillating circuit can be compared to *mass* in a mechanical vibrating system, capacitance in an oscillating circuit can be compared to *compliance* in a mechanical system, and resistance in an oscillating circuit can be compared to *friction* or to *mechanical resistance*. A few examples will help you to understand what these new terms mean.

Consider any large, heavy body on wheels; an automobile will do as an example. When pushing the car on a smooth, level road, you know that



Radio operators for commercial or amateur communication systems ordinarily use a pair of headphones like those shown here, in which two units are mounted on the headband and connected together in series. Single headphones with a headband are widely used by experimenters, by hospitals having radio facilities for each patient, and by the hard-of-hearing. A single headphone unit with a handle is used chiefly by those who have only slightly impaired hearing and who therefore need use the sound-amplifying system only at intervals.

considerable *force* is required to set it into motion, but once the auto is moving at a definite speed, it can be kept at that speed with little additional effort. In order to set such a heavy object into motion, we must overcome the inertia of its *mass;* the heavier the object, the greater is its mass and inertia, and the more we must push to set it into motion. We have the same situation in an electrical circuit; an inductance has an electrical inertia which serves to limit the initial flow of current. *Mass in a mechanical vibrating system therefore corresponds to the inductance of a coil in an electrical circuit.*

Now let us consider an ordinary steel coil spring. Experience has taught us that force is required to stretch the spring, and now we learn that this ability of a spring to stretch under the application of force is referred to by engineers as its *compliance.* The greater the compliance of a spring, the more it will stretch when a given force is applied. This compares very closely to a condenser, where greater capacity means that we can store more electricity in the condenser.

As you well know, motion of any object involves friction. It is far more difficult to move an automobile from which all four wheels are removed than a car having wheels, for without wheels there is a great deal more friction between the chassis and the pavement. You know also that friction can be reduced by making the sliding surfaces perfectly smooth and by lubricating the sliding surfaces with grease. Friction of the type which exists when one object rubs against another is quite familiar to you, but in loudspeakers it is the friction produced by an object moving in air which is of importance. An example will illustrate the nature of this friction.

Suppose we take a mass, as shown in Fig. *3A,* and a spring, as shown in Fig. *3B,* and connect them in series as shown in Fig. *3C.* When both the spring and the mass are stationary, pull down on the mass and then release it. The spring stretches when you pull down, but since it is under tension it immediately starts to pull the mass up again after you have re-

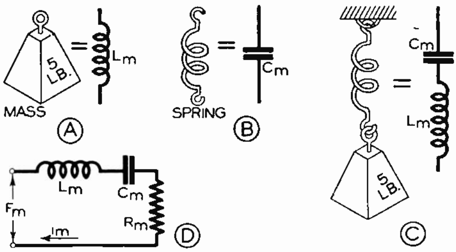


FIG. 3. These diagrams will help you to remember that mass can be considered as a mechanical inductance, that springiness or compliance of any kind (a spring) can be considered as mechanical capacitance, and that a complete mechanical vibrating system acts in much the same way as a series-resonant electrical circuit.

leased it. Having reached its original position, the mass continues moving upward because it has acquired momentum. The mass stops moving upward when it has lost this momentum; the mass then drops downward, moving past its normal stationary position again because of momentum, and continues to bob up and down in what we call mechanical vibration. This vibration continues until all of the original energy imparted to the spring and mass by pulling it down is wasted in friction. This friction occurs in two different ways here, between the mass and the air particles, and internal friction produced by bending of the spring. If this entire system were in water or in a thick oil, there would be even greater friction between the water or oil particles and the mass than in the case of air, and the vibration would stop sooner.

We need not necessarily have five-pound weights and large, stiff springs in order to secure a mechanical vibration; the weight or mass need be only a fraction of an ounce, and the spring can have far more compliance than that shown in the illustration. No matter how small the mechanical structure happens to be, vibration can be secured if there is mass and compliance in the system.

Now you can readily see that the diaphragm in a bi-polar magnetic driving unit has mass and compliance. It will therefore vibrate. Radio engineers have found that its exact behavior during vibration is far easier to understand if the mechanical system is replaced by an equivalent mechanical circuit which has all the appearances of an electrical circuit. Figure *3D* shows such a circuit for the diaphragm of the headphone unit; it will make the mechanical action of a headphone considerably easier for you to understand. Remember, however, that this is not the actual electrical circuit in the headphone; it is simply an imaginary series-resonant circuit which acts in the same way as the mechanical system.

Natural Frequency of Vibration. Notice that we have mechanical force F_m acting upon mechanical inductance L_m, upon mechanical capacitance C_m and upon mechanical resistance R_m. When this force is applied for a short instant of time and then removed, the system goes into vibration and mechanical current i_m, which you can think of as the *velocity* at which the diaphragm moves back and forth, is the result. The natural frequency of vibration of the diaphragm (or of any other physical object) will be determined by the mechanical inductance (mass) and the mechanical capacitance (compliance) of the diaphragm or other object. When a continuously vibrating force is applied, the vibration of the assembled parts will follow this force, and the amount of mechanical current will depend upon the mechanical reactance of L_m and C_m

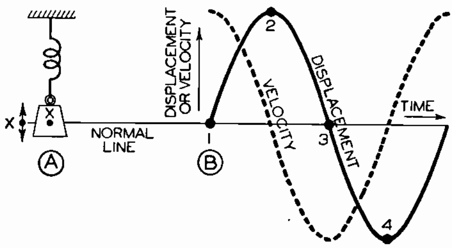
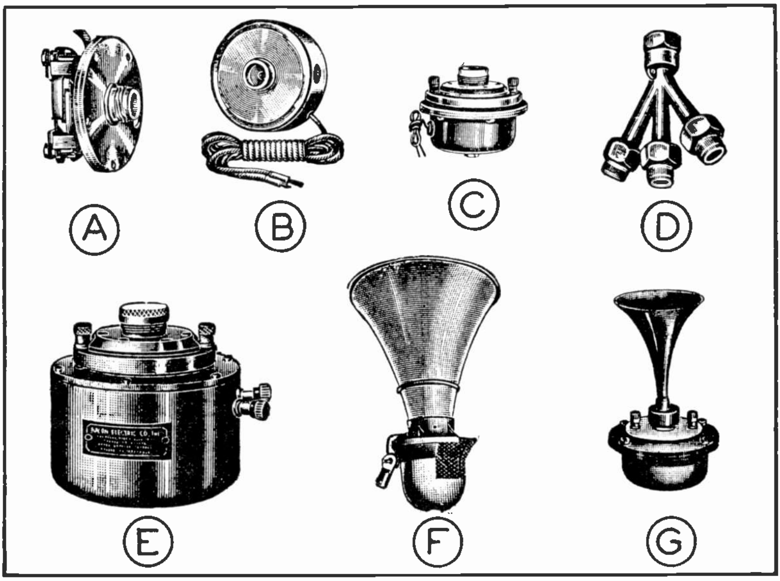


FIG. 4. A careful study of this simple diagram will help you to understand the meaning of *velocity* or *mechanical current* in connection with a loudspeaker.

and the mechanical resistance of R_m, just as in any series resonant circuit. By adjusting the frequency of the vibrating force or by changing L_m and C_m mechanically, you can make the mechanical circuit act either as a mechanical resistance, a mechanical inductance, or a mechanical capacitance.

Velocity of a Diaphragm. Let us get a clearer picture of this mechanical current or velocity, for it is extremely important in connection with our study of loudspeakers. Suppose we have a mass and compliance arranged as shown in Fig. *4A;* we set this mechanical system into vibration. Under this condition, any particle on this mass, such as point X, will be moving continually above and below its normal position or normal line. If we plotted from instant to instant the position of particle X with respect to this normal line, we would secure the solid line curve shown in Fig. *4B*. Yes, this plotting of displacement against time for a vibrating mechanical system results in a pure sine wave; this is why mechanical vibration of a simple mass and compliance has a simple sine wave motion.

When particle X is moving across the normal line at point 1, it has a greater mile-per-hour speed than at any other point along its path; in other words, the particle has maximum velocity when it crosses the normal line. A quarter of a cycle later, when particle X is at point *2*, its highest position above the normal line, it actually comes to a standstill for an instant, and its velocity is zero. As particle X drops down toward the normal line again, its velocity in-



These diagrams illustrate a number of interesting features of horn loudspeakers. *A*—Low-power magnetic driving unit of the balanced armature type, with diaphragm feeding into a standard ⅝-inch throat for use with horn loudspeakers; *B*—balanced armature magnetic driving unit in its housing, with connecting leads clearly visible. Units like this can handle up to 2 watts of input power; *C*—electrodynamic driving unit for horn loudspeakers. Note the two field coil leads coming out of the side of the housing or pot; *D*—special three-way connecting throat which permits the attachment of three separate driving units to a single trumpet or horn; *E*—another electrodynamic driving unit for horn loudspeakers. Size and weight are general indications of power-handling ability in units of this type. A 20-pound unit will handle approximately 25 watts of input power continuously and 50 watts on peaks, while a 6-pound unit will handle about 5 watts continuously and 10 watts on peaks. If more than the rated continuous power is fed to a unit, overheating and failure may occur. If more than the rated peak power is fed at any instant of time, the unit may rattle because of excessive diaphragm displacement. The knurled protective cap on the throat is removed when the unit is installed; *F*—dynamic driving unit employing a large diaphragm which is coupled to a trumpet horn; G—horn loudspeaker designed specifically for high frequencies, from 3,000 cycles to 15,000 cycles. The trumpet horn used on this unit is spun from a single piece of aluminum.

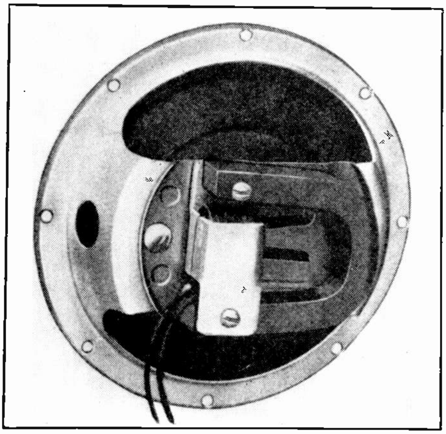
creases again to a maximum as it goes through point *3*, and then gradually decreases to zero again at point *4*. If we plot this velocity of particle *X* from instant to instant, we secure the dotted line curve in Fig. *4*.

Maximum Displacement. When we deal with the vibrating systems used in loudspeakers, we are particularly interested in the peak or maximum displacement of the mass or of particles on it. In the bi-polar magnetic driving unit, for example, a strong coil current will give a greater displacement than a weak current, and an alternating coil current will cause the diaphragm to move in and out in an alternating manner similar to that shown in Fig. *4B*. If the alternating current is of high frequency, then the diaphragm will likewise vibrate at this same high frequency.

Suppose that the diaphragm is moving the same distance (has the same peak displacement) first for a low frequency and then for a high frequency; clearly it will take less time to go through one complete cycle at the higher frequency. The speed or velocity of the diaphragm is therefore *considerably greater* at the higher frequencies of vibration.

Velocity of a Vibrating Mass. At a given frequency of vibration, any increase in displacement likewise means an increase in the velocity of the mass or particle. Your own experience will prove this to be true, for you know that the farther you pull the weight in Fig. *3C* down from its "at rest" position, the faster will it move upward past its "at rest" position when released. The velocity of a vibrating mass therefore depends upon *the frequency of vibration* and upon *the maximum displacement of the mass* from its normal position.

When the diaphragm of a headphone or loudspeaker is vibrating, it causes particles of air in its vicinity to vibrate in a similar manner. These air particles will vibrate at the same frequency as the diaphragm, and will also have the same velocity as the diaphragm at any instant. The vibration is transmitted from one air particle to another, giving rise to sound waves. It is the frequency at which these air particles vibrate which determines the pitch or tone of the sound, and it is the *velocity* of the *air particles* which determines the power * (loudness or volume) of the sound.



Courtesy Arlavox Mfg. Co.

This magnetic loudspeaker, available with cone diameters ranging from 3 inches to 8 inches, will be found in many small Universal A.C.-D.C. receivers. It uses a balanced armature type of driving unit. Note the U-shaped permanent magnet.

* You know that in an electrical circuit like that in Fig. *3D*, the power absorbed by the resistor is equal to the square of the current multiplied by the ohmic value of the resistor ($P = I^2R$). Likewise, in a mechanical vibrating system, the square of the air velocity multiplied by the mechanical resistance gives the *mechanical power* used by the system; this represents acoustical power.

Facts to Remember about Vibrating Systems. It will be some time before you will be able to appreciate fully the facts just brought out in connection with the vibrating systems used in loudspeakers. For your present study of loudspeakers, it will be sufficient for you to keep in mind the following important facts:

1. **Any physical object has *mass*, which can be considered as *mechanical inductance*.**

2. **A physical object can have *compliance* (you can call this springiness if you prefer), and this characteristic can be considered as *mechanical capacitance*.**

3. **The motion of any physical object is accompanied by friction, which represents power used or wasted.**

4. **Any physical object which has mass and compliance can be shocked into vibration by a sudden application of force; it will then vibrate at its natural frequency of vibration, which is determined by its *mechanical inductance* (mass) and its *mechanical capacitance* (compliance). Increasing either of these two values lowers the natural frequency of vibration.**

5. **The application of a steady alternating force to a vibrating system will cause a corresponding alternating or vibrating motion of the system at the same frequency. We can consider this mechanical vibrating system as equivalent to an electrical series resonant circuit. When the natural frequency of the system corresponds to the frequency of the applied alternating force, resonance occurs and the system acts as a mechanical resistance. At frequencies above resonance, the vibrating system acts as a mechanical inductance (a mass). At frequencies below the natural resonant frequency, the system acts as a mechanical capacitance.**

6. **Since mass can be considered as an inductance, and compliance as a capacitance, these parts of a mechanical vibrating system have the additional property of mechanical reactance, which takes frequency into account.**

7. **The application of an alternating force to a vibrating system causes the system to vibrate with a velocity dependent upon its mechanical reactance and mechanical resistance.**

Mechanical Resonance in Headphones

Referring again to Fig. *2A*, we recognize that the diaphragm is the mechanical vibrating system in this bi-polar magnetic driving unit. Even though quite small, the diaphragm has mass (weight) and compliance (springiness). When the diaphragm is set into vibration by an alternating current flowing through the coils, it causes air particles in the vicinity to vibrate in a corresponding manner. The resulting sound produced naturally represents radiated energy, and therefore the diaphragm must overcome mechanical resistance in radiating this energy. The diaphragm has a small mass and therefore its mechanical inductance is low; being quite stiff, it has a low compliance and its mechanical capacitance is likewise small. The natural frequency of vibration of the diaphragm is therefore quite high; in fact, diaphragms in high-fidelity headphone units are designed to have a natural frequency of vibration which is considerably above the highest audio frequency being reproduced. This prevents resonant peaks in the response curve of the headphone. Clearly the question of mechanical resonance is of great importance when high fidelity is required from a bi-polar magnetic driving unit such as is used in a headphone.

Balanced Armature Type of Magnetic Driving Unit

Although the bi-polar magnetic driving unit is remarkably simple in design and can be made to have high sensitivity, it is not entirely suitable for loudspeaker applications where high sound output (high volume) is required. Application of excessive input signal voltage to this type of unit results in distortion, due either to the diaphragm striking the pole tips or to a frequency-doubling effect which occurs when the air gap is increased to permit greater volume. Furthermore, normal movements of the diaphragm cause the air gap to vary, with the result that the permanent magnetic flux also varies and a certain amount of distortion occurs. When the diaphragm is made stiff enough to prevent it from hitting the pole pieces, it then becomes quite thick, and its increased mass lowers the natural frequency of vibration. A stiff, lightweight disc would be desirable, but this cannot be easily obtained in the bi-polar type of construction.

The balanced armature type of magnetic driving unit, illustrated in Fig. *5A*, overcomes most of these disadvantages. A light-weight strip of soft iron, called the armature, is pivoted in the center of a coil through which flows the A.F. signal current. This coil may have only a few turns when large A.F. currents are available, but may be built with several thousand turns for low A.F. currents. The coil does not interfere in any way with the movement of the armature. The ends of the armature move between two U-shaped pole pieces which are clamped to a U-shaped permanent magnet which is generally larger and more powerful than the permanent magnet used in bi-polar units. The permanent magnet in this case makes one set of pole pieces permanently of north polarity and the other of south polarity. One end of the armature is rigidly linked to a diaphragm which may be made of mica, duralumin, or any other light material; if the diaphragm is not sufficiently stiff a spring steel metal strip may be attached to the other end of the armature as indicated, to increase the stiffness (reduce the compliance) of the system.

When no current is flowing through the coil, the armature is not magnetized. All four pole pieces then attract the armature equally, and we have a balanced condition in which the armature stays midway between the pole pieces. It is from this characteristic that the balanced armature magnetic driving unit gets its name. When a current i flows through the coil in the direction shown (arrow indicates electron flow), this current will magnetize the armature and give it the polarity indicated in Fig. *5A*. The N pole of the armature will be attracted to the nearest S permanent pole and will be repelled by the permanent N pole. A similar action occurs at the other end of the armature, which is magnetized with south polarity. The result is that the armature twists on its pivot in a counter-clockwise direction, as indicated by the curved arrow line, pushing the diaphragm upward. When the current through the coil reverses its direction, the armature is twisted in the other direction and the diaphragm is pulled downward.

Figure *5B* shows the two paths taken by the magnetic flux produced by the armature when currents flow through the coil. These paths are entirely through soft iron, which has a low reluctance and therefore permits a large amount of flux to circulate. Notice that movement of the armature in either direction will cause one air gap in one of the paths to decrease and the other air gap in that path to increase, with the result that the total air gap for any one path remains essentially the same regardless of the position of the armature. This is a desirable condition for distortionless operation.

Now let us see what effect the position of the armature has upon the path taken by the permanent magnetic flux. Referring to Fig. *5B*, let us assume that the armature is rotated counter-clockwise, so that air gaps g_1 and g_2 are considerably smaller than the other two. Naturally the flux coming out of the north pole of the permanent magnet will choose to take the path through pole N_1 because g_2 offers less reluctance than g_3. This flux will pass through the entire armature and then through gap g_1 to pole S_2. The result is that poles N_1 and S_2 are strengthened, while poles N_2 and S_1 are weakened. But remember that the motion of the armature depends upon repulsion as well as attraction; an increase in the attraction on any one end of the armature is offset by a decrease in the repulsion on the same end, with the result that the effect of the permanent magnetic flux upon the armature *is essentially independent of the position of the armature.*

A balanced magnetic driving unit can swing through considerably greater distances than a bi-polar magnetic unit without serious distortion. The use of large and powerful permanent magnets made of new magnetic alloys makes possible a large air gap, with resulting increase in output volume. The moving system can be made light enough to prevent mechanical resonance in the range of audio frequencies being handled.

With the balanced armature type of construction there is generally ample

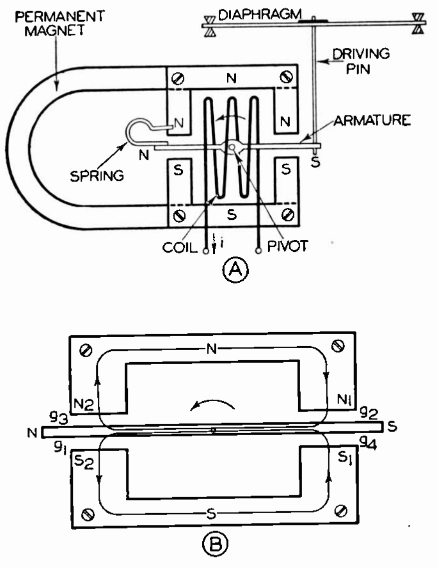


FIG. 5. These diagrams illustrate the construction and principle of operation of a balanced armature type magnetic driving unit.

room for the coil, permitting the use of larger-sized wire with fewer turns in order to reduce the coil inductance. This allows higher-frequency audio currents to flow, increasing the frequency range of the loudspeaker. In general, then, a balanced armature type magnetic driving unit gives higher output and a wider frequency range than a bi-polar magnetic driving unit. With proper design the magnetic type of driving unit can be made to have reasonably uniform frequency response over the middle range of frequencies, from 150 cycles to 3,000 cycles.

Dynamic Driving Units

The amount of audio sound power radiated by a given loudspeaker at a definite frequency depends upon two things: the area of the diaphragm, and the displacement or maximum movement of the diaphragm. These two factors together determine the

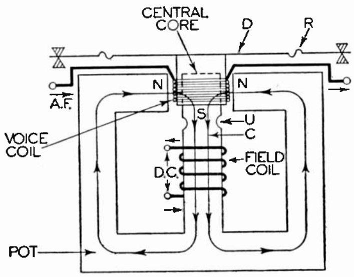


FIG. 6. Simplified diagram illustrating the operating principles of an electro-dynamic driving unit.

volume of air moved and thereby determine the amount of sound produced at a particular frequency. (The in-and-out motion of a loudspeaker diaphragm is often referred to as *piston action,* for the diaphragm acts much like the piston in a water or air pump; the larger the piston area and the farther it moves, the more water or air will be moved.) The greater the volume of air which is moved by a given diaphragm, the greater is the load on the diaphragm and the greater is its mechanical resistance.

With the maximum displacement of the diaphragm limited by the air gap length in magnetic types of loudspeaker driving units, engineers turned to an entirely new type of electro-mechanical driving system, known as the *dynamic loudspeaker.* A study of the simplified diagram in Fig. *6* will show the operating principles of this dynamic unit, which consists simply of a small coil, carrying signal current, which is attached to a large diaphragm and which is located in a strong magnetic field.

Bear in mind that the diagram in Fig. *6* represents a cross section of a cylindrical unit. The permanent magnetic field is provided by sending direct current through a field coil wound around the center cylindrical soft iron core. An iron shell or *pot* surrounds this core and coil to complete the magnetic path up to the air gap in which is located the voice coil; this coil consists of a few turns of fine wire wound on a bakelite-impregnated paper or mica coil form. It is essential that the air gap be kept as small as possible without having the coil or its form rubbing against the cylindrical pole piece or the central core. To reduce the thickness of this voice coil, a spiral groove is often cut in the form for the wires. Mica is often used for the coil form because it will not warp when subjected to excessive heat due to resistance losses in the voice coil. The leads to the voice coil must, of course, be exceptionally flexible and arranged in such a way that they do not interfere with the movement of either the coil or the diaphragm.

Diaphragm *D,* to which the voice coil is attached, is usually made of stiff duralumin, in order that the coil will return to its normal no-current position when the voice coil current drops to zero. The diaphragm is corrugated around its edges, such as at *R*, in order that the inner portion of the diaphragm can move with the voice coil even though the outer edges are rigidly clamped in position.

Now let us see how this dynamic driving unit operates. First of all, I want to point out that the operation is the same regardless of whether the permanent magnetic flux through the air gap is produced by a coil carrying direct current or by a powerful permanent magnet having essentially the same shape as the soft iron core shown in Fig. *6*. It is the interaction between the permanent magnetic flux and the flux produced by the voice coil current which produces motion; the principle is the same as that applying to electric motors.

To understand just why the voice coil should move when current passes through it, consider only one part of the air gap, as shown in Fig. *7A*. The magnetic lines of force here come out of the ring-shaped *N* pole piece and go through the air gap to the cylindrical center core which is made an *S* pole by the permanent magnet or by the field coil. This is the field which is present in the vicinity of the voice coil at all times.

As you know, any wire which is carrying current will have around it a circular magnetic field like that shown in Fig. *7B*. If the electron flow through this wire is into the paper, the magnetic lines of force will have the direction shown.

When this single current-carrying wire is in the air gap, we have the conditions shown in Fig. *7C*. The two magnetic fields react with each other. Notice that the magnetic lines of force underneath the wire are in the same direction and reinforce each other, while those above the wire are in opposite directions and tend to cancel out. There is a crowding of flux lines below the wire and a less-than-normal number above the wire; the motion of the wire will be such as to redistribute the flux more uniformly, and the wire will therefore move upward as indicated by the long arrow. If the current through the wire reverses, the magnetic field of the wire will be reversed in direction and the wire will be forced downward. With a voice coil in the air gap, this same

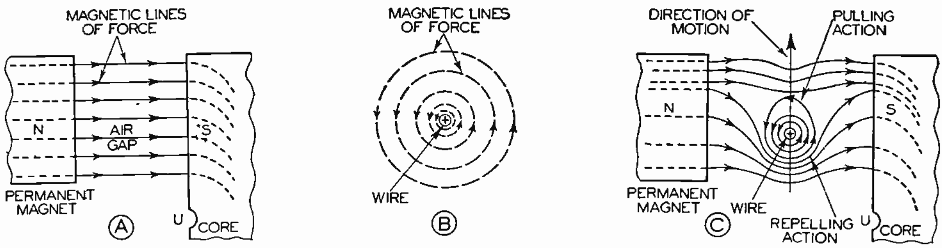


FIG. 7. What makes the voice coil move in a dynamic loudspeaker? These diagrams will tell you. The fixed magnetic field is shown at *A*, while the magnetic field around a voice coil wire is shown at *B*. The inter-action of these two fields, as at *C*, results in motion of the voice coil. The + symbol in the wire indicates that the electron current is flowing into the paper (away from you) through the wire.

action takes place at all points in the air gap and on all turns of the voice coil, with the result that the entire voice coil is either moved upward or downward depending upon the direction of current flow.

The strength or magnitude of the force acting upon the voice coil depends upon three things: *1, the strength of the fixed magnetic field* existing in the air gap; *2, the length of the wire used for the voice coil; 3, the voice coil current.* Increasing any one or all of these three factors increases the force acting upon the voice coil.

If the force acting on the voice coil is to be proportional to the voice coil current at all times, the magnetic flux must be of uniform strength throughout the air gap. You will generally find a groove cut into the central core at *U* to prevent the flux from thinning out at the lower edge of the air gap; furthermore, the length of the voice coil will generally be less than the height of the air gap.

The weight of the diaphragm and voice coil assembly should be low, and the diaphragm should have sufficient stiffness so that mechanical resonance will occur above the audible frequency range.

Since the voice coil in a dynamic unit has only a few turns of wire (from 1 to 50 turns), its reactance is quite low even for the highest audio frequencies; the high-frequency response of a dynamic loudspeaker is therefore not limited by the voice coil inductance, but rather by the mass of the moving system. Diaphragm movements of one-half inch are not uncommon in dynamic loudspeaker units which are capable of handling large amounts of audio power.

Condenser Driving Units

Although condenser loudspeakers are relatively little used today, they have certain special advantages which make it advisable for you to be familiar with their construction and operating principles. They depend for their operation upon the attraction of a positive charge for a negative charge, and might therefore be called electrostatic units.

In a condenser driving unit a heavy, stationary plate is charged with one polarity and a light, movable plate, mounted a short distance away, is charged with opposite polarity. The separation between plates is uniform and is made as short as possible without causing the charges to equalize by jumping across the air gap. As you know, these two plates constitute a condenser; increasing the areas of the plates and reducing the distance between them increases the capacity of the condenser and thereby increases the charge which can be stored on the plates. For a given electrical charge on the plates, reducing the air gap between them increases the force of attraction between the plates.

Application of a high-voltage A.F. signal to the plates is not enough to give the desired operation, for the plates will always be of opposite polarity and will therefore always attract each other (except when the voltage is zero, which occurs twice during each cycle). As a result, we have a frequency-doubling effect just as would occur in a bi-polar magnetic unit if there were no permanent magnet. The remedy is quite simple and comparable to that used in the headphone unit; a D.C. or polarizing voltage is applied to the plates, so that there is a constant attraction between the plates. The A.F. voltage acts in series with this fixed or polarizing voltage, increasing or reducing the attraction. In this way the displacement of the light, movable plate corresponds to the wave form of the A.F. signal.

In practical condenser loudspeakers the movable plate usually consists of metal foil which is cemented over a sheet of thin, stretched rubber which is supported at its edges. A D.C. polarizing voltage of about 500 volts is applied to the plates. The essential features of this construction are shown in Fig. 8.

Although condenser loudspeakers are simple in construction and comparatively inexpensive, their power output is limited because of the extremely limited displacement of the moving plate (the maximum obtainable displacement is always much less than the thickness of the stretched rubber sheet). When increased output is desired, it is necessary to use several condenser loudspeaker units arranged side by side and connected in parallel; each unit ordinarily is about one foot square. Another drawback is the fact that the rubber used as an insulating material has a limited life, becoming hard or deteriorating with time. The low-frequency response of a condenser unit is rather poor, and some provision for correcting this must ordinarily be made in the audio amplifier. The high-frequency response is quite good, however, for the reactance of the loudspeaker unit decreases with frequency and the mass of the moving system is not great enough to prevent high-frequency movement. High-frequency response is further improved by punching holes in the stationary plate to permit free movement of air through this plate. Sounds travel out from a condenser loudspeaker at right angles to its moving plate, and the units therefore have desirable directional characteristics.

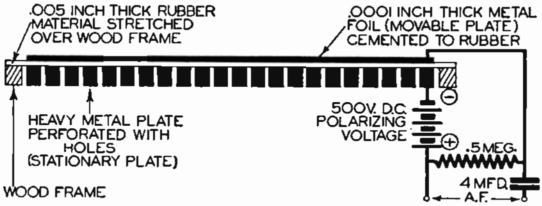


FIG. 8. Cross-section view of a typical condenser loudspeaker, showing essential constructional features. The plates were usually made about 8" x 12" in size.

Crystal Driving Units

The basic action of a crystal loudspeaker is as follows: The application of a voltage of given polarity to the faces of specially-cut crystal slabs causes a change in shape which is used to drive a diaphragm or cone.

Rochelle salt crystals, which can be grown artificially from chemical solutions in quite large sizes and in a relatively short time, are most often used in crystal loudspeakers. A typical Rochelle salt crystal slab might be cut to a size of about 2.5 inches square and ⅛ inch thick, as shown in Fig. *9A*. The slab must be cut from the crystal in a definite manner in order to secure a maximum change in shape when voltage is applied. When this crystal element is rigidly fastened at three of its corners, *A*, *B* and *C*, the application of an electric charge to its faces by means of tinfoil sheets cemented on each side will cause length *A-D* to increase or decrease, depending upon the manner in which the slab was originally cut from the complete crystal and the polarity of the applied charge. This change in length is of course quite small, but engineers have discovered how to utilize it to greatest advantage.

In the practical crystal loudspeaker, two slabs are cemented together. One increases in length when a voltage with a given polarity is applied, while the other decreases in length; the result is that the combined slab bends at its free corner through a distance far greater than the original change in length of either crystal. The principle is much like that of the bimetallic strip so widely used in some thermometers (two different metals are welded together in the form of a thin rectangular strip; one expands more than the other when temperature increases, with the result that the strip bends or curls with changes in temperature).

When two crystal elements are cemented together, giving a two-crystal unit, we have what is known as a *bi-morph cell.* The construction of the usual bi-morph cell is as shown in Fig. *9B*, where tinfoil sheets are cemented to each face of each crystal before the crystals are cemented together; in this way each crystal can be so charged that one will expand while the other contracts.

The construction of a typical crystal driving unit is shown in Fig. *9C*. Three corners of the bi-morph crystal cell are rigidly supported between rubber pads, while a metal cap and a driving link or lever are cemented to the fourth corner. The entire cell is mounted in a water-proof housing, for Rochelle salt crystals dissolve in water and deteriorate in the presence of moisture. They are also affected by high temperatures and must not be used in locations hotter than 125° F. The motion of the free edge of the crystal unit is transferred to the diaphragm by the mechanical link or lever system.

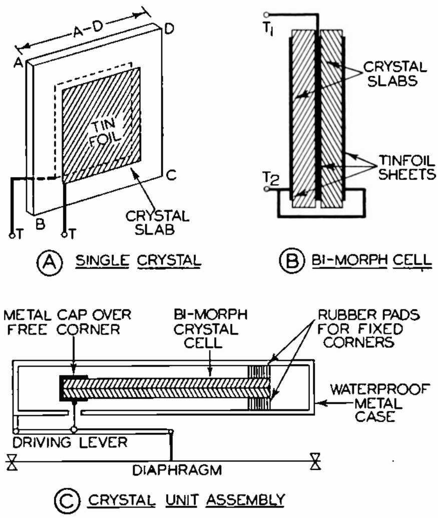


FIG. 9. How does a crystal loudspeaker work? These three diagrams give you the complete story.

Crystal driving units are essentially condensers; in fact, a 2.5 inch square bi-morph crystal cell has a capacity of about .03 mfd. This means that its reactance will decrease at the higher frequencies, and it will therefore have a very good high-frequency response. Although crystal driving units can be designed to reproduce the entire audio frequency range, they are primarily used for the reproduction of the higher audio frequencies.

Loudspeakers Can Also Serve as Microphones

Before considering further details of sound-reproducing units, it is worth noting that any device for converting A.F. signals to sound can also be operated in reverse, so that sounds produced in the vicinity of the diaphragm or moving system will develop an electrical signal of corresponding wave form; in other words, a loudspeaker will also operate as a microphone. The better the fidelity of the loudspeaker as a sound reproducer, the better will be its performance as a microphone. One basic difference must be kept in mind; sound reproducers are designed to furnish large sound output powers, with the diaphragm or moving element pushing a large volume of air, while microphones are usually designed to respond to movements of small volumes of air or to weak sound inputs. In modern intercommunicating systems, small dynamic loudspeakers are widely used as microphones.

Action of a Horn as a Loudspeaker Coupling Unit

We have now considered the various methods ordinarily used for setting the diaphragm of a loudspeaker into vibration. Naturally we want this vibration of the diaphragm to produce a large sound output. Since the horn is a common air coupling system used for this purpose, it will be taken up next.

As you already know, the acoustical characteristics of a vibrating diaphragm in a driving unit may be represented by an electrical circuit like that shown in Fig. *10*. The mass of the diaphragm is represented by L_m (mechanical inductance), the compliance or springiness of the diaphragm is represented by C_m (mechanical capacitance), and the mechanical resistance of the diaphragm is represented by R_m. The mechanical force applied to the diaphragm by

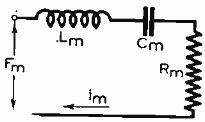


FIG. 10. Equivalent mechanical circuit of a vibrating diaphragm in a loudspeaker.

the driving unit is represented by F_m; for simplicity we can assume that it is an alternating force having a simple sine wave characteristic. We can then vary the frequency of this source and determine the effects of these variations on the performance of our loudspeaker.

The simple series circuit in Fig. *10* will serve as our guide for analyzing the action of a vibrating diaphragm. The applied force F_m causes the diaphragm to vibrate, and at any frequency the velocity of vibration will be governed by the mechanical reactances of L_m and C_m and by the mechanical resistance of R_m. When the two mechanical reactances are exactly equal, their effects cancel and we have mechanical resonance, with only R_m in the circuit to limit mechanical current flow. This mechanical current (i_m) represents the velocity of the diaphragm, and consequently also represents the velocity of air particles in the vicinity of the diaphragm. It is this air velocity which contributes toward the desired sound output. At input frequencies below the resonant frequency of the diaphragm, the mechanical reactance of C_m will be greater than that of L_m, and the diaphragm will act as a mechanical capacitance in series with a mechanical resistance. At above-resonance frequencies, the diaphragm will act as a mechanical inductance in series with a mechanical resistance but neither the mass (inductance) nor the compliance (capacity) involves loss of power; they merely offer opposition to changes in diaphragm position. It is the mechanical power absorbed by R_m which determines the loudspeaker sound output.

From Fig. *10* it is obvious that increasing the value of R_m increases the amount of mechanical power absorbed and therefore increases the sound output of a loudspeaker. Likewise increasing the driving force F_m will cause greater mechanical current flow, increasing the diaphragm displacement and velocity and thereby increasing the air velocity and the sound output power.

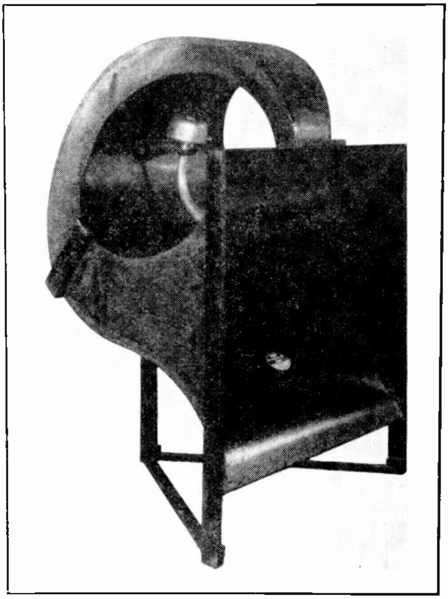
In the case of crystal or condenser driving units, the mechanical force F_m can be increased directly by increasing the A.F. voltage applied to the driving unit, while in other types of driving units an increase in the applied A.F. voltage will cause greater A.F. current to flow and this will increase the mechanical force F_m. Increased mechanical force F_m obviously will cause greater diaphragm displacement and greater air velocity, with more power being absorbed by R_m.

If a driving unit of a loudspeaker were placed in a vacuum, R_m would merely represent losses due to friction in the diaphragm itself; there would be no useful sound output since no air would be moved. The only limitations to the velocity of motion of the diaphragm would be this very low value of R_m and the difference between the mechanical reactances of L_m and C_m; at resonance these mechanical reactances would balance out, and we could expect extremely large velocities and displacements of the diaphragm. Considering these facts from a practical standpoint, we can easily see that with a loudspeaker operating outside the gondola of a balloon high in the stratosphere (where atmospheric conditions approach a vacuum), the displacement of the diaphragm might be large enough to ruin the driving unit.

When the diaphragm is allowed to act upon air, a load is applied or coupled to the diaphragm and this is equivalent to increasing the value of R_m. This is a desirable condition, for it allows us to secure a greater amount of useful work from the loudspeaker.

Measuring Loudspeaker Efficiency. When loudspeaker engineers desire to check the efficiency of a particular loudspeaker as a sound reproducer, they measure the electrical resistance of the loudspeaker input terminals under the following two conditions: *1*, with the driving unit blocked, so that the diaphragm and the other moving elements cannot move; this gives the resistance due to electrical losses in the driving unit only, and is known as the *blocked resistance* of the loudspeaker; *2*, with the moving elements free to move.* These resistance measurements are repeated for a number of frequencies over the entire audio range. The difference between the two measured resistance values at each audio frequency then represents the additional resistance due to the production of sound; this is called *motional resistance.* The ratio of the motional resistance to the total resistance when the diaphragm is free determines the loudspeaker efficiency; multiplying this ratio value by 100 gives the percentage efficiency. If, for example, these tests show that a loudspeaker has an efficiency of 10% at 1,000 cycles, the engineer knows that he will only get 2 watts of acoustical power out of the loudspeaker when he feeds 20 watts of electrical power into the loudspeaker.

Loading the Diaphragm. Loudspeaker engineers quickly learned that small diaphragms operating in free air without horns or other air coupling systems gave little sound output regardless of their velocity or displacement; measurements of loudspeaker efficiency verified this by indicating a very low motional resistance. The reason for this is easy to see; air directly in front of the diaphragm is alternately compressed and thinned out, and the same effect occurs at the back of the diaphragm. Whenever there is compression in front, there is thinning out or rarefaction at the back. Since compressed air tries to spread out or relay its effects to adjacent air particles in the easiest way possible, it merely moves around the diaphragm to the rear to equalize the thin air there, and only a very small volume of air is thus actually set into vibration by the diaphragm.



Curled exponential horn with circular cross-section near throat; the ⅝" diameter throat fits into a standard driving unit. Note the square cross-section at the mouth and the rectangular cross-section in the middle region. The shape of cross-section is unimportant as long as the cross-sectional area of the horn increases in an exponential manner from throat to mouth.

One way of overcoming this trouble is to use a large diaphragm or cone which will set a large volume of air into motion. Another way is to prevent the air in front of a small diaphragm from reacting on the air in back of the diaphragm. Either of these procedures increases the load on the diaphragm, thereby increasing the

* In order to secure a true A.C. resistance measurement at the chosen frequency, the reactance of the voice coil is tuned out by means of a condenser in both cases.

motional resistance, producing more acoustical output and increasing the loudspeaker efficiency.

The mounting of a megaphone or conical-shaped horn like that shown in Fig. *11A* around the diaphragm of a driving unit was an early attempt to load the diaphragm by preventing air from escaping behind it, and also was intended to direct the moving air toward the listener. Results were not satisfactory, however, for the use of a conical-shaped horn did not take into account the fact that air in motion travels in definite natural paths. We have a small amount of air vibrating at high velocity near the diaphragm; what we really want is a horn which will cause a greater amount of air a farther distance out to vibrate at a somewhat lower velocity, this process continuing until at the opening of the horn a very large volume of air will be vibrating at a low velocity. There must be no dead spots in the horn (regions unaffected by the vibration of the diaphragm); there must be no cancellation of effects along the length of the horn, no turbulence of air and no wasted energy. If all this is realized, the entire amount of air in the horn will be properly coupled to the driving unit, increasing the motional resistance and giving the desired increase in efficiency. Securing this desirable condition is known as matching the impedance of the air with the impedance of the driving unit; it serves to load the unit effectively and give a maximum of useful sound power output.

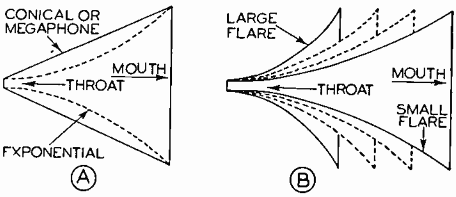


FIG. 11. Comparison of shapes of a conical horn with various types of exponential horns used with loudspeaker driving units.

Exponential Horns. No doubt you are already familiar with loudspeaker horns. At the small end or *throat* of a horn the cross-sectional area is small, while at the large end or *mouth* the cross-sectional area is large and is a maximum. It makes little difference whether the cross-sectional shape of a horn is square, rectangular or circular; it is the manner in which the cross-sectional area increases from the throat to the mouth which determines the effectiveness of the coupling between the driving unit and the air in space. When this area increases according to what mathematicians call an *exponential* formula, giving a graceful curve like that shown by the dotted lines in Fig. *11A,* the coupling will be most effective.

For a given throat area and a given mouth area, there can be any number of exponential horn shapes, but each would have different length and a different flare, as indicated in Fig. *11B*. The *flare* of a horn refers to *the amount of spreading outward in a given horn length*; the shortest horn shown in Fig. *11B* thus has the greatest flare. The amount of flare has a definite and important effect upon the frequency range of a horn loudspeaker, for it determines the efficiency of coupling at various frequencies in the audio range.

The formula used by loudspeaker design engineers in computing the shapes of various forms of exponential horns involves considerable mathematical knowledge, and will not be taken up here since it is seldom if ever needed by the practical man. There are certain facts to be derived from this formula which are of practical interest, however. The smaller the flare (amount of spreading out) of the horn, the lower will be the frequency which can effectively be coupled to the driving unit and the longer will be the horn for a definite throat and mouth area. That horn in Fig. *11B* having the largest flare consequently cannot be expected to reproduce low frequencies as well as the horns having smaller flares. Remember—a horn which is to provide effective coupling between the air and a loudspeaker driving unit at low frequencies should have a small flare.

Mouth Area. Although the area of the mouth of a horn does not have an appreciable effect upon the cut-off frequency of the horn (the lowest audio frequency which it will radiate effectively), the mouth area does affect the uniformity of the loudspeaker response curve. A small mouth results in a sudden change in the velocity of air particles as they leave the horn, causing some of the sound

Courtesy Utah Radio Products Co.

Assembly line in the Utah loudspeaker factory. Finished electrodynamic loudspeakers are placed on the conveyor belt which moves down the center of the long table.

waves to be reflected back into the horn. This gives rise to peaks and dips in the loading of the driving unit, causing a ragged sound output. In general, for a horn with a circular cross-section, the diameter of the mouth should be equal to at least one-fourth the wavelength of the lowest frequency which is to be reproduced (the wavelength of sound is equal to its velocity of travel, 1,089 feet per second, divided by its frequency in cycles; at 50 cycles, then, the wavelength would be 1,089 ÷ 50, or about 22 feet). Thus a horn which is to handle frequencies down to 50 cycles should have a mouth diameter equal to at least 22 ÷ 4, or 5.5 feet. The length of this horn would be quite long, for the small flare required to secure efficient coupling at this low audio frequency would make necessary the long length in order to secure the required mouth area.

Throat Area. The throat area of a horn is controlled essentially by the size of the diaphragm. It is common practice to design driving units for use with a circular throat having a diameter of 5/8 inch, in order that standard horns and driving units can be used interchangeably. With a considerably larger throat area, a short horn with a small flare would provide a fairly low-frequency cut-off, but experience has shown that such a horn would not give efficient coupling at higher frequencies. With a small diaphragm and the conventional small throat, good high-frequency output is possible but the movement or displacement of the diaphragm must be increased in order to secure good bass output. Yes, there are plenty of tough problems confronting the loudspeaker designer.

Courtesy Vac-O-Grip Co.

Four dynamic cone loudspeakers with single-piece spun aluminum exponential horns are here mounted on an ingenious carrying frame which can be used on any passenger car without damaging the roof. Rubber vacuum cups beneath each support prevent the assembly from sliding off while the car is in motion.

Construction of Horn. Any material is satisfactory for horn construction as long as it is dead as far as sound is concerned; in other words, the material must not vibrate under the influence of sound waves. Aluminum is an excellent material, but when used for the longer horns, it should be reinforced with ribs on the outside to prevent the large surfaces from vibrating in unison with the diaphragm. Plywood is widely used for horns of rectangular cross sections. Some horns are made of papier mache (molded paper fiber), while others are made of layers of cloth impregnated with a special glue or binder and formed to the desired shape. Horns which must withstand outdoor weather conditions generally are of sturdy metal construction; when plywood or some other non-metallic material is used, it should be treated to withstand moisture.

As a rule, a straight horn like that shown in Fig. *12A* will give better results than a curled horn like that in Fig. *12B*. It is common practice to build up a large horn in sections, different constructional procedures being followed for each type and size of horn and each type of material. That section which screws onto the driving unit is generally spun or cast from aluminum, and has the same form of exponential curve as the remaining sections of that particular horn.

Where space prevents the use of a long, straight horn having the desired characteristics (a horn length of 18 feet is by no means unusual where frequencies down to 50 cycles must be reproduced), the horn may be curled in the manner shown in Fig. *12B*. The sharpest bend in the horn must not cancel any of the high-frequency sounds. If the difference in length between sound paths *3-4* and *1-2* in Fig. *12B*, around a sharp bend, is less than one-half the wavelength of the highest frequency to be reproduced, the cancellation of sound will not be serious. Cancellation occurs whenever two sound waves become 180° out of phase, and this can occur when one wave travels one-half wavelength more than the other. Curled horns can generally be designed to meet any reasonable space requirements while still observing the flare, mouth area and curvature specifications required for a desired performance.

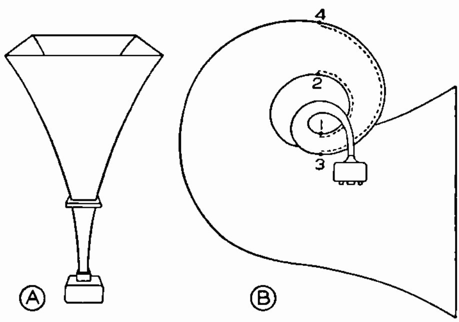


FIG. 12. Straight and curled exponential horns having standard ⅝" throats.

Horn Ratings. If a horn is able to resist heavy sound pressures without self-vibration, it can handle unlimited sound output power. Good horns are therefore rated according to frequency range and *not* according to power-handling ability. Either high- or low-power driving units may be attached to any particular horn. Oftentimes several driving units are used on a single horn by redesigning the throat end of the horn or by inserting the proper type of connecting unit. In general, a long horn with a small flare and a large mouth will have a wide frequency range and will have high efficiency.

Design of Dynamic Driving Units for Horn Loudspeakers

In the high-power dynamic driving units used with horn loudspeakers, the

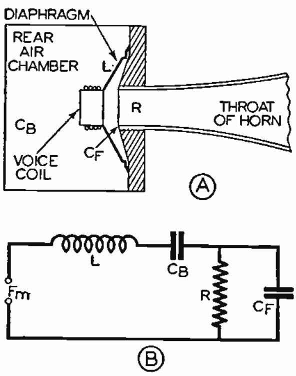
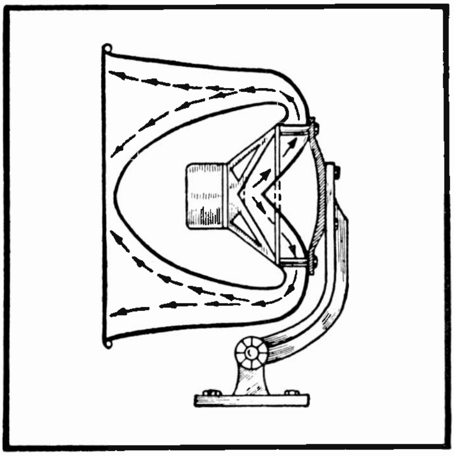


FIG. 13. Method of mounting horn with ⅝" throat on driving unit having a diaphragm considerably greater in diameter than ⅝", and equivalent mechanical circuit for such a combination.

diaphragm is generally made considerably larger than the ⅝ inch throat diameter of the horn, in order to move a larger volume of air and secure a higher initial air velocity. The arrangement of a dynamic driving unit might be as shown in Fig. *13A*. The diaphragm is made in the shape of a cone, to prevent buckling when a



Marine-type mounting of dynamic cone loudspeaker. This weather-proof unit, made by Atlas Sound Corp., gives excellent distribution of sound and at the same time is capable of withstanding the extremely severe weather conditions encountered on board ships, on sound trucks and even on fire trucks. Tests have shown that a stream of water can be played directly into the mouth of the loudspeaker without affecting loudspeaker operation. The horn is made from heavy-gauge aluminum and steel spinnings. Arrow lines show paths of sound waves.

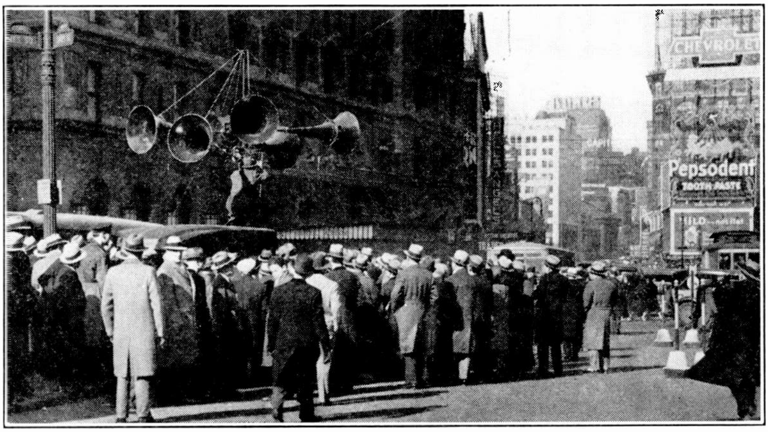
strong force is applied at its center by the voice coil.

The mounting of the diaphragm is such that it has a certain amount of natural springiness, which returns it to a normal position when no current flows through the voice coil, or the cone and the chamber in back of it are made air-tight so that the air space in back of the diaphragm will act as a cushion or spring which returns the diaphragm to its normal position. The diaphragm therefore has mechanical capacitance. Furthermore, since the diaphragm and voice coil together have a certain amount of mass, they also have mechanical inductance. The experience of loudspeaker engineers has shown that these act in series, as shown in Fig. *13B*. The load which is placed upon the cone-shaped diaphragm by the exponential horn can be represented as a mechanical resistance acting in series with the mechanical inductance and mechanical capacitance. We must not overlook the air chamber between the cone and the surface directly in front of it which supports the throat end of the horn. This air space can be considered an extra mechanical capacitance C_F acting in parallel with the mechanical resistance.

We know how an electrical circuit resembling that in Fig. *13B* will behave under various conditions, since it is a common radio circuit, and consequently we can predict the behavior of our loudspeaker by studying this circuit.

Assuming that the value of C_F is small, as it ordinarily is, we can see that the mass of the cone (L) and the compliance of the rear chamber (C_B) form a series resonant circuit. Resonance will occur at some particular frequency, and at resonance the input force F_m will depend upon the length of the wire in the voice coil, upon the voice coil current and upon the flux density in the air gap surrounding the voice coil. Furthermore, at resonance the input force will be acting solely upon mechanical resistance R, and practically all of the input force will serve to produce useful sounds (assuming a perfect exponential horn). The loudspeaker designer can select the values of L and C_B so that mechanical resonance occurs at a low audio frequency, thus providing reinforcement of bass notes, or at some intermediate frequency. This is one way of securing a desired frequency response for a loudspeaker.

At high frequencies the mechanical reactance of C_F becomes important. Referring to our equivalent mechanical circuit in Fig. *13B*, C_F by-passes



Courtesy Racon Electric Co., Inc.

Battery of trumpet horn loudspeakers set up in front of the Hotel Astor at Times Square, New York City for a special event. This arrangement for radiating sound equally well in all directions requires a number of horns, with separate driving units for each.

high-frequency signals around the load, and consequently in the loudspeaker this air chamber ahead of the cone definitely suppresses the high audio frequencies. The volume of air in this chamber determines to a considerable extent its mechanical capacity, and therefore the effects of this chamber can be reduced by making it as small as possible while still allowing ample room for cone movement. The shape of this air chamber alongside the throat is important for another reason; if the shape is such that air in the chamber can take several paths, of varying length, to the throat of the horn, it is possible that some of the high-frequency sounds will reach the throat out of phase and will cancel. In high-power horns the air pressure in this chamber may be tremendous; air cannot be compressed uniformly under these conditions, and distorted wave forms are the result. All these factors must be taken into account when designing the driving unit for a horn loudspeaker.

A number of typical mounts for the throat and diaphragm of a dynamic horn loudspeaker are shown in Fig. *14*. In each case the air chamber ahead of the diaphragm or cone is designed to give desired performance while reducing undesirable effects. When a wide range of sound frequencies is to be reproduced, it is generally best to use two loudspeakers; one loudspeaker for frequencies from 50 cycles to 6,000 cycles, called a *"woofer,"* and another loudspeaker for frequencies from 6,000 cycles to 15,000 cycles, called a *"tweeter."*

The science of horn loudspeaker design has now advanced to the point where efficiencies of up to 50% can be expected, with reasonably flat response. This means that the best horn loudspeakers will deliver 5 watts of sound power for each 10 watts of electrical input to the voice coil.

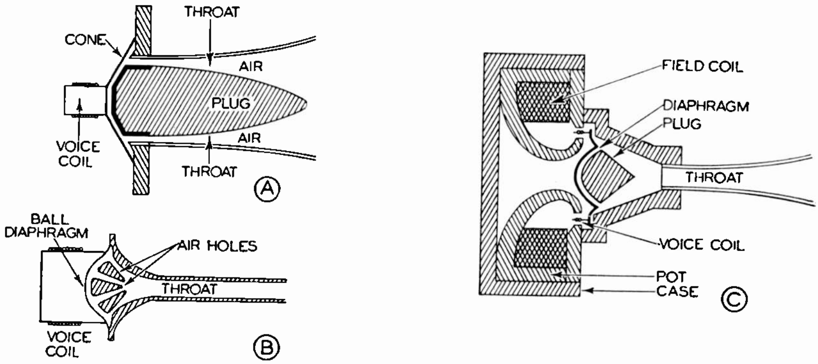


FIG. 14. Constructional features of three typical dynamic driving units are shown here. *A:* Unit employing a ring-shaped air chamber between the cone and the throat (secured by mounting a plug in the throat). The chamber is carefully shaped to reduce cancellation of sound waves at the higher frequencies. *B:* Unit using multiple outlet paths from diaphragm to throat (secured by forming air holes in a plug) to release the back pressure. *C:* Complete dynamic driving unit energizing a modification of the ring-shaped air chamber shown at *A*.

TEST QUESTIONS

Be sure to number your Answer Sheet 26FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Name the three sections of a complete loudspeaker.
2. Into what four general groups can loudspeakers be divided?
3. How is the undesirable frequency-doubling effect eliminated in a bi-polar headphone unit?
4. What does mass in a mechanical vibrating system correspond to in an electrical oscillating circuit?
5. What determines the natural frequency of vibration of any physical object?
6. What three things determine the force acting upon the voice coil of a dynamic loudspeaker?
7. What is the basic action of a crystal loudspeaker?
8. What is meant by the flare of a horn?
9. If a horn is to provide effective coupling between the air and a loudspeaker driving unit at low frequencies, should a large or a small flare be used?
10. Are horns rated according to power-handling ability?

LOUDSPEAKERS AND HOW THEY OPERATE

PART 2

27FR-2

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

DELIVER THE GOODS

"There are 57 rules for success. The first is to deliver the goods. Never mind the rest."

Like many striking assertions, the quotation above is not altogether true, because there are other rules which cannot be ignored. But there is a lot of truth in this statement.

If you want to be a success in life, deliver the goods. No matter what your opportunities in life, no matter how good your training, and no matter how good your intentions are, you cannot succeed unless you deliver the goods—unless you deliver full value to your employer or to your customers.

Employers want men who can be depended upon to earn their salary each and every day—men who not only have the training required for their particular jobs, but also know how to *and actually do* apply their knowledge to their work. Customers come back only when the services received for their money have been entirely satisfactory.

You can always excuse yourself if you fail—but nobody else will ever excuse you. Customers may be polite to you, and may feel sorry for you, but they will go elsewhere the next time they need radio service work. Employers are equally indifferent to excuses, for they must have good men if they themselves are to deliver the goods.

Make it your business in life to be where you are needed, when you are needed, with the service or the help that is needed. Have all the knowledge which may be required for you. Be the man who delivers the goods and gets the money.

J. E. Smith

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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Loudspeakers and How They Operate
Part 2

Cone Loudspeakers

LOUDSPEAKERS of the horn type, having the required wide frequency range for high-fidelity reproduction, are too bulky for use with the average home radio receiver even when curled to occupy a minimum of space. Engineers recognized this fact soon after loudspeakers first came into use, and eliminated the horn entirely by increasing the size of the diaphragm and setting a large amount of air directly into motion.

Since a large, flat diaphragm will buckle or bend readily even when driven from its center, loudspeaker engineers shaped this diaphragm in the form of a cone, attaching the driving unit to its apex or point. The outer edges of the cone are free to move, being held in alignment by a soft leather ring or washer cemented to the edges of the cone and supported by a circular steel frame. The entire cone moves in and out in unison with the driving unit, at least for low frequencies.

In the early days of radio, a cone as large as 36 inches in diameter was quite common, being used to secure good low-frequency output, but the high-frequency response of these cones was irregular. Today cones are generally from 6 to 14 inches in diameter; because loudspeaker engineers now have a better understanding of the exact operation of a cone loudspeaker, remarkably flat response characteristics are being secured.

The cone arrangement of a typical cone loudspeaker is shown in Fig. *1*. Observe that the frame of the cone is held against a flat surface known as a baffle, which may be either of wood, plywood, fiber board or other sound-absorbing material in which a circular hole the same diameter as the cone has been cut. This baffle board serves to prevent sound waves produced at the rear of the cone from interfering with sounds produced at the front of the cone. For the present we will assume that the baffle is so large that no interference or can-

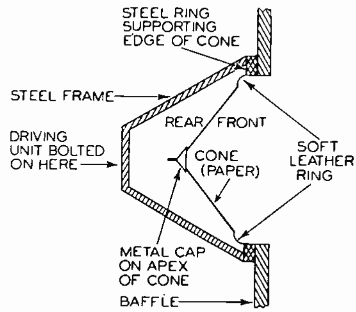


FIG. 1. Cross-section view of a cone loudspeaker and its supporting structure, as mounted on a wood baffle. Driving unit is not shown.

cellation of sound can take place; later in this text-book we will consider baffle design in detail.

In general, cone loudspeakers will be found with balanced armature magnetic driving units, with electro-dynamic or permanent magnet dynamic driving units, and with crystal driving units. A number of typical cone loudspeakers are shown in Fig. *2*.

The unit in Fig. *2A* is typical of cone loudspeakers using a balanced armature magnetic driving unit. The apex or point of the cone is driven by a metal extension arm or lever attached to the vibrating armature. In many cone loudspeakers, the mechanical lever system is so arranged that it provides mechanical amplification of the cone movement;

in other words, the apex of the cone may move twice or three times as far as the point on the armature to which the lever is attached. Even with this mechanical lever arrangement, the movement of the cone is definitely limited by the movement of the balanced armature between the pole pieces. Magnetic loudspeaker units of this type ordinarily will not handle much more than 2 watts of electrical input power.

In Figs. *2B* and *2C* are two views of a representative dynamic cone loudspeaker. The transformer which matches the voice coil impedance to the output impedance of the power stage of the receiver can be seen mounted directly on the loudspeaker frame, as is the usual practice. If, in addition to the leads coming from the matching transformer, there are two or three more leads coming from the pot or cylindrical housing at the back of the loudspeaker, we can assume this to be an electrodynamic unit, with the permanent magnetic flux being produced by direct current flowing through the field coil. If there are no additional leads, the unit is of the permanent magnet dynamic type.

The cone unit alone of a dynamic loudspeaker is shown in Fig. *2D*. Observe that the voice coil is attached directly to the cone. The size of the voice coil leads has been exaggerated in the drawing in order to make them visible; actually they are made of very fine flexible wire. The outside edges of the cone are cemented to a cardboard ring, with corrugations or a soft leather ring just inside the cardboard to permit free movement of the entire cone. The cardboard ring is in turn either cemented or bolted to the steel ring which is a part of the loudspeaker frame. This type of cone construction is widely used in order to simplify replacement

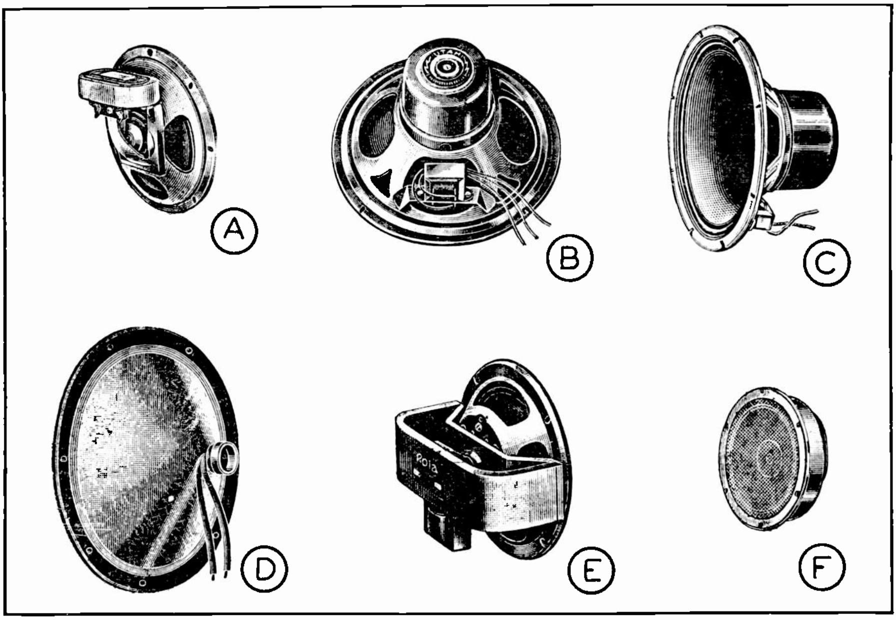


FIG. 2. Typical cone loudspeaker units.

of cones which have become damaged or have deteriorated through continuous use.

A permanent magnet dynamic cone loudspeaker is shown in Fig. *2E*. Here the large U-shaped steel bar serves as the permanent magnet. Both tips of this bar are magnetized with the same polarity, the center being of opposite polarity. The soft iron central core for the voice coil is attached to the center of the permanent magnet, and is therefore opposite in polarity to the soft iron pole piece which is in contact with the ends of the U-shaped permanent magnet.

A crystal cone loudspeaker unit is shown in Fig. *2F*. Ordinarily this will be found with a small, light cone about 5 inches in diameter. Crystal loudspeakers are often called "tweeters," and are used to reproduce the higher audio frequencies, in conjunction with an ordinary loudspeaker designed to reproduce the bass notes.

Dynamic Loudspeaker Design Problems

The Spider. One important part of a dynamic cone loudspeaker has not yet been taken up, simply because it does not appear in ordinary loudspeaker illustrations; this part is the *spider,* a springy sheet of fiber or bakelite material cut as shown in Figs. *3A* and *3B*. The spider serves two purposes, that of *centering the voice coil* with respect to the soft iron core and pole pieces, and that of *returning the voice coil and cone to a normal position* when the driving force drops to zero.

In horn loudspeakers the back of the driving unit is completely enclosed and the air in the enclosed rear chamber provides the springiness required to return the diaphragm to its normal position; in dynamic cone loudspeakers, however, this back air chamber is usually absent. The ordinary cone has little natural springiness because of the nature of its mounting, and therefore a spring must be used to provide the restoring action which is essential to correct loudspeaker operation. This spring is called a *spider.*

The *internal* spider unit shown in Fig. *3A* is cemented inside the voice coil at the point where it joins the cone. The center part of the spider is fastened to the cylindrical iron core

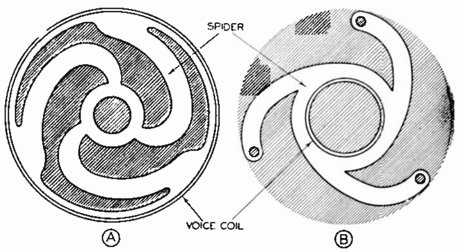


FIG. 3. Typical spiders used in cone dynamic loudspeakers to keep the cone and voice coil assembly properly centered with respect to the central iron core. That at *A* is for the front of the cone, and the form shown at *B* is for mounting on the back of the cone, around the voice coil. Spiders also provide a restoring spring action for the cone. Spiders of the type shown at *B*, which must surround the voice coil, will be considerably larger than those at *A*, which fit inside the voice coil.

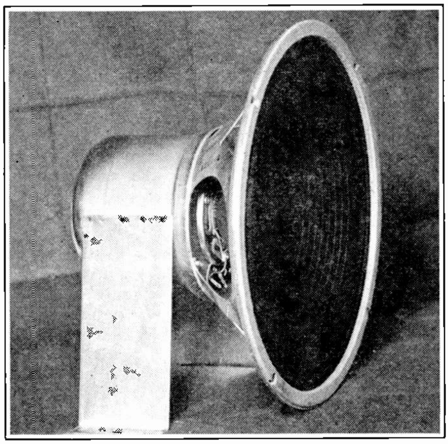
inside the voice coil but is held away from the core by a bushing. A machine screw passing through the center hole of the spider and the bushing firmly anchors the spider. When this screw is loosened, the spider, voice coil and cone assembly can be moved a small amount in any direction to permit exact centering of the voice coil.

Sometimes the spider is of the shape shown in Fig. *3B,* and is cemented to the outside of the voice coil at the point where it joins the cone. Three machine screws, one for each leg of the spider, hold it firmly against the outside housing or pot of the loudspeaker. Occasionally you will find an *external* spider of this type made from webbed cloth which has been treated with bakelite varnish to give it springiness.

Since dynamic loudspeakers are by far the most common of any types in use today, it will be worth while to consider in detail a number of their peculiar design features which are not apparent at first sight. A great many design problems must be solved in connection with the driving unit, the cone and the spider in order to secure good frequency response and high efficiency.

You already know that the force acting upon the cone of a dynamic loudspeaker is determined by the current flowing through the voice coil, by the length of the wire used in the voice coil, and by the flux density in the vicinity of the voice coil. Before we can determine the effectiveness of this force in producing air velocity or sound, however, we must analyze the characteristics of our moving or vibrating system. Referring to Fig. *4A,* we can see that the voice coil has a certain amount of mass, which we can consider as mechanical inductance L_V. The cone has a mass which can be considered as mechanical inductance L_C, and the air which is moved directly by the cone also has a certain amount of mass, which can be represented as mechanical inductance L_A. The spider provides most of the springiness or compliance, and this can be represented as mechanical capacitance C_S. The opposition offered by air particles to the movement of the diaphragm can likewise be represented as mechanical resistance R_A. Experiments have shown that all these parts can be considered as acting in series, as shown in Fig. *4B*. Note the absence of a mechanical capacitance shunting R_A; there being no air pocket in front of the cone, the dynamic loudspeaker does not have this capacitance which in a horn unit reduces the high audio frequency output. The grille cloth usually found in front of a dynamic loudspeaker is loosely woven, so that sound waves can travel through it readily at all audio frequencies.

Mechanical Resonance in Dynamic Loudspeakers. From our knowledge of electrical circuits like that shown in Fig. *4B,* we know that mechanical resonance will occur in our vibrating system when the combined mechanical reactances of L_V, L_C, and L_A are exactly equal to the reactance of C_S. In a dynamic loudspeaker the spider (or whatever mechanical restoring spring action is used) has a high compliance, and hence the mechanical capacity is high. High values of capacity acting with high values of mechanical inductance make mechanical resonance occur *at low frequencies* in dynamic cone loudspeakers. In the average dynamic cone loudspeaker unit, resonance occurs below 100 cycles. This resonant action is usually utilized to reinforce the response of the loudspeaker at bass frequencies.



Courtesy Utah Radio Products Co.

The external spider, surrounding the cone end of the voice coil, can be seen on this photograph of a Utah dynamic loudspeaker.

At resonance the entire input power is utilized in producing useful sounds; unless the cone is properly loaded by means of a suitable baffle, the movements of the cone will be excessive at resonance, resulting in distortion or even in damage to the voice coil, and particularly to its spider.

Piston Action. At frequencies above resonance, the circuit acts as a mechanical inductance in series with the mechanical resistance, which means that the driving force has only mass and resistance to oppose it. You know that inductive reactance increases with frequency, and consequently our mass reactance in this mechanical system would likewise increase if it were not for the fact that the mechanical resistance R_A increases also and compensates for the increased mass to a certain extent. (Actually, tests have shown that the air resistance R_A increases uniformly with frequency up to the point where the diameter of the cone becomes one-half wavelength.) This essentially flat or uniform output response is obtained up to the frequency where the cone begins to vibrate with nodes and peaks as shown in Fig *4C*. Under this condition the cone is no longer acting upon the air in the manner of a piston, but is itself vibrating. Once this condition is reached, the mechanical resistance R_A stays essentially constant, while the mass reactance of the unit decreases with increasing frequency. Although this would tend to give greater output at high frequencies, unfortunately the cone will vibrate as indicated in Fig. *4C* only for certain frequencies. This means that the high-frequency response of the loudspeaker will have many irregular peaks rather than the desired uniform response.

In a 12-inch cone (the diameter of the free edge), this change from piston action to vibrating cone action takes place at about 750 cycles. For an 8-inch cone the change occurs at about 1,000 cycles, and for smaller-diameter cones it occurs at correspondingly higher frequencies.

Since pure piston action is desirable in the cone of a dynamic loudspeaker in order to secure a flatter frequency response, the loudspeaker designer uses a scheme which automatically reduces the diameter of the cone for the higher frequencies. One such scheme involves placing a number of concentric corrugations in the cone, as shown in Fig. *5A*; the result is that at low frequencies the entire cone will be effective, with edge *1* serving as the free edge. At slightly higher frequencies the free edge of the cone will move inward to the corrugation at point *2;* under this condition only that part of the cone between corrugation *2* and the voice coil will be in motion. At increasingly higher

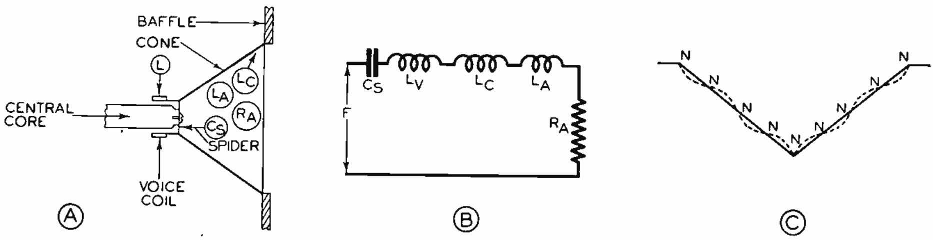


FIG. 4. A cone loudspeaker like that at *A* can be studied by means of an equivalent acoustical circuit like that at *B*. The diagram at *C* illustrates how a cone itself can vibrate at high audio frequencies; the points marked *N* represent nodes, which are points at which there is no vibration. The dotted line curve represents the maximum amplitude of the viration at any other point along the cone.

frequencies, the effective cone diameter becomes increasingly less; at the highest frequency, corrugation *3* becomes the free edge.

A typical dynamic cone loudspeaker having corrugations in the

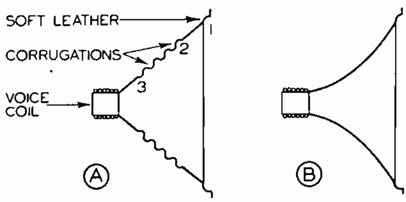


FIG. 5. Two methods of improving the high frequency response of a cone loudspeaker are illustrated here.

cone to reduce self-vibration and thereby improve the high-frequency response is shown in Fig. *6*.

Another scheme for increasing efficiency by securing pure piston action involves using a special shape of cone, the free edge of which will automatically shift towards the voice coil as the audio frequency increases. A suitable shape for accomplishing this result is shown in Fig. *5B*; since the curve of this cone corresponds to that of a parabola (a special geometric curve), it is often called a *para-curve* or a *curvalinear* diaphragm.

A third scheme involves gradual thinning out of the cone material from the voice coil toward the free edge. Each of these schemes gives a reasonably flat frequency response up to about 3,000 cycles, with decreased and somewhat non-uniform output at higher frequencies. This does not mean, however, that no high-frequency output is obtained; actually the high-frequency output can be quite satisfactory for ordinary radio receiver requirements, but for more nearly perfect reproduction, a second loudspeaker, designed specifically for uniform high-frequency reproduction, should be considered.

Double Voice Coils. Even if we could limit cone movement to that region immediately in the vicinity of the voice coil at high frequencies, in order to secure the desired piston action, the voice coil itself would still have too much mass for perfect results. This mass can be reduced by careful design of the voice coil in order to keep its weight at a minimum, and this in turn extends the upper frequency range of the loud-

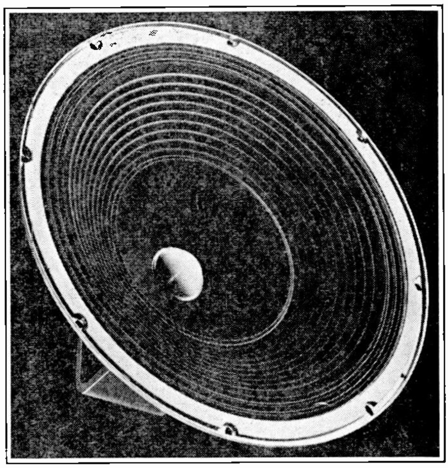


FIG. 6. The corrugations which serve to reduce the effective diameter of the cone at higher frequencies are clearly visible in this photograph of an RCA Victor dynamic cone loudspeaker unit.

speaker a certain amount. To further extend this range, two voice coils are sometimes used together, as illustrated in Fig. *7*. The coils are connected by an elastic coupling band which can be represented as C_1. Coil L_1 has considerably greater mass than L_2. At low frequencies the mechanical capacitance C_1 is ineffective (the elastic coupling does not bend), and the driving forces produced by both coils act upon the cone. At high frequencies only the smaller coil is capable of moving at the high rate of vibration involved, and the elastic coupling at C_1 allows this coil alone to drive the cone, while L_1 remains essentially fixed. In this way the cone can be made to produce uniform outputs up to about 6,000 cycles, with lowered output at higher frequencies than this. Coils L_1 and L_2 each have their own leads, being externally con-

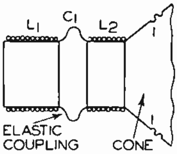


FIG. 7. The double voice coil construction shown here is sometimes used to reduce the effective mass of the vibrating system at high frequencies and thus improve the high-frequency response.

nected together in series. L_1, the heavier coil, is ordinarily shunted with a condenser whose value is such that high-frequency currents will be by-passed around it and will flow only through L_2, where they will produce a useful mechanical force.

Baffles

When the voice coil pushes the cone of a dynamic loudspeaker forward or away from the pot, the air in front of the cone is compressed or made heavy, while the air at the rear of the cone is simultaneously thinned out or made rare, as indicated in Fig. *8A*. Those particles of air which are compressed will exert force on adjacent air particles, transferring this compressed condition to nearby air particles at the speed of sound, which is about 1,089 feet per second. It is a natural tendency for these compressed air particles to move outward in all directions, with many of them moving around the edges of the cone to the rear. If the air at the rear of the cone is rarefied at the time when compressed air particles arrive, the particles rush to the rear to equalize the air pressure, and this rush of particles in turn brings more compressed air particles from the front to the rear. The result is cancellation of useful sound, since sound is produced the instant that air is compressed at the front of the cone.

To limit this natural tendency for air to avoid doing useful work, we can place around the loudspeaker a baffle made up of a square or circular board having cut in it a hole equal to the diameter of the cone. A baffle such as this is indicated in Fig. *8B;* we can immediately see that air particles which are compressed in front of the cone must travel completely around the baffle before they can reach the back of the cone. It takes a certain amount of time for this compressed air condition to be transferred from

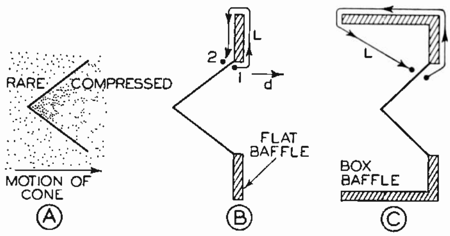


FIG. 8. The shortest sound wave path from the front of a cone around the baffle to the rear must be at least one-half the wavelength of the lowest sound frequency to be reproduced if cancellation of sound waves is to be avoided.

point *1* around the baffle to point *2*, and this time should be made long enough to allow the cone to begin compressing the air at the rear on its backward movement. Under this condition there is practically no cancellation of compressed air by rarefied air, and a considerably greater amount of useful sound is radiated by the front of the loudspeaker.

Let us assume that the cone is moving in and out in a sine wave manner. When the cone is farthest forward, compression of air at point *1* will be a maximum. This compressed air will take the shortest path to point *2*, where a rarefied condition exists at this moment; naturally this will be path L around the baffle. The time taken for air movement along this path will be equal to the length of the path divided by the speed of sound; if this time is such that the cone has gone through a complete half cycle by the time the compressed air reaches point *2*, then the cone will be compressing air at point *2*, the compressed air from that point will meet air which is equally compressed, and no cancellation will take place. As a result, the compressed air at the front will be *forced* to move in the desired

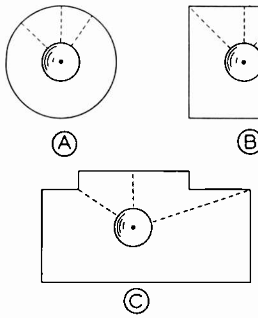


FIG. 9. The irregular-shaped flat baffle at *C* gives more uniform frequency response than either the circular baffle at *A* or the square baffle at *B*. Dotted lines indicate possible sound wave paths.

forward direction. The path length required to prevent front-to-rear cancellation can readily be figured out by dividing 1,089 by twice the frequency of the lowest sound signal to be reproduced. For example, if the lowest frequency to be reproduced is 50 cycles, the minimum path length *L* would be equal to 1,089 divided by 2 times 50, which is 10.89 feet.

The longer the path *L* around the baffle, the lower will be the cut-off frequency of the loudspeaker. Where space is limited, as it is in the conventional radio receiver cabinet, the loudspeaker is usually mounted in a box like that shown in Fig. *8C*. Here path *L* would be measured as indicated.

Although each baffle has a definite cut-off frequency, with sounds below this frequency being eliminated or greatly reduced in strength, this is no assurance that frequencies above the cut-off value will be reproduced without attenuation. Suppose that the diameter of the circular baffle shown in Fig. *9A* is such that cut-off occurs at 100 cycles. When a 200-cycle sound is fed to the loudspeaker mounted on this baffle, the cone will go through one complete cycle during the time required for the sound to travel from the front to the rear, and consequently the compressed air traveling around the baffle will encounter rarefied air at the rear. Cancellation takes place and loudspeaker output is low at 200 cycles. This same effect will occur at each higher multiple of the cut-off frequency (3 times, 4 times, 5 times, etc.), but in the case of these higher multiples the cone will have gone through so many cycles during the time required for the compressed air to get around the baffle that most of the sound produced at the front of the cone will have traveled too far out to be affected. It is at the frequency equal to twice the cut-off frequency that cancellation is the most serious.

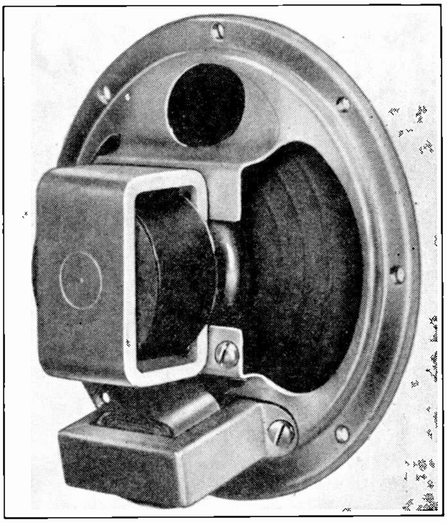
Irregular-Shaped Baffles. With a square baffle like that shown in Fig. *9B*, the paths around the baffle are of many different lengths, so that even though cancellation occurs on some paths there will always be other paths at which a particular frequency is not entirely cancelled out. The result is that the frequency response of the loudspeaker system is far more uniform in the low frequency region down to the minimum cut-off frequency (determined by the longest baffle path length). The most uniform response at low frequencies is obtained with an extremely large baffle or with a special form of completely enclosed box baffle, sometimes known as an *infinite baffle.* An irregular shape of baffle like that shown in Fig. *9C* is better than a square or circular baffle, for this provides a number of widely different path lengths.

Box Baffles

The cabinet in which the cone loudspeaker of the average home radio receiver is mounted is essentially a box. Although this box does give the desired long path for sound around the baffle, the presence of the box or cavity behind the loudspeaker is not always desirable. This cavity can in itself be a sound resonator, acting much in the manner of a horn and setting air into vibration at some frequency. In the average radio receiver cabinet this cavity can be shocked into vibration at a low or bass frequency in many cases, producing an undesirable high bass output. The cavity is in addition a load on the cone, increasing its mechanical resistance and altering the frequency response of the loudspeaker; on the other hand, if this load produced by the cavity is properly proportioned, it can be a real aid to loudspeaker operation. Since many loudspeaker installations take into account the design of the back resonating chamber or box baffle, we will analyze this problem in greater detail in order that we can better understand the unique constructions which are sometimes employed.

With a cone mounted on a large flat baffle, the back of the cone must move equally as large a mass of air as the front of the cone. This mass has an inertia which opposes any force which tries to set it into motion, and consequently we can consider this mass as a mechanical inductance.

With a flat baffle, the mass of air in back of the cone has little stiffness, for it can expand equally well in all directions behind the baffle. As we bend back the edges of the baffle to form a box-like chamber around the rear of the cone, we confine the mass of air to a limited region and reduce the mass upon which the back of the cone is compelled to act. Confining this air to a definite volume increases its stiffness, with the result that



Typical electrodynamic loudspeaker, available from Jensen Radio Mfg. Co., Chicago, Ill., in 5, 6 and 8-inch sizes (cone diameters) with various output transformers and various field coil resistance values for replacement purposes.

greater force must be applied to the cone in order to move this air. This reduces the compliance of the rear chamber, thereby reducing its mechanical capacitance. (In the case of a flat baffle, this mechanical capacitance was so high that its effect could be neglected.) The mechanical force must therefore act simultaneously upon a mechanical capacitance and a mechanical inductance in parallel.

We know also that a certain amount of sound always escapes from the rear of the chamber; this radiated sound must be represented by mechanical resistance acting in series with the air mass. A completely closed box has no sound radiation at the rear and therefore has zero mechanical resistance. A flat baffle has a large mechanical resistance, its value being equal to the mechanical resistance existing at the front of the cone. An open box has a medium value of mechanical resistance.

With these facts in mind, we can set up the equivalent mechanical circuit of a loudspeaker mounted in a box baffle, and use this as our guide in analyzing the good and bad fea-

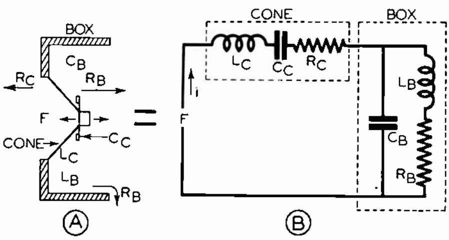


FIG. 10. Rear chamber of a box baffle, and equivalent circuit of the entire system, including the chamber.

tures of this particular baffle. Figure *10A* shows a cone and voice coil mounted in a box baffle, and Fig. *10B* represents the equivalent circuit including the back chamber. The mechanical force acting upon the entire system varies in an alternating manner corresponding to the variation in voice coil current. This force acts first upon the mass of the cone and voice coil assembly, represented in Fig. *10B* as mechanical inductance L_C, upon the spider which provides springiness or mechanical capacitance C_C, and upon the mechanical resistance due to sound radiation from the front of the cone, represented as R_C. The additional load placed upon the cone by the back chamber can be represented by mechanical capacitance C_B in parallel with mechanical inductance L_B, representing the mass of the back chamber air; the mechanical resistance introduced by sound radiated from the rear of the baffle is represented as R_B, acting in series with L_B.

We can now see that C_B and L_B in Fig. *10B* together form a parallel resonant circuit. Furthermore, this resonant circuit can be shocked into self-oscillation by the driving force F acting through the reactances of L_C and C_C, under which condition the air in the cavity will vibrate and radiate sound through the cone. This self-produced sound may set the cone into vibration, producing frequencies which were not present in the original program and giving the so-called boomy response which some loudspeakers have. Furthermore, if the driving force F has the same frequency as the resonant frequency of the cone loudspeaker unit (resonant circuit L_C-C_C), the cone will be set into excessive vibration, giving a whooping sound. This occurs because L_C-C_C acts as a low mechanical resistance at resonance, allowing more of the driving force F to be applied to the cavity and increasing the sound output of the back chamber at that particular frequency.

Natural Resonant Frequency. Increasing the size of a box baffle increases the volume of the cavity and thereby increases the values of mechanical capacitance C_B and mechanical inductance L_B; this *lowers* the natural resonant frequency of the cavity (the resonant frequency of the parallel resonant circuit). If the box is made sufficiently large or if an infinite flat baffle (where no sound waves whatsoever can escape to the rear of the cone around the baffle) is used, the natural frequency of the region behind the cone can be made so low that the effects of cavity resonance will not be heard at all.

A radio receiver which has an open back is generally designed so that when the cabinet is kept a few inches away from the wall or is placed in a corner so there is free movement of air behind the cabinet, C_B will be high enough in value to prevent audible cavity resonance effects. Placing the radio receiver back up against the wall tends to close up the back chamber and reduce C_B; under this condition cavity resonance may occur at an audible bass frequency, in the form of boominess and the whooping sounds mentioned before. Remember: radio receivers with open backs will sound best when kept a few inches away from the wall or when located across a corner of a room.

Infinite Baffles. Suppose that we closed up the back of the cabinet completely, thereby making the values of C_B and L_B constant. This, of course, does not in itself eliminate cavity resonance, but if we make the resonant frequency of C_B-L_B equal to the resonant frequency of L_C-C_C, an entirely new effect will take place. When the driving force F has this same frequency, the series resonant circuit will act as a very small resistance, but the parallel resonant circuit will act as a very high resistance, greatly limiting the flow of mechanical current i. This means that there will be no vibration of the cone at resonance, no whooping sounds, no sound waves will be radiated by the back of the cabinet, and we will have what is known as an *infinite baffle.* Figure *11* shows more clearly what happens under this condition; curve *1* shows how cone velocity, which determines sound output to a great extent, increases gradually with frequency up to a maximum value at a frequency equal to the natural resonant frequency of the cavity. At frequencies above cavity resonance, the cone velocity drops again. Curve *2* is for the condition where the cavity is tuned to the natural resonant frequency of the cone; you can see that the peak has been reduced considerably at resonance, while cone velocity is still high enough to give the system desired bass reinforcement. *Adjusting the cavity resonant frequency to the natural frequency of the cone system* will greatly reduce the undesirable effects of cavity resonance in a box type baffle.

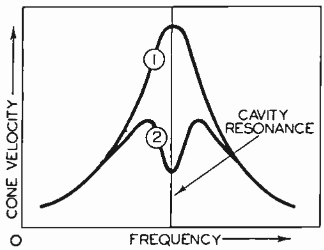
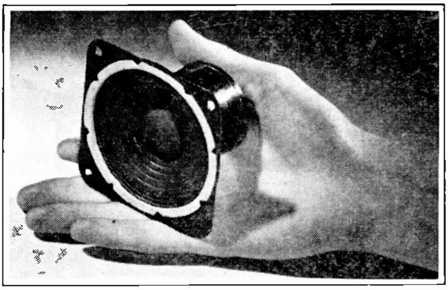


FIG. 11. These curves show how cone velocity (which determines sound output) varies with frequency for an ordinary box baffle (curve *1*) and for a box baffle which is tuned to the natural resonant frequency of the moving system (curve *2*).



Courtesy Oxford-Tartak Radio Corp.

Truly a midget is this Oxford permanent-magnet dynamic loudspeaker unit with 3″ diameter cone, designed for use in midget table model radios and in intercommunication systems.

Standing Waves. At frequencies higher than the cavity-resonance frequency, the cavity will act as a low-reactance condenser which does not seriously affect the response of the loudspeaker. At the higher sound frequencies, however, where the wavelengths involved become shorter than the dimensions of the box, there will be considerable reflection of sound from one side of the box to the other. If these reflections occur continually over the same path, the compressions and rarefactions of air will be reinforced at definite points, and *standing sound waves* will occur; these give resonant effects much like those produced in organ pipes and in musical wind instruments. In other words, sounds at certain frequencies will be prolonged somewhat, due to the production of harmonics, and the reproduced sound will not be natural.

Using a shallow cavity or making it irregular in shape so that reflected sounds cannot build up along the same path will cure this trouble. Other remedies involve lining the box with a sound-absorbing material, hanging heavy sound-absorbing materials down from the top inside the box, or lining the sides of the box with rectangular pieces of wood, thereby preventing sounds from being reflected back and forth over the same path. Whenever sound waves are reflected repeatedly over a path which is some multiple of a half wave in length, compression will occur at the same points along this path for each reflection. Reinforcement of sound occurs under this condition due to the building up of pressure, and the resulting standing waves produce annoying sounds. The box itself should be made of heavy wood, so it will not vibrate at the lower bass frequencies.

So far we have considered box baffle arrangements which are intended to prevent cavity resonance at low frequencies and standing waves at high frequencies. In each case the sounds produced by the rear of the cone were either suppressed or absorbed, and were therefore wasted.

Bass-Reinforcing Box Baffles. Increased bass output is practically always desirable in a loudspeaker if it can be secured without at the same time producing undesirable cavity resonance effects. We know that the sounds coming from the rear of the cone are out of phase with those coming from the front; if, however, we can reverse the phase of the bass notes coming from the rear and allow them to emerge at the front of the loudspeaker, we can secure desirable reinforcement of bass notes without increasing cavity resonance problems. The loudspeaker arrangement which accomplishes this result is known as a *low-pass, phase-reversing acoustical filter*.

RCA Sonic-Arc Baffle, also known as the Magic Voice, which provides bass reinforcement and at the same time prevents standing waves.

The back of the cabinet or box is ordinarily closed completely when bass reinforcement is desired, and outlets for air are provided either underneath the cabinet or at the front, below the main outlet at the front of the cone. Our equivalent mechanical circuit for this condition is therefore the same as that shown in Fig. *10B*. Again we can assume that undesirable effects of cavity resonance are greatly reduced *by making the resonant frequencies of the cavity and the cone identical.*

Above the resonant frequency of the cone or the cavity, the series resonant circuit L_C-C_C acts as a mechanical inductance, while the parallel-resonant circuit L_B-C_B acts as a mechanical capacitance. To simplify further our analysis, let us assume an above-resonance condition (in which the frequency of mechanical force F is higher than the natural resonant frequencies of the cone and box). In

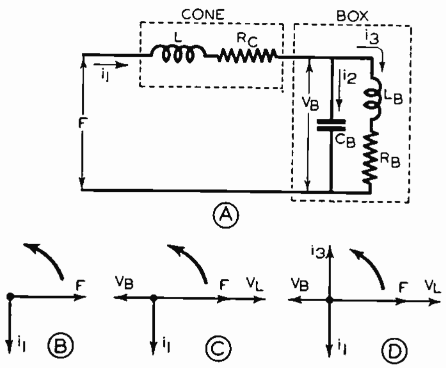


FIG. 12. Equivalent acoustical circuit of a closed box baffle which is acting as a low-pass, phase-reversing acoustical filter at frequencies above the resonant frequency of the cone, and vector diagrams showing how it acts.

this case, series resonant circuit L_C-C_C, representing the cone assembly, will act as a mechanical inductance (which we can designate as L) in series with mechanical resistance R_C; the equivalent mechanical circuit will now appear as shown in Fig. *12A*.

If we can prove that mechanical current i_3 flowing through mechanical resistance R_B is 180° out of phase with mechanical current i_1 flowing through R_C, we will have shown that radiation of sound from the cavity will be 180° out of phase with the sound radiated by the *back* of the cone, and will therefore be *in phase* with sound radiated from the front of the cone.

Above resonance, parallel resonant circuit L_B-C_B will act as a mechanical capacitance, and if by design its mechanical reactance is *less than* the mechanical reactance of L, the mechanical force F will feel an inductive load. The mechanical current i_1 delivered by F will therefore lag F by 90°.

A vector diagram will show at a glance the exact phase relationships between the various mechanical currents and voltages in our circuit. Let us use F as our reference vector, drawing it as shown in Fig. *12B*. Since we have just found that i_1 lags F by 90°, we draw i_1 downward, 90° clockwise from F.

The mechanical force acting upon C_B and L_B will be equal to the applied force F minus the mechanical force dropped across inductance L. (We are now neglecting R_C and R_B, as they have little effect.) This mechanical force (mechanical voltage) V_L which is dropped across L will *lead* the current i_1 through L by 90° (coil voltage always leads coil current by 90°), so we draw vector V_L 90° counter-clockwise from vector i_1, as in Fig. *12C*. Now we can see that V_L is in phase with F.

We also know that the voltage across a condenser lags its current by 90°. Since parallel resonant circuit L_B-C_B *acts as a condenser* at frequencies above resonance, mechanical voltage V_B across this circuit will lag i_1 by 90°; we therefore draw in vector V_B 90° clockwise from i_1, as in Fig. *12C*. Since V_B acts upon L_B, we can say immediately that mechanical current i_3 through L_B will lag V_B by 90°, and can draw in vector i_3 90° clockwise from V_B, as in Fig. *12D*. Our vector diagram now shows clearly that i_3 is 180° out of phase with i_1, which is exactly what we desired to prove.

By proper selection of the mass (L_B) and compliance (C_B) of the box cavity in relation to the mass (L_C) and compliance (C_C) of the loudspeaker cone, an engineer can secure a loudspeaker system which will behave like the circuit in Fig. *12A*. Sound waves escaping from the box will then be in phase with the sound radiated from the cone front, and the desired bass reinforcement will be secured at frequencies above the cavity resonant frequency.

At high sound frequencies, mechanical capacitance C_B serves as a shunt path for mechanical current, with the result that practically no mechanical current flows through R_B, and no high-frequency sounds emerge from the box cavity.

Stromberg-Carlson Acoustical Labyrinth. An excellent example of the baffle design features just discussed is the acoustical labyrinth or winding passageway which is built into the cabinets of some Stromberg-Carlson receivers for four distinct purposes: *1, to prevent cavity resonance; 2, to prevent standing high-frequency sound waves; 3, to give a low cut-off frequency* for the baffle without resorting to an excessively large cabinet; *4, to give reinforcement of bass response* by allowing low frequency sounds radiated from the rear of the cone to travel through the labyrinth and emerge at the front in phase with the sounds normally radiated from the front of the cone. The two views in Fig. *13* illustrate the nature of this special loudspeaker baffle construction.

Observe that a felt hood covers the entire rear face of the cone, with only the pot exposed to air for cooling purposes. Sounds radiated by the rear of the cone are therefore directed into the rectangular cross-section passageway which winds back and forth down to the bottom of the cabinet. The insides of this passageway or labyrinth are lined with a porous sound-absorbing material which is held together by coarse metal screening. High-frequency sounds are totally absorbed by this material, while lower frequency sounds are only partially absorbed. The long passageway with its outlet at the far end has the essential features of mass, compliance and resistance which are necessary for a low-pass phase-reversing acoustical filter at bass frequencies, and the result is that bass sounds emitted at

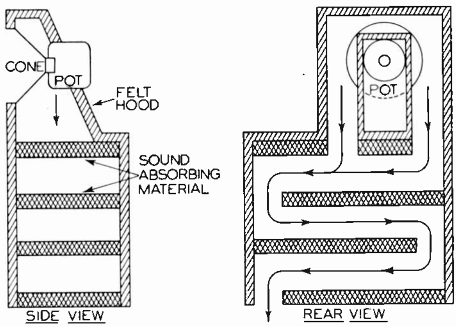


FIG. 13. Essential constructional features of the Stromberg-Carlson Acoustical Labyrinth.

the lower end of the labyrinth reinforce the bass sounds radiated from the front of the cone.

Special RCA Box Baffles. To secure the same effects as are provided by the acoustical labyrinth, RCA engineers use the construction shown in Fig. *14A* for some of their receivers. The back chamber is completely closed, but there are holes at the bottom of the chamber, each surrounded by a length of pipe, through which air can escape. The back chamber thus has mass and compliance, and that air which escapes through the pipe provides mechanical resistance. The pipes are intended to adjust the mass in order to make the chamber resonate at the same frequency as the cone. The entire cabinet of this RCA receiver is made of heavy wood, to prevent it from vibrating and radiating sounds from all sides when powerful bass notes are being reproduced. Only sounds emerging from the pipes are capable of reinforcing the normal output.

Pipes are by no means essential in the design of an acoustical low-pass filter; simple outlets are sufficient if the cabinet is properly designed to secure the correct resonant frequency for the cavity. Many RCA receivers have this simplified construction, illustrated in Fig. *14B*. The back of the cabinet is closed by a curved sound reflector which serves two purposes, that of reflecting high-frequency sounds in all directions to prevent standing sound waves, and that of stiffening the back so it will not vibrate as readily as would a flat board. The air enclosed by this chamber provides compliance and mass, and the air escaping through the outlet at the bottom provides mechanical resistance; we thus have the conditions necessary for bass reinforcement.

Another example of this simplified construction is illustrated in Fig. *15*. This is a special high-fidelity, high-power loudspeaker unit made by Jensen and known as the Peridynamic or bass reflex loudspeaker. The cabinet is made of thick, solid material so its sides will not vibrate. The box is made shallow so standing waves will be negligible. The cavity is properly proportioned to give the essential requirements of an acoustical filter.

Some manufacturers of radio receivers and cabinets follow the practice of closing up the back of the cabinet with a solid board which is reinforced with crossed ribs to prevent it from vibrating, allowing sounds to escape only from the corners of the back through holes which are left at these points. Again, proper design gives desirable bass reinforcement and eliminates undesirable features of a

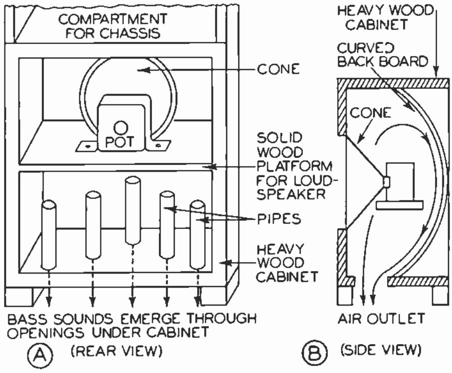


FIG. 14. Constructional features of two types of low-pass, phase-reversing acoustical filters used in RCA receivers.

cavity. Do not think that because a loudspeaker cabinet appears simple in construction, it is easy to design and build; careful engineering is required in order to prevent cavity resonance, to prevent standing sound waves at high frequencies, and to secure the proper proportioning of acoustical elements in the cone and cavity in order to obtain the desired bass reinforcing action.

FIG. 15. Jensen Peridynamic loudspeaker unit. Reinforcing bass notes emerge from the rectangular opening below the cone.

Acoustic Clarifiers. When no attempt is made to utilize bass sounds emerging from the rear of a loudspeaker system, the chief problem is that of removing cavity resonance effects or making them inaudible. It is possible to do this by inserting in the cavity an acoustic clarifier, a device which itself vibrates readily at all times and serves to cancel the air vibrations in the cavity. Some Philco receivers utilize this principle, in the form of a small cone which is suspended on an elastic spider mounted in the cabinet cavity or chamber. Any sudden loud sounds or sustained sounds which would otherwise set the cavity into vibration are transferred to this suspended cone, causing it to vibrate and absorb the energy present in the chamber. As a result there is very little vibration of the air in the chamber, and no sounds are emitted from the rear. Several of these acoustic clarifiers are generally used in a single cabinet, so as to increase the coupling between the cavity and the clarifiers. The clarifiers are sufficiently broad in frequency response to prevent cavity resonance effects when the back of the cabinet is open and the cabinet is placed flat against a wall. Remember, however, that acoustic clarifiers are not loudspeakers.

The principle of an acoustic clarifier can best be explained by referring to the electrical circuit shown in Fig. *16*. Here we have a parallel resonant circuit made up of L_1 and C_1, driven by an A. C. voltage source V; this, as you know, is equivalent to the parallel resonant circuit representing the back chamber of a loudspeaker cabinet. At resonance, large currents flow through L_1 and C_1, making this circuit act like a high resistance. If we place across this parallel resonant circuit a series resonant circuit made up of C_2 and L_2, and make both resonant circuits tune to the same frequency, the series resonant circuit will at resonance act as a short across the parallel resonant circuit. As a result, the source V will be supplying current to the series resonant circuit, while the parallel resonant circuit will receive practically no current. This series resonant circuit is the equivalent of the acoustic clarifier; it cancels the sound waves which otherwise would result in oscillation or vibration of the air in this back chamber.

Sound Diffusers

When sound is produced by a small source, all audio frequencies travel equally well in all directions away

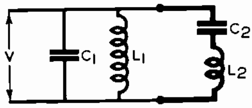


FIG. 16. An electrical circuit explaining the operation of the Philco Acoustic Clarifier.

from the source. When the size of the sound-producing source is quite large, however, as is the case with loudspeakers using large diaphragms and cones, only the low audio frequencies will travel equally well in all directions. The higher frequencies tend to travel best straight ahead of the loudspeaker, concentrating into a beam which becomes smaller and smaller in size as frequency is increased.

Loudspeaker engineers utilize what is known as a polar radiation pattern to show how a particular loudspeaker radiates various audio frequencies in different directions; one such pattern, representing the manner in which a cone loudspeaker with a baffle radiates one particular sound frequency in various directions, is shown in Fig. *17A*. Let us first see how a pattern such as this is secured, for then we will be better able to appreciate the interesting information which it can give about a loudspeaker.

With our loudspeaker and baffle set up in a large room having sound-absorbing walls, floor and ceiling, and a definite audio frequency fed through the voice coil of the loudspeaker, we measure the loudness of the sounds produced by the loudspeaker at various points such as at P_1, P_2, P_3 and P_4, which are all the same distance away from the center of the loudspeaker and make various angles, such as θ (Greek letter *theta*), with the center line O-P_3. We will designate as I_3 the loudness level measured at point P_3. We now draw on paper a simple sketch of our loudspeaker, much like that in Fig. *17A*, and mark point O as the approximate center of the sound-producing source. Point P_3 is placed on the diagram next, directly in front of the loudspeaker, and at any convenient distance away. A line is drawn from O to P_3, and along this line we plot the measured value I_3 to any convenient scale, starting from O. We next move our measuring apparatus to position P_2, which is off to one side of line O-P_3 by the angle θ but is still the same distance away from O. We measure the angle θ made by lines drawn from O to P_2 and P_3, and use this angle as our guide in locating P_2 on the diagram. The loudness level measured at P_2 is now plotted along line O-P_2, starting from O; this gives point I_2 in Fig. *17A*. The same procedure is repeated for points P_1, P_4 and various other points which are all the same distance away from O and at various angles off to each side. A smooth curved line drawn through the resulting points I_1, I_2, I_3 and I_4 now gives the polar radiation pattern. In the case of Fig. *17A*, this pattern tells us that at a definite distance away from the loudspeaker, sounds will be loudest directly in front of the cone and will gradually become weaker as we go off to one side or the other of the center line.

Radiation patterns for three different frequencies, as secured with a large dynamic loudspeaker mounted in a box baffle, are shown in Fig. *17B*. All three curves are for measurements made at the same distance away from the loudspeaker. These curves tell that a listener at position P_1 would hear middle frequencies best, with bass frequencies slightly less loud and treble frequencies about half as loud. On the other hand, a listener at position P_2 would hear bass frequencies the best, with middle frequencies slightly weaker and treble sounds scarcely distinguishable at all. A line drawn from any other listening position to point O will give this same information for that position; simply observe where the line intersects each of the three curves. Now you can readily understand why the output from a loudspeaker sounds best when you are located directly in front of it.

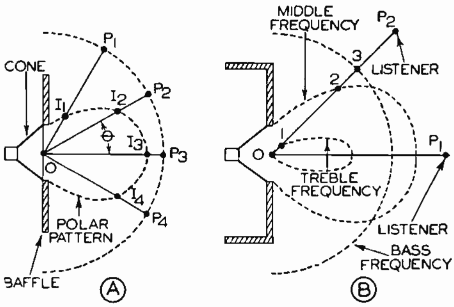


FIG. 17. Polar sound radiation patterns for cone loudspeakers.

Uniform distribution of sound from a loudspeaker throughout a room is highly desirable, for the non-uniform distribution shown in Fig. *17B* tends to cancel out, for certain listening positions, all the advantages gained by careful design of the radio receiver and loudspeaker. Since high frequencies give the greatest trouble in this respect, the loudspeaker engineer often builds vanes in front of the loudspeaker to deflect these frequencies and spread out the beams. If the vanes are of the proper size, at least as wide as the wavelength of the high-frequency sounds to be deflected, the vanes will have no effect upon low and medium frequencies.

A wall-type loudspeaker, with deflecting vanes mounted in front of the cone for this purpose, is shown in Fig. *18A*. Sometimes these vanes are mounted behind the grille cloth or are made a part of the cabinet itself.

A well designed deflector for high-frequency sounds is shown in Fig. *18B;* this is a curved cone anchored rigidly inside the regular sound-producing cone of the loudspeaker. High-frequency sounds are deflected by this cone and spread out on all sides, while low- and medium-frequency sounds travel around the cone just as if it were not present.

Horn loudspeakers concentrate all sounds into relatively narrow beams, with the highest frequencies being concentrated the most. When a horn loudspeaker is used as a tweeter for the reproduction of high frequencies only, it is often sectionalized in the manner shown in Fig. *19* in order to spread out the beam and make the distribution of high-frequency sounds similar to that of the low- and medium-frequency sounds as produced by the woofer (low- and medium-frequency) loudspeaker. The presence of vanes in one or more units of a reproducing system is usually a sign of high-fidelity reproduction over a wide range of frequencies; this particularly holds true for the loudspeakers used in public address systems.

Horn-Shaped Baffles

Large cone loudspeakers are widely used in public address systems requiring high sound outputs. Cone loudspeakers mounted in a large flat baffle or in a box baffle radiate sound over a wide angle; this may not be desirable in some installations, for it is often necessary to concentrate sound in a definite direction and over a definite area. Horn-shaped baffles are used for this purpose; when properly designed, these make the loudspeaker more directional and at the same time improve its efficiency considerably.

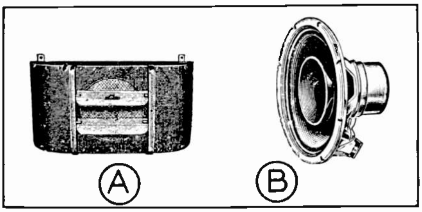


FIG. 18. Examples of cone loudspeakers which utilize deflecting vanes to spread out high-frequency sound waves.

Loudspeaker Efficiencies. The ordinary large cone loudspeaker, when mounted in a box baffle or on a flat baffle, rarely has an efficiency of greater than 3 per cent, whereas a driving unit used with an exponential horn can have an efficiency as high as 50 per cent. This means that if 10 watts of electrical power are fed into a cone loudspeaker, only about .3 watt of acoustical power will be delivered. This low cone loudspeaker efficiency is satisfactory for the aver-

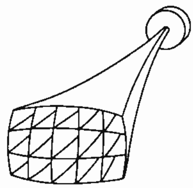


FIG. 19. Horn loudspeakers designed for use as tweeters are often divided into sections as shown above in order to spread out high-frequency sounds.

age home radio receiver, but in loudspeakers designed for high-power public address systems it is necessary to improve this efficiency by improving the coupling between the cone and the surrounding air. Loudspeaker engineers therefore turn naturally to the exponential horn when the efficiency of an ordinary baffle for a cone loudspeaker proves unsatisfactory.

An early attempt to improve the directional characteristics of a cone loudspeaker is shown in Fig. *20A;* the performance of this flat-sided horn was no better than that of the early megaphone used with smaller driving units. Modern exponential horn baffles or cone loudspeakers are shown in Figs. *20B* and *20C*. Since these start with a large throat, they need not be extremely long in order to secure good response over a wide range of frequencies. If the loudspeaker and cone are designed with a closed back, to give high air velocity at the front of the cone, and the usual precautions are taken to secure piston action over the entire audio range of frequencies, the addition of an exponential horn of this type will greatly improve the efficiency of operation.

In Fig. *21* is shown a large exponential horn which is fed by six large cone loudspeakers. Careful design is essential to prevent reflection of sounds back and forth inside the horn. The area of the mouth of the horn approaches the area of a circle whose diameter equals 1/4 wavelength at the lowest frequency to be reproduced.

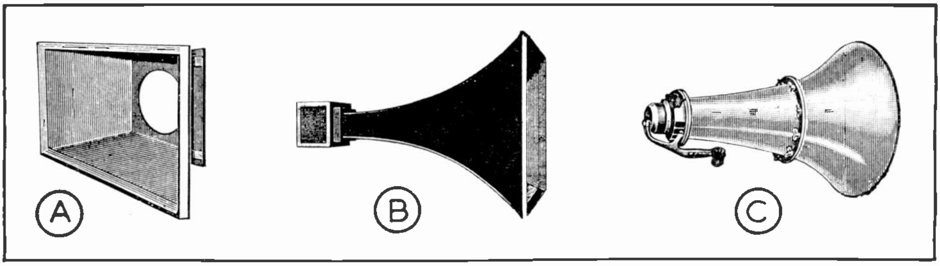


FIG. 20. Examples of horn baffles for cone loudspeakers. *A*—simple flat-sided, megaphone-like horn; *B*—complete cone loudspeaker unit with true exponential horn baffle having a square cross-section; *C*—another complete cone loudspeaker unit with an exponential horn of the trumpet type, spun from aluminum.

Loudspeaker Impedance

Any loudspeaker has a definite electrical impedance. The value of this impedance will depend upon the frequency of the source voltage applied to the loudspeaker, upon the electrical characteristics of the loudspeaker (inductance and resistance for magnetic and dynamic driving units, and capacitance with resistance for crystal and condenser driving units), and upon the load which is placed upon the loudspeaker by the surrounding air.

We have already seen that the driving unit of a loudspeaker, when

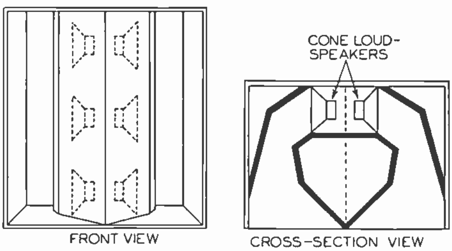


FIG. 21. Two views of an unusually large exponential horn baffle which is fed by six large cone loudspeakers. This assembly is capable of delivering high sound output power at high efficiency. It is made by Lansing Manufacturing Company, Los Angeles, Calif.

in operation, has mechanical inductance, mechanical capacitance and mechanical resistance. Let us consider a simple loudspeaker in which these three mechanical components act in series upon a dynamic cone loudspeaker having electrical inductance and resistance. The complete circuit for this loudspeaker is best represented as in Fig. *22*. Here e_P represents the A.C. source voltage applied to the loudspeaker (this will be the A.C. output voltage of the audio amplifier), r_P represents the resistance of the source (the A.C. plate resistance of the output tube), R_V represents the resistance of the voice coil, L_v represents the inductance of the voice coil, M represents the electromechanical coupling, L_M the mechanical inductance (the mass of the moving element), C_M the mechanical capacitance (the compliance or springiness of the spider), and R_M the mechanical resistance. Clearly these mechanical components exist only when the driving unit is in motion; when the voice coil is wedged in position so it cannot move, the source would feel only the electrical components, R_V and L_V. By measuring the electrical characteristics of the loudspeaker under this condition, we can determine what these electrical values are.

When the voice coil and cone of the loudspeaker are free to move, and the loudspeaker is accomplishing useful work in converting electrical power into acoustical power or sound, the source feels all of the mechanical components just as if they were in an electrical circuit like that shown in Fig. *22*. For example, if the source frequency is such that the mechanical reactance of L_M equals the mechanical reactance of C_M, mechanical resonance occurs and only mechanical resistance R_M is reflected through M into the primary circuit. When the source frequency is above the resonant frequency of the secondary, the mechanical reactance of L_M exceeds that of C_M, with the result that a mechanical inductance and mechanical resistance are reflected into the primary as a mechanical capacitance and mechanical resistance.

These facts are mentioned merely to show that when the electrical impedance of a loudspeaker is measured across its terminals (between terminals *1* and *2* in Fig. *22*), a different value of impedance will be secured at each frequency; furthermore, this impedance will not be made up of voice coil reactance and resistance alone, but will also include those effects of the mechanical components which are felt by the source. The circuit in Fig. *22* tells us that the power input to the loudspeaker and consequently the useful sound power output will be a maximum when the source impedance (resistance) r_P is exactly matched to the load impedance (the loudspeaker input impedance) as measured between terminals *1* and *2*.

Clearly the matching of the loudspeaker impedance with that of its voltage source is quite important if greatest sound power output is to be obtained. The circuit in Fig. *22* shows that the D.C. resistance R_V of the loudspeaker, which can be measured with an ohmmeter, cannot be considered alone when securing a proper match; it is the loudspeaker impedance as measured while the loudspeaker is actually in operation which must be matched to the source impedance.

Determining Loudspeaker Impedance. Unfortunately the impedance of a loudspeaker is not constant for all frequencies, nor is the mechanical load of a loudspeaker as simple as is represented electrically in Fig. *22*.

For these reasons it is necessary to measure the loudspeaker impedance at the frequency which we wish to reproduce at greatest volume, and secure a correct impedance match for this frequency.

For the average loudspeaker an impedance match at about 1,000 cycles is usually quite satisfactory. With tweeter loudspeakers, however, a match at 4,000 cycles would be better. Loudspeaker manufacturers recognize these problems, and specify a value of loudspeaker impedance which, if matched, will give the best over-all results over the frequency range to be handled. For example, when the impedance of a loudspeaker voice coil is specified as 8 ohms, this will take into account mechanical as well as electrical factors and will probably be an impedance measurement made while the loudspeaker was reproducing a 1,000 cycle audio signal.

When the impedance of a dynamic loudspeaker is unknown, some servicemen measure the voice coil resistance with an ohmmeter and assume an impedance value equal to 1.5 times this measured D.C. resistance. We know that this value can be considerably in error, but it at least serves as a guide when a more accurate impedance value is not available.

Matching. Knowing the impedance of the loudspeaker at the average or predominant frequency in the range of audio sounds being handled, the next step is to match this impedance to the impedance of the electrical signal source, in order to secure maximum useful sound output. When vacuum tube amplifiers, which are the usual signal sources for loudspeakers, feel anything different from the correct, properly matched load, the wave form of the signal fed to the loudspeaker will be distorted. The reason for this is simply that with an improper impedance match the output tube of the amplifier no longer operates over the linear portion of its dynamic E_g-I_p characteristic. Regardless of whether the output stage uses class A, push-pull or push-push operation, best results are obtained when the load placed on the stage has the correct impedance value.

With the loudspeaker impedance and the required load impedance of the amplifier known, there remains only the connecting together of source and load by means of a suitable matching or output transformer. Since the required plate load impedance is usually much greater than the loudspeaker impedance, a step-down transformer is needed; its turns ratio is determined simply by dividing the required plate load impedance by the loudspeaker impedance and then taking the square root of the resulting number. (Taking the square root of a number means finding a smaller number which, when multiplied by itself, will give the original number.) The primary winding, which connects into the plate circuit of the output tube or to the plates of the tubes in a push-pull or push-push output stage, will have the greatest number of turns and will therefore usually have the greatest D.C. resistance. The secondary winding has the least turns and connects to the loudspeaker voice coil leads. Here is an example: If a push-pull output stage

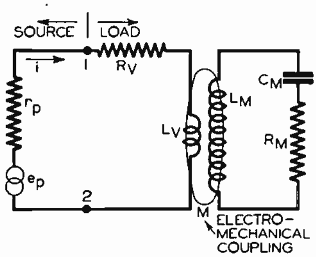
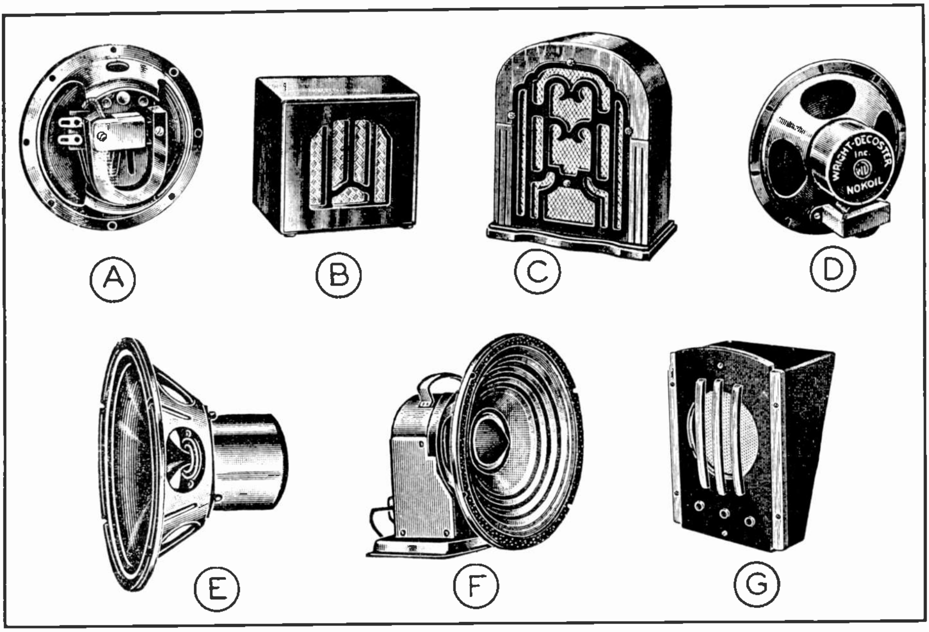


FIG. 22. Equivalent circuit of a complete loudspeaker unit connected to a source of audio frequency power.

requires a 2,000-ohm load for greatest undistorted output power, and the loudspeaker has a specified impedance of 20 ohms, our impedance ratio is 2,000 divided by 20, which is 100. Taking the square root of 100, we get 10 as the turns ratio of the output transformer. The primary winding

Typical Loudspeaker Matching Circuits. A typical connection of a loudspeaker and output transformer to a single tube output stage is shown in Fig. *23A*. The recommended plate load impedance of the pentode output tube and the average voice coil impedance of the loudspeaker determine



These diagrams illustrate a number of the interesting features of cone loudspeakers which are taken up in this lesson.

***A*—Balanced armature driving unit which is coupled mechanically to a medium-sized free-edge cone. This unit is commonly known as a magnetic loudspeaker.**

***B* and *C*—Typical small cabinets used for magnetic loudspeakers.**

***D*—Permanent-magnet dynamic cone loudspeaker; this is similar in appearance to many electrodynamic loudspeakers, but the trade name NOKOIL indicates a permanent magnet construction.**

***E*—Special form of dynamic loudspeaker employing a para-curve or curvalinear cone in order to provide uniform response over a wide range of frequencies.**

***F*—Dynamic loudspeaker employing a corrugated cone construction for uniform response over medium frequencies; the conical plug over the moving coil in the center of this cone serves to diffuse high frequency sounds in all directions and to increase the frequency range over which piston action is secured.**

***G*—Special dynamic loudspeaker cabinet designed for wall mounting. Magnetic loudspeakers are also available in cabinets like this.**

will therefore have 10 times as many turns as the secondary winding. With the loudspeaker connected to the secondary winding and an audio signal of average frequency being fed into the primary winding, the measured impedance of the primary will be 2,000 ohms, and we therefore have a correct impedance match.

the turns ratio required for the output transformer.

A typical loudspeaker connection for a two-tube output stage is shown in Fig. *23B*. With class AB or A′ push-pull operation, a C bias resistor must be inserted in the circuit at point *X* to provide a negative C bias for each tube, and this resistor must be shunted with a high-capacity condenser. Since only one tube works at any instant of time, and feeds into only one-half of the output transformer primary winding, we must multiply the recommended plate load impedance for one tube by 2 in order to determine the turns ratio for the entire output transformer.

With high-impedance loudspeakers, such as those employing magnetic, condenser or crystal driving units, the loudspeaker impedance may be very close to that required by the output tube. The loudspeaker may in this case be connected as in Fig. *23A*, using a 1-to-1 turns ratio output transformer (having the same number of turns on the primary as on the secondary), or a direct loudspeaker connection to the plate circuit may be made in the manner shown in Fig. *23C*. In this latter case the D.C. plate current of the output tube flows through iron-core choke coil *CH* to the power supply, while signal currents flow through D.C. blocking condenser C_B and the loudspeaker. The inductance of choke *CH* must be sufficiently high to prevent excessive bypassing of audio frequency current around the loudspeaker.

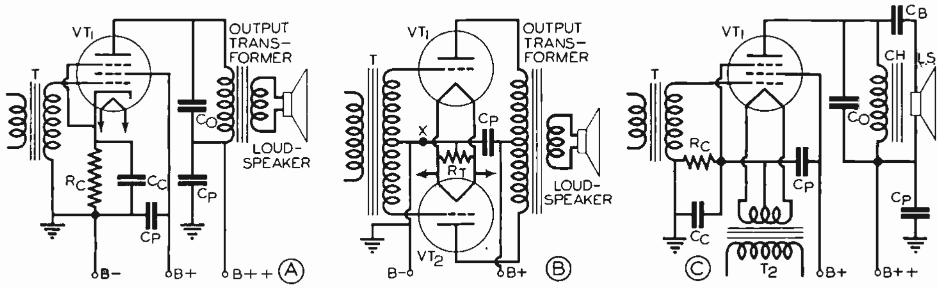


FIG. 23. Typical loudspeaker connections to output stages. Condenser Co is often included to prevent self-oscillation of the output stage, to alter the frequency response of the amplifier, or for both reasons.

Replacement of Output Transformers. When output transformers become defective and must be replaced, it is best to use an exact replacement transformer in every case in order to insure a correct match and duplicate the original performance of the receiver. This is particularly important in the case of receivers or public address amplifiers designed for high-fidelity operation.

When exact replacement transformers are not available, you can make a satisfactory replacement with little apparent change in performance by selecting a transformer having the correct turns ratio and a sufficiently large power-handling rating. Few radio men are able to order transformers on this basis, however; for this reason radio supply houses list replacement transformers for use with particular output tubes and for either single- or two-tube output stages. These transformers are designed on the assumption that most dynamic loudspeakers have a normal voice coil impedance of about 10 ohms.

Radiotricians oftentimes prefer to use universal output transformers, a few of which they can keep on hand at all times. These transformers are available in various power ratings, and have a number of taps on the secondary to provide various turns ratios. The primary winding has a center tap which is used with two-tube output stages but is ignored in the case of a single-tube output stage. The taps on the secondary usually provide for voice coil impedances of from 1 to 30 ohms. Use that tap which gives the greatest volume along with clearest tone when an actual radio program is being reproduced. For a more accurate determination of the correct tap, connect a cathode ray oscilloscope to the voice coil terminals, feed into the audio amplifier a pure sine wave signal first at 100 cycles, then at 1,000 cycles and 4,000 cycles, and select that tap which gives the greatest output voltage along with sine wave output for all three of these frequencies.

Field Coil Connections for Electrodynamic Loudspeakers

Most of the dynamic or moving coil loudspeakers used in radio receivers are of the electrodynamic type, employing a field coil for the production of a fixed magnetic flux. The average power used is from 7 to 15 watts. In many cases these coils are made to serve also as chokes for the power pack system, for at power line frequency the field coil has an appreciable inductive reactance. When used in this manner in place of a filter choke, the D.C. resistance of the field coil becomes important, for this resistance reduces the net D.C. supply voltage which is available for the tubes in the receiver.

The loudspeaker field coil connection shown in Fig. *24A* is without doubt the most widely used connection today in radio receivers. The D.C. resistance of a field coil used in this manner will usually be somewhere between 500 and 2,000 ohms. Since the D.C. current drawn from the power pack by the various receiver circuits must pass through this field coil, the coil must be capable of handling this current without excessive overheating. When the receiver has a push-pull output stage, complete filtering of the plate and screen grid voltages for the stage is not necessary, and a somewhat higher D.C. voltage is obtained by connecting to point X rather than to $B+$.

Since the power pack output voltage in a universal A.C.-D.C. receiver is considerably lower than that in an A.C. receiver, any loudspeaker field coil connection which would reduce this output voltage even more is obviously not desirable. For this reason the field coil of a loudspeaker in a universal receiver is usually independently supplied with rectified current in a manner similar to that shown in Fig. *24B*. In this circuit, one half of the 25Z5 double diode rectifier tube supplies current for the field coil, with filter condenser C_1 removing the pulsations in the half-wave rectified output current. The other diode section of this tube likewise delivers half-wave rectified current which is smoothed by filter condenser C_2 and choke coil CH. This choke coil is sometimes replaced by a resistor or is omitted entirely, and a higher-capacity filter condenser is used to provide the necessary filtering. The D.C. resistance of the loudspeaker field coil is usually larger than 2,000 ohms in a circuit of this type, in order to limit field coil current and prevent overloading of the rectifier.

In addition to providing a fixed magnetic flux and filtering the power pack output current, a loudspeaker field coil is sometimes made to serve a third purpose, that of providing a negative C bias voltage for the receiver stages. A tap is provided on the field coil for this purpose, as indicated in Fig. *24C*; the value of the bias voltage produced depends upon the resistance which is present between the $B-$ terminal of the power pack and the tap, and upon the amount of D.C. current flowing through this resistance. The entire D.C. voltage drop across the loudspeaker field coil can also be utilized for C bias purposes; the *C*-- terminal in Fig. *24C* thus provides a greater negative bias voltage than the *C*— terminal.

Separate Field Supplies. Loudspeakers used with public address amplifier systems must often be located a considerable distance away from the Fig. *24E*. The vacuum tube rectifier normally supplies an output voltage of over 250 volts, and the field coil used with this supply must therefore have a high resistance in order to limit the current to a safe value. With the dry disc type of rectifier, the output voltage will usually be less than 100 volts, and a lower-resistance field coil can be used. The present trend is toward use of permanent magnet

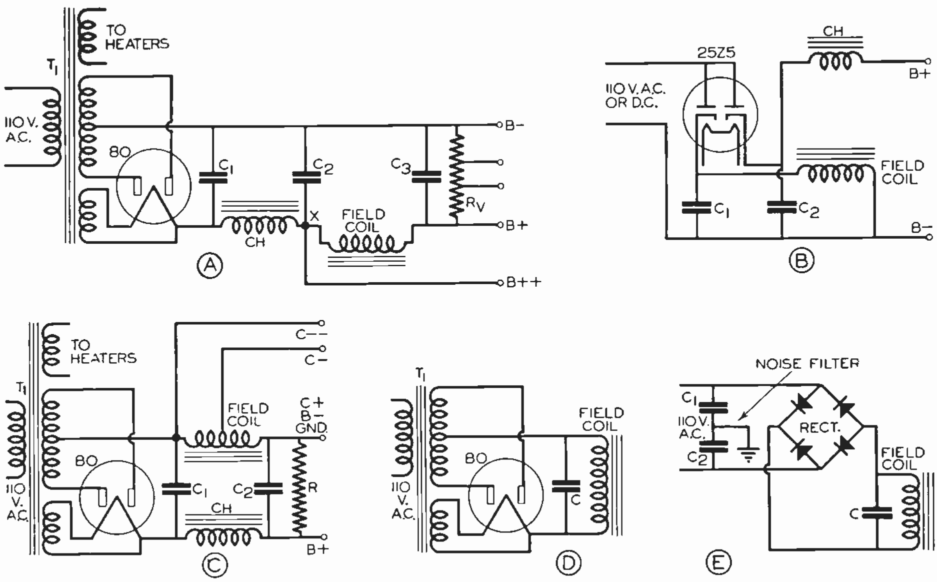


FIG. 24. Typical electrodynamic loudspeaker field supply connections.

amplifiers. If field coil leads were run from the loudspeaker location to the amplifier, the resistance in these leads would be excessive. The same holds true for extra loudspeakers, which are often connected to radio receivers but located some distance away from the receiver. In cases like these, it is necessary to use a separate field supply located at the loudspeaker if it is of the electrodynamic type. This field supply may consist of a full-wave vacuum tube rectifier like that shown in Fig. *24D*, or may be a full-wave bridge type rectifier using copper-oxide discs, as indicated in dynamic loudspeakers, however, thus eliminating entirely the need for a separate power supply at the loudspeaker location.

With battery receivers the extra current drain due to the field coil of an electrodynamic loudspeaker would obviously be undesirable; for this reason the loudspeakers used in battery receivers will generally have either a balanced armature type magnetic driving unit or a permanent magnet dynamic driving unit. Auto radio receivers use electrodynamic loudspeakers extensively, with the field coil so designed that it can be connected directly to the 6-volt storage battery; permanent magnet dynamic loudspeakers are also used with auto radios.

Elimination of Hum. We have seen how the rectified current supplied to the field coil of the loudspeaker in an A.C. receiver is usually incompletely filtered. Up to a few years ago this ripple current was not objectionable because the average loudspeaker was not able to reproduce sounds as low as the hum frequency of 120 cycles. Recent improvements in loudspeaker design have extended the low frequency response of the loudspeaker well down to the lowest audible sound frequencies; the result is that any ripple currents induced in the voice coil are heard as objectionable hum. This condition arises because magnetic flux produced by the field coil passes through or links with the voice coil, giving the effect of a transformer in which A.C. or ripple current going through the primary induces corresponding A.C. voltages in the secondary or voice coil. The two basic methods used for eliminating hum due to A.C. in the field of a dynamic loudspeaker are: *1, use of a shading ring; 2, use of a hum-bucking coil.*

Shading Ring. A large copper ring called a *shading ring* or shading coil is placed around the central core, as shown in Fig. *25A*. This shading coil acts as a short-circuited turn which, when A.C. currents flow through the field coil, sets up an out-of-phase A.C. flux in the core to cancel out the effects of the original A.C. flux. The result is that no A.C. voltages are induced in the voice coil.

Hum-Bucking Coil. A more widely used scheme, shown in Fig. *25B*, involves winding on the central core a number of turns of wire (usually a few less than are in the voice coil). This extra coil, known as a *hum-bucking coil,* is connected in series with the voice coil but is wound in the opposite direction. Any A.C. flux which is present in the core induces an A.C. voltage in the voice coil and also in the extra coil. Since these voltages are out of phase and acting in series, they balance or buck each other, and no A.C. current flows through the voice coil to react with the permanent magnetic flux. Circuit diagrams usually indicate when a

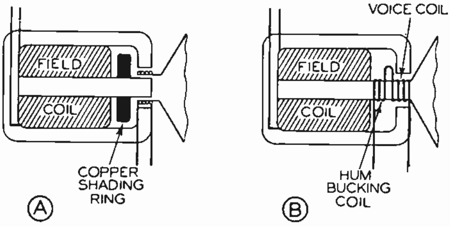


FIG. 25. Here are two methods used by loudspeaker design engineers for overcoming hum which is due to the presence of A.C. components in the field coil current of an electrodynamic loudspeaker.

hum-bucking coil is present in the loudspeaker; typical schematic circuit diagrams illustrating this hum-elimination feature are shown in Fig. *26*.

Acoustical Problems of High-Fidelity Reproduction

The output of the average loudspeaker begins to drop rapidly at frequencies above 4,000 cycles. This drop in high-frequency output can be offset to a certain extent by designing the audio amplifier to have a peak response in the high-frequency region, but there is a limit to the amount of treble-boosting which can be incorporated in the audio system without introducing new circuit problems. This is one of the reasons why modern high-fidelity loudspeaker systems usually employ two separate loudspeakers, a woofer, which is capable of giving flat response up to about

3,000 cycles, and a tweeter, which provides satisfactory reproduction of the higher frequencies. Typical response curves for a woofer and a tweeter are shown in Fig. *27*. The

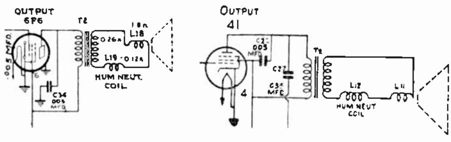


FIG. 26. Schematic circuit diagrams of radio receivers usually indicate, in a manner similar to that shown above, whether a hum-neutralizing (hum-bucking) coil is used in the loudspeaker.

dotted line gives their combined response over the region in which they overlap, and shows that the combined effect is a greatly increased range over which flat response is secured. A low-pass filter (often simply a shunting condenser) is placed in the woofer circuit and a high-pass filter is placed in the tweeter circuit (a series condenser will often suffice) to prevent useless currents from overloading the loudspeakers.

In public address systems, both woofer and tweeter may be of the horn type, or the woofer may be a dynamic cone loudspeaker using an exponential horn baffle, with a horn type tweeter. Deflecting vanes are often built into the tweeter to broaden its directional characteristics.

In home radio receivers the woofer

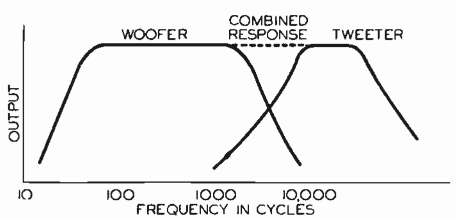


FIG. 27. Response curves for a high-fidelity, two-loudspeaker arrangement.

is usually a dynamic cone loudspeaker mounted in a box baffle having acoustic low-pass phase-reversing construction, with a tweeter loudspeaker of either the cone type using a crystal driving unit or the trumpet horn type also mounted on the baffle. A typical woofer-tweeter combination in a special box baffle is shown in Fig. *28*.

Room Acoustics. Although most people recognize the fact that a theatre or auditorium must be properly treated with sound-absorbing material in order to give natural reproduction of sounds, the average radio receiver owner gives very little attention to the acoustic treatment of the room in which his radio receiver

FIG. 28. A large dynamic cone loudspeaker (woofer) and a horn type tweeter are here mounted on a single box baffle to give uniform response over a wide range of audio frequencies. The inside of the box is lined with sound-absorbing material to prevent standing waves.

is located. It is the duty of the Radiotrician to point out that a room having overstuffed furniture, heavy draperies, and a large, heavy rug is desirable. There will then be sufficient sound absorption to prevent sounds from being reflected back and forth between the walls of the room and various objects in it, and there will be no echo or reverberation effects. The Radiotrician can also recommend that the loudspeaker be pointed or directed in such a way that sound can travel a maximum distance before being reflected. If the radio is in one corner of a room, the receiver should be facing another corner diagonally opposite, giving a long path through air for the radiated sounds.

High-frequency sounds are so directional in nature and so easily absorbed by rugs and furniture that they should be heard directly rather than after reflection. Some receivers utilize inclined sounding boards or baffles which cause these high-frequency sounds to be directed at an upward angle, away from the floor, for this purpose.

By this time it should be quite clear to you that the securing of high-fidelity reproduction in a radio receiver system or public address system can be best obtained only by proper design of each and every link in the long chain between the microphone in the broadcast studio and the listening location in the home.

Loudspeaker Replacement Hints. Tone controls can compensate to a certain extent for deficiencies in loudspeaker response, but manufacturers of high-quality receivers will sometimes introduce equalizer circuits in an audio amplifier in order to make the amplifier response peaked in a region where the loudspeaker response is low. The combination response of the system can in this way be made almost uniform for high sound levels. Tone controls then correct for the peculiarities of the human ear at low sound levels. Changing of loudspeakers may therefore alter the performance of a high-fidelity receiver, unless an exact duplicate replacement loudspeaker is used. When the loudspeaker cone in a high-fidelity receiver must be replaced, always use the exact duplicate replacement cone which is supplied by the receiver manufacturer; cone design has considerable influence on loudspeaker response.

TEST QUESTIONS

Be sure to number your Answer Sheet 27FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Why are large flat diaphragms unsatisfactory for loudspeakers?
2. What two purposes does a spider serve in a dynamic loudspeaker?
3. Does mechanical resonance occur at *high, medium* or *low* frequencies in dynamic cone loudspeakers?
4. Why is pure piston action desirable in the cone of a dynamic loudspeaker?
5. Is an irregular shape of baffle better than a square or round baffle?
6. Can the natural resonant frequency of a box baffle be lowered by increasing the size of the box?
7. How can the undesirable effects of cavity resonance be reduced in a box type baffle?
8. What are the four distinct purposes of the acoustical labyrinth?
9. What are the approximate maximum obtainable efficiencies for a large cone loudspeaker in a box baffle and for a driving unit used with an exponential horn?
10. What are the two basic methods of eliminating hum due to A.C. in the field of an electrodynamic loudspeaker?

METERS FOR MEASURING CURRENT

THE CATHODE RAY OSCILLOGRAPH

28FR-2

PIONEER HOME STUDY RADIO SCHOOL

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NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

GETTING ALONG WITH PEOPLE

"Diplomacy" is another of those words that can be defined in various ways. Often we think of diplomacy as being a sort of under-cover scheming such as statesmen and politicians use when they want to get something without seeming to ask for it.

But in the better sense of the word, diplomacy is not much more than a high degree of courtesy and a true diplomat is one who, in all his associations with his fellowman, shows a deep appreciation of the other fellow's feelings.

A diplomat knows when to agree with you—and how to disagree. He will not come to blows with you on some trivial matter but he will win your good will by yielding to you. But when it comes to something important, he will bring you to his way of thinking—painlessly. He will be able to get you to do what he wants you to do—or to believe what he wants you to believe—without your realizing that your will is being influenced by his.

Now turn matters around—and you be the diplomat. No matter what you are doing—your job calls for diplomacy. If you are an employer, an employee, or if you are in business for yourself and working alone—learn diplomacy.

In conversation, ordinary or business, try to gauge the other fellow. Be considerate of his feelings—his pet beliefs. Don't contradict people flatly—they might have more basis for their stand than you have for yours. If you are sure you are right and the other fellow wrong, be reasonable about it. Explain your position in a friendly way.

There are some few people who can be frank, say exactly what is in their minds, and get away with it. For the most part, however, people just tolerate this sort of person and call him a "character"—possibly "not all there."

People like the man who thinks before he talks—who doesn't make rash or crude statements. And if you can get people to like you, you can count on them to help you—to give you the sort of cooperation that will mean success for you.

So learn diplomacy—and practice it in all your contacts with your fellowmen.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1941 Edition

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Meters for Measuring Current

ELECTRICAL QUANTITIES

The knowledge of *how great* or *how small* a thing is, is of just as much importance in radio as in any other phase of life. If you go to the carpenter and tell him to make a table for you, he will ask you how long you want it, how high it should be, how much weight it must be able to bear, and so on.

Immediately you think of a foot-rule, or a yardstick, or some other length-measuring instrument with which you are familiar. You tell the carpenter that the table must be 6 feet long. You are unconsciously comparing the length which you desire the table to have with the length of a piece of wood you have at home, which you call a foot-rule. What you really mean when you tell the carpenter that the table is to be 6 feet long is that it should be six times as long as that particular piece of wood.

It is clear from this that all measurements are really *comparisons.* The thing which you wish to measure is compared with some other thing with which you are familiar. Everything has a certain property or characteristic which we call quantity. Length, weight, velocity, resistance, capacity, time, current, voltage, density—all these are quantities. All these are measured by comparing them with a certain standard which we call a *unit.*

The *foot* is a unit of length; the *second* is a unit of time; the *pound* is a unit of weight; the *henry* is a unit of inductance; the *ohm* is a unit of resistance, and so on almost indefinitely.

Sometimes we have several units for the same property. For example, the unit of length may be the *inch,* the *centimeter,* the *mile,* etc. But this all amounts to the same thing, because we know that there must be certain simple relations between these various units. The inch is equal to 2.54 centimeters; if we measure a length and find it to be 10 inches long, we know immediately that if we had used a centimeter scale instead of an inch scale, our measurement would have given us 25.4 centimeters as the length. In other words, the length may be considered as so many times any standard unit. If measurements are made by different persons using different systems of measurement, then the relation between the two systems must be known.

All practical measurements are *comparisons.* Some comparisons may be *direct* and some may be *indirect.* For example, by laying a foot-rule along a certain pencil line, we compare the length of line with the length of the rule, a direct comparison. But we can't measure the speed of a train in any such way. First we have to measure a certain distance with our foot-rule, or by some other convenient means; then as the train runs over this distance, we measure the time it takes it to do so with a stop-watch. This involves another comparison; we compare the time which the train takes with the time it takes the hand of the clock to travel around the face of the watch, which in turn is compared with the time the earth takes to revolve completely around on its axis. Then, knowing the distance and the time, we simply say that the train has passed over so many miles in so many minutes, and we have a third unit which is called *miles-per-minute*. This unit measures speed. This is an indirect measurement or comparison. We must measure two quantities in order to know the third.

Although the foot-rule divided into inches and fractions of an inch, and the watch, are common everyday measuring equipment, they are not the standards, as we call them. The absolute* standards of time and length are carefully guarded by the National Bureau of Standards, in Washington, the Nation's Capital. Here the standard foot is kept and your rule will be compared with this standard by the Bureau at a nominal fee. Over years of use, manufacturers of rulers are able to produce rulers with considerable exactness, but after all, they are only *secondary* standards, whereas the standard at the Bureau of Standards is the *primary* standard.

Twice each day, at 12 noon and 10 p.m. Eastern Standard Time, the Government sends out time signals, which are determined by astronomical means. And these time signals afford a means of regulating clocks and watches so they become accurate devices to measure time, in seconds, minutes, and hours; and they become the secondary standards of time.

Now let us turn to electrical and radio units. To be sure, you may buy a one ohm resistor which has been checked to be very nearly equal to the one in the Bureau of Standards; or you can purchase a coil with an inductance of one henry; or a condenser with a capacity of one microfarad. Even though they may have been compared to similar standards held by the Government, are the latter the primary standards? They are not, as the primary standards are obtained in a different manner. For example, an *ohm* is really a unit to measure a property of a conductor and by definition it is the resistance property that a conductor has when it allows only one ampere to flow when an electric pressure of one volt is applied. But how much is a volt or an ampere? Scientists have many procedures of determining the absolute values of voltage and current, but these are not the practical standards. At the Bureau of Standards you will find a small wet cell capable of generating exactly 1.01865 volts, determined by the absolute methods known to scientists; it is the primary standard. When kept under rigid atmospheric conditions, especially temperature, its voltage hardly varies. Yet you can buy a secondary standard cell, as shown in Fig. *1a*, which has been checked against the primary standard.

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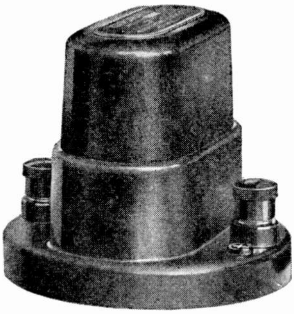
* It is a fact known to scientists that such basic qualities as *amperes, volts, ohms, henries, farads, pounds, etc.,* may be expressed in units of *length, time* and *mass,* which are referred to as the *absolute units* and any measurements in terms of absolute units are known as *absolute measurements.*

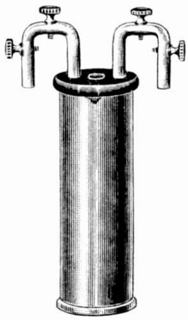
Even though an ohm represents the unit property of a conductor, it is now customary to have a definite size and kind of conductor to represent the *standard ohm.* Incidentally it happens to be the resistance of a column of mercury 106.300 centimeters long of uniform cross-section, the mercury weighing 14.4521 grams, at the temperature of melting ice. But for practical use, secondary standards as shown in Fig. *1b,* made of special resistor wire are used. Given a standard volt and a standard ohm, by Ohm's law the standard current can be produced for purposes of comparison. Again we measure two quantities in order to know the third.

However, we can only measure current by what it will do. What we may do is this: we construct a movable coil system, suspended in a constant magnetic field, and when we pass a current through the coil work is done, the coil moves and by attaching an indicator the amount of movement can be observed. This movement is a measurement of the



COURTESY WESTON ELECTRICAL INSTRUMENT CORP.

FIG. 1a



COURTESY LEEDS & NORTHRUP CO.

FIG. 1b

current. The exact current is known because the ohms in the circuit and the volts applied to it are easily compared to secondary standards. Thus we produce a secondary current indicating standard.

Now all that I have said about absolute, primary and secondary standards is of no great concern to the practical radio man, if the following ideas are clearly understood. If you understand that the meters you use in testing are only approximately correct, that they can only be considered more correct by comparing to secondary standards, which in turn are checked against a primary standard, which from time to time is checked by absolute methods, you get the whole scheme of measurements by the means of comparison. Remember this: a practical measuring instrument is calibrated by comparing it with an accepted secondary standard.

In radio and electrical design, research, maintenance and servicing we definitely depend on our ability to measure electrical quantities, and the important units are:

Amperes	units of current
Volts	units of potential difference
Watts	units of power
Cycles per second	units of frequency
Ohms	units of resistance, reactance or impedance
Farads	units of capacity
Henries	units of inductance

As practical men we have need for measuring instruments that will simplify the measurement of any of these quantities. And the question constantly arises, what instrument shall I use to measure this or that quantity? You must select this instrument fully aware of what it will or will not do. For example, every ammeter cannot be used to measure one ampere of high frequency current. There is a correct type to use, and the ability to select the proper type only comes from a knowledge of meters and how or why they work. Instrument design involves com-

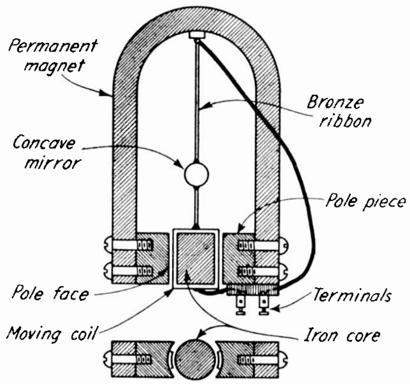
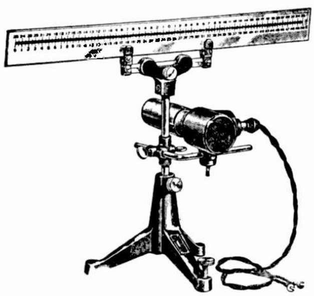


FIG. 2



Scale and lamp for semi-portable galvanometer

FIG. 3

plex mathematical work, hence our study will be limited solely to the practical side, their construction, operation, and limitation. As the current meter is essentially the basic instrument, it will be studied first.

THE D'ARSONVAL GALVANOMETER

The D'Arsonval galvanometer is by far the most important D.C. current-measuring device. In this type of instrument we have a moving coil suspended in a permanent magnetic field, the indicating device being a small concave reflecting mirror attached to the coil system, as shown in Fig. 2. The coil is small, very light in weight, and rectangular in shape. It consists of a number of turns of very fine, copper wire, and the entire coil is suspended on a thin, flat, phosphor-bronze ribbon. The suspension is such that the coil can rotate at right angles to the magnetic lines of force from one pole face to the other. The small mirror shows its movements by the change in the direction of light reflected from it onto a graduated scale.

The current to be measured is made to flow through the coil. Then the magnetic field set up about the coil reacts with the permanent magnetic field, forcing the coil to rotate in one direction or the other, depending on the direction of current. The tendency of the coil to rotate is opposed by a counter-twist of the flat suspension ribbon. Therefore, the coil will turn until the torque (twisting force) due to the current is equal to the counter-torque of the suspension. At this point the indicating device will remain fixed, and the position is a measure of the current flowing through it.

Of course, it isn't difficult to realize that a meter of this type can be made extremely sensitive by using a very strong magnetic field, a large coil, a large number of turns and a weak repelling force in the galvanometer suspension.

The sensitivity of this type of galvanometer can be greatly increased by a special method of magnifying the movement of the indicat-

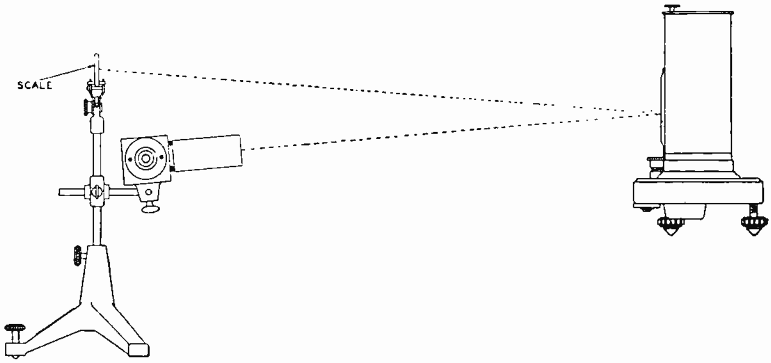


FIG. 4

ing device. The additional equipment is shown in Fig. *3*, and how it is used is shown in Fig. *4*—there being a long-filament lamp in front of the concave mirror of the galvanometer so the image of the filament is reflected and magnified by the mirror onto a frosted semi-transparent scale. Then the least rotation of the galvanometer will show up on the enlarged scale.

The scales may be laid off in any convenient manner and each unit divided into ten equal parts. With this arrangement we can compare currents by the amount of deflections produced on the scale.

CALIBRATING A GALVANOMETER

A galvanometer, as you have probably suspected, is merely a current indicating device. To be sure, a current indicator is quite valuable, especially when radio or electric circuits are adjusted or balanced so zero current (no meter deflection) exists. But the greatest use for a current indicating device is its ability to indicate how much current exists, and to do this a galvanometer is calibrated. When it is calibrated it becomes a current meter, or ampere meter. We usually refer to calibrated current meters as ammeters; if they indicate values of 1/1000 of an ampere they are called milliammeters; if they measure microamperes, they are called microammeters. Calibrating a galvanometer is quite simple if you have secondary standards. The meter manufacturer who makes the testing instruments for use has the facilities to calibrate his product.

To calibrate the galvanometer shown in Fig. *4*, we need an accurate source of voltage and precision resistors. We first would determine roughly how much current will make the galvanometer read full scale. We could take a 10 volt source, connect it to the galvanometer using a variable high resistance in series; gradually decrease the resistance until full scale reading is obtained. Suppose 10,000 ohms give full scale deflection. Obviously 10 ÷ 10,000 (Ohm's Law) or .001 ampere gives full scale deflection. We say that the galvanometer has a 1 milliampere full scale range.

For an exact calibration, the circuit shown in Fig. *5* would be assembled. Let us say that the galvanometer scale is divided into 100 divisions, and that the resistance of the meter is about 15 ohms. We would proceed to adjust the variable resistor until the reading was 100 divisions—and we find that this is roughly 10,000 ohms. How much resistance does it take to produce scale deflections of 90, 80, 70, 60, etc.? In determining these resistor values you are taking the initial steps in the calibration. Suppose the values we got were as follows, where D is the divisions on the scale, R the resistor value in ohms, easily read from the variable standard:

D	R	I_1	I_2	D	R	I_1	I_2
100	10,000	.001	1000	50	20,000	.0005	500
90	11,100	.0009	900	40	25,000	.0004	400
80	12,500	.0008	800	30	33,300	.0003	300
70	14,000	.0007	700	20	50,000	.0002	200
60	16,700	.0006	600	10	100,000	.0001	100

Knowing that the voltage is 10 volts, we can by Ohm's Law ($I = E \div R$) determine the exact current flowing for each deflection.* The current values are shown in units of amperes under I_1 and in units of microamperes under I_2 in the above table.

Of course, a graph or calibration curve is far more useful than a table, for it is easier to determine the current for odd deflections like 63, 27, etc. A calibration curve is shown in Fig. *6*. Notice how straight the calibration curve is. We say that the meter has uniform or linear response. And this characteristic is quite valuable in a meter, and the

* In this case the meter resistance may be neglected. If it happened to be a larger value, for example 522 ohms, the meter resistance (furnished by the maker) would have to be included.

device is designed to have this property whenever possible. Now when a meter has this property we may say that the current for a definite deflection is the *deflection* (scale reading) *times a number*, and the latter is called the *meter constant.* Expressed as a formula we say: $I = K \times D$. The meter constant (K) is easy to determine: Divide the amount of current (in the units you wish to use) known to exist at any scale division by the number shown on the scale at the point you selected. The reading at full scale deflection is generally used. Let us say we want to use the meter as a microammeter. The amount of current known to exist at 100 on the scale is .001 ampere, or 1 milliampere, or 1,000 microamperes. In our case it is 1,000 (we are selecting microamperes) divided by 100, and the meter constant is 1,000 $\div$ 100 equals 10. Hence, if the calibrated galvanometer is used to measure current in units of microamperes and a reading of 63 is obtained, we know at once it is 630 microamperes.

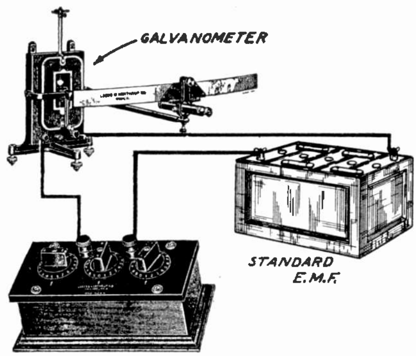


FIG. 5

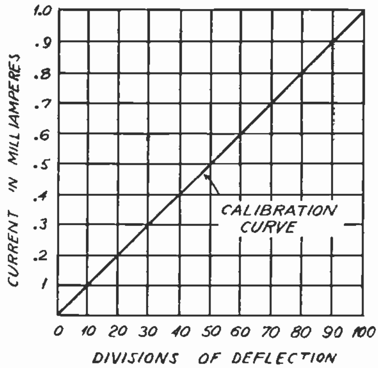


FIG. 6

Now all this is quite important because you may have a current meter or a galvanometer that you may wish to calibrate, and this is one way it may be done if you have no standard meter to compare it with.

D. C. AMMETERS AND MILLIAMMETERS

The D'Arsonval calibrated galvanometer principle was used by Edward Weston in 1888 in the development of what might be considered the first practical, modern, portable galvanometer. Details of the construction of the Weston galvonometer are shown in Figs. 7 and 8.

There is a small, compact but powerful permanent magnet, with soft steel pole pieces and a soft steel core. The pole pieces are bolted to the permanent magnet and to a non-magnetic support.

The coil is wound of many turns of silk-covered fine copper wire on a non-magnetic metallic frame. The coil is mounted in a pivot arrangement. There is a pivot point at each end of the coil exactly in the center of the core and the pivots themselves are set in polished, hard steel pivot holes, arranged directly above and below the exact center of the core. In modern high grade meters, jewel pivot sockets are used.

To the coil is attached a long needle which swings over an indicating scale. It is conventional for zero on this scale to be at the extreme left and maximum deflection to the right. In some cases zero is in the center of the scale and the indicating needle swings either to the right or left, depending on the direction of the current through the meter.

The air gap in which the coil rotates is made as small as possible so that the magnetic field through it will be strong. If linear response is important the distribution of flux in the area through which the coil moves must be uniform and the coil must not be allowed to swing beyond the point of uniform field, or beyond the curvature in the pole pieces. A coiled ribbon spring is connected to the pivot and anchored to an arm which is a part of the end piece holding the bearing. The arm is adjustable so that the tension of its spring can be changed. The

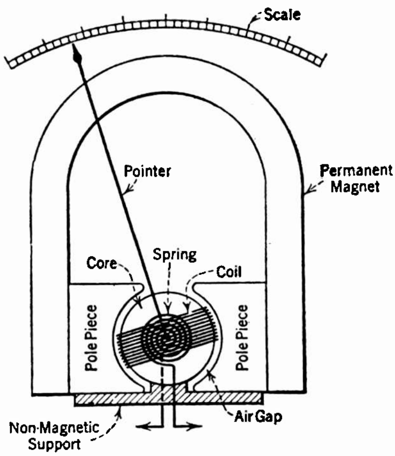


Fig. 7

needle is adjusted for zero in the same way. A spring coil is also used on the lower pivot, both springs being of phosphor-bronze. They provide the electrical connection to the coil windings provided the springs are led to insulated terminals.

A current flowing through the coil sets up a magnetic field which reacts with the permanent field, forcing the coil to rotate until the twist is balanced by the tension of the coil spring. The amount of current flowing can be calculated from the same formula we used with the D'Arsonval galvanometer $(I = K \times D)$.

SHUNTS TO EXTEND THE CURRENT RANGE

You probably know that the range of an ammeter may be extended by using a resistor shunted across the meter terminals, as shown in Fig. *9*. Thus part of the current to be measured passes through the shunt and some through the meter. Of course, the shunt must be selected so a definite proportion of the whole passes through itself and the meter. Only precision resistors, two types of which are shown in Fig. *10*, should be used as shunts, to insure the greatest accuracy. As a rule they will have extremely small ohmic resistance, and carry the bulk of the current to be measured—you do not want the basic meter to overheat.

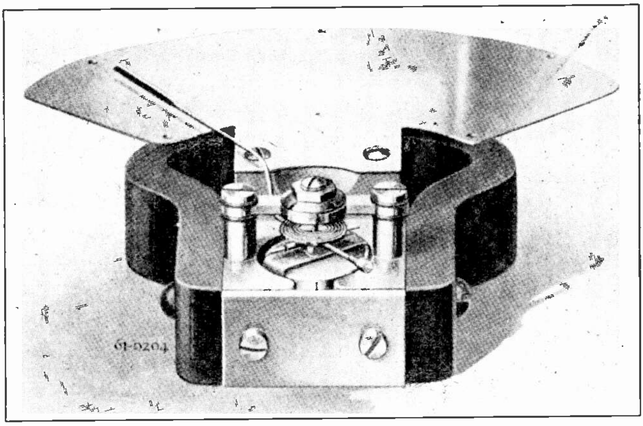


FIG. 8. D'Arsonval D.C. ammeter with case removed

Let us follow through the calculation of several shunts on a typical meter that you as a Radiotrician may constantly use. The meter selected has a range of from 0 to 1 milliampere and its coil has a resistance of 12 ohms. The scale is divided into 10 divisions, and each of these is divided into 10 smaller divisions. Each small division represents 10 microamperes and each large division .1 milliampere (ma.). As there are 100

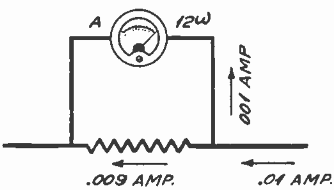


FIG. 9

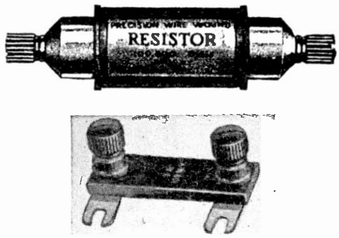


FIG. 10

divisions on the scale and as these hundred are designed to represent 1 ma., K will be in this case $1 \div 100$ or .01.

By the use of shunts of various values, this basic milliammeter can be used to read from 0–10 ma., 0–20 ma., 0–100 ma., etc. The shunt to be used can always be calculated from Ohm's law. For example, suppose we want this 0–1 milliammeter to read from 0 to 10 ma. We must use a shunt which, in parallel with the 0–1 milliammeter will allow only .001 ampere to flow through the instrument and .009 ampere through the shunt—at the new maximum current range. This simple circuit is shown in Fig. *9*. Knowing this distribution of current and the resistance of the basic current meter, calculating the correct shunt is simple.

The voltage drop across the milliammeter is $12 \times .001$ or .012 volt. The same voltage exists across the shunt. The resistance of the shunt must be such that, with that voltage across it, only .009 ampere will flow. The value of this resistance, from Ohm's law, is:

$$(1) \qquad R = \frac{E}{I} = \frac{.012}{.009} = 1.33 \text{ ohms.}$$

Suppose we wanted to adapt our meter to read from 0 to 20 ma. Of course, full scale deflection will mean that 1 ma. flows through the meter and 19 ma. through the shunt—and the total current measured will be 20 ma. Again the voltage across both meter and shunt is .012 volt. The resistance of the shunt required is equal to $\frac{.012}{.019} = .63$ ohm.

For a 0–100 mil. range R will have to be $\frac{.012}{.099} = .121$ ohm.

The procedure just shown may be presented in a form to enable you to calculate a shunt for any current meter. It is as follows:

$$(2) \qquad \textit{Shunt Resistance} = \frac{\textit{Meter Resistance} \times \textit{Its Current Range}}{\textit{Current the Shunt Must Pass at the New Maximum Range}}$$

where: Resistance is in ohms, Currents are in the same units.

PRACTICAL METER CALIBRATION

When the required shunt resistance for a particular meter is accurately known, the shunt may be adjusted to this required value by means of a precision ohmmeter. Another and perhaps more widely used method involves placing a shunt of approximately the correct value across the meter in question, and then adjusting the shunt by means of the calibrating circuit shown in Fig. *11*. The meter and its shunt are placed in series with a standard meter of suitable range, a voltage supply E and a current-adjusting resistor R. This variable resistor is adjusted until the standard meter indicates a current equal to the desired full-scale reading for the meter-shunt combination being calibrated. The shunt is now adjusted until its meter reads full-scale. This adjustment is simple if the shunt resistor has a sliding clamp like that shown at a in Fig. *11*. If the resistor is of the fixed wire-wound type, however, select one having slightly greater resistance than is required, and short out turns with hot solder or remove turns one at a time until the desired full-scale reading is secured.

Any number of shunts may be prepared in this way for a single milliammeter movement, making each shunt extend the meter range by some convenient multiple of its original range. Thus you might have shunts which increase the range 10, 20, 50 and 100 times.

If shunts are available to extend the range of a 0-1 ma. meter 10 times and 100 times, you might be tempted to connect these shunts as shown in Fig. *12*. This circuit is not practical, however; when switching from the 0-10 ma. range to the 0-100 ma. range, there will be a time when no shunt is in the circuit to protect the meter.

In Fig. *13* is shown a more practical multi-range milliammeter circuit. The R_1-R_2-R_3 combination is a single wire-wound resistor having two adjustable sliders or taps, at *a* and *b*. The ohmic value of this resistor must be such that the desired lowest range is secured with the entire shunt across the meter (with the selector switch at the 0-1 terminal). The settings of the sliding clamps are then readily determined by means of the standard calibrating circuit shown in Fig. *11*.

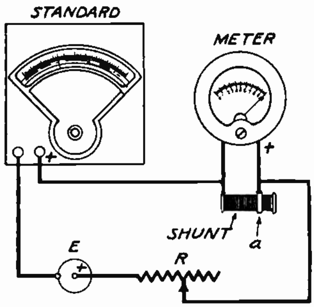


FIG. 11

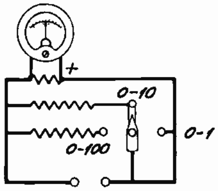


FIG. 12

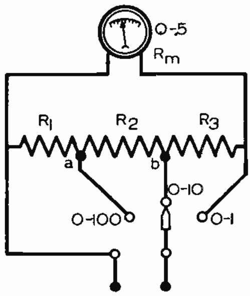


FIG. 13

READING METER SCALES

Let us first consider the scale of a 0-10 ma. D.C. milliammeter, which will have uniform graduations as shown in Fig. *14A*. Full-scale deflection will be 10 ma., and half-scale deflection will be 5 ma. The entire scale is divided into ten major divisions, one of which is indicated as *x;* each represents 1 ma. When the pointer is at *a*, it is three major divisions to the right of zero, and we read 3 ma. At *c* the pointer has passed over six major divisions, and we read 6 ma.

Now observe that each main division is divided into five smaller divisions; each small division must therefore be one-fifth of 1 ma., or .2 ma. If the pointer is at *b*, which is four large divisions and three small divisions to the right of zero, the reading will be 4 plus 3 $\times$ .2, or 4.6 ma. With the pointer at *d*, we can readily see that it has passed 8 major divisions and 2½ small divisions. A little thought will show you that in this case the meter reading is 8.5 ma.

The 0-10 scale shown in Fig. *14A* can also be used to indicate zero to 100 ma. when the meter has a shunt which increases its range to this value. Read the scale directly in the manner just described, and then mentally multiply the reading by 10, the amount which the meter range has been increased. For example, if the pointer is at *b*, we would first read 4.6 ma., then multiply by 10 to give 46 ma. If you are familiar with decimal numbers, this multiplying by 10 can easily be done by moving the decimal point one place to the right.

Sometimes the additional range is printed right on the scale, as in Fig. *14B*, for easy reference. In this case, when using the 0-100 range, we would read the lower numbers. For example, with the pointer at *b* we would note that four major divisions (each representing 10) and three small divisions (each representing 2) have been passed, and would therefore read 46 ma. Likewise, with the pointer at *d*, we would read 85 ma. on the 100 ma. scale.

A 0-10 scale can also be used for a 0-1 ma. range; divide the direct reading by 10 (or move the decimal point one place to the left). Likewise, if a 0-10 range is extended five times, to 0-50, one way to read the scale would be to multiply the direct reading by 5. An easier procedure

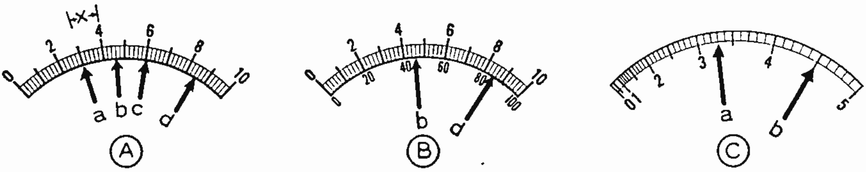


FIG. 14

for mentally reading a meter whose range has been extended five times, is *to mentally divide the direct reading by 2, and then add a zero (0) to the answer.*

Only D.C. meter scales have uniform divisions. The scales of A.C. meters are usually non-uniform, as indicated in Fig. *14C*. Here there are five major divisions, each of which covers a different amount of space on the scale. Each large division (except the first) is divided into ten small divisions; if the full-scale range is 5 ma., then each large division will be 1 ma. and each small division will be .1 ma. With the meter pointer at *a*, which is three large divisions and three small divisions beyond zero, the reading would thus be 3.3 ma. Likewise, when the pointer is at *b*, 4 large divisions and 5 small divisions are included, and the reading would be 4.5 ma.

In reading a meter scale, three facts should be considered: *1*, the value of each large division; *2*, the value of each small division; *3*, the range-multiplying value.

HOT WIRE AMMETERS

Until recent years the hot wire ammeter was extensively used in measuring radio frequency currents. Today, the thermocouple ammeter has almost universally replaced them. However, the operation of the hot wire ammeter is important as you will still find many of them in daily use.

Figure *15a* shows the working mechanisms of the hot wire ammeter. There is an alloy wire of platinum and silver, or platinum and iridium, stretched between A and B. The tension on the wire may be increased or decreased by adjustment of the set screw S. Between C and E there is a phosphor-bronze ribbon. From point D on this ribbon, around a cylinder to a coil spring F, is wound a silk cord. When a current is passed through wire AB, an I^2R loss takes place and the wire becomes hot. Naturally the wire expands and sags. The sag is transmitted to FP through the action of the spring, causing the cylinder P to rotate. An indicating needle attached to P moves over a convenient scale. As the resistance of the hot wire remains substantially constant in value,

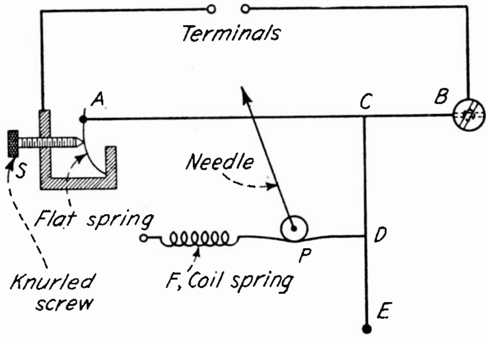


FIG. 15a

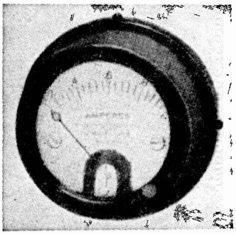


FIG. 15b

the sag in the wire, hence the deflection of the needle depends on the current squared (current times current). For that reason, low current readings are "bunched" together as you can see by looking at the hot wire ammeter scale shown in Fig. *15b*.

As D.C., A.C., or R.F. currents will produce heat and the resistance of a straight wire is essentially the same for any frequency of current, the hot wire ammeter may be calibrated on D.C. or A.C. and safely used to measure high frequency currents. Unfortunately, a hot wire ammeter is not a very sensitive meter, and ranges of 0 to 20 milliamperes are extremely difficult to make, besides are very fragile. Their use is generally limited to current ranges of one ampere and more.

THERMOCOUPLE AMMETERS

For the reasons just explained, hot wire ammeters are not practicable for the measurement of currents much smaller than 20 ma. But R.F. currents that have to be measured are often of the order of a few microamperes. It is for measuring these small R.F. currents that thermocouple ammeters must be used; in fact, the thermocouple ammeter has replaced the hot wire ammeter for almost all current ranges.

It is known that two dissimilar metals, like copper and iron, or copper and constantan (a special alloy), when joined together at one end and heated at the joint will produce a D.C. voltage across the open ends. This is the principle used in thermocouple ammeters. Any kind of current to be measured causes the joint between two dissimilar metals to heat up, and a D.C. voltage appears across the ends of these metals which can be measured by a D'Arsonval needle type galvanometer. As D.C. indicators can be made in any degree of sensitivity (ranges as low as 0 to 1 microamperes are not uncommon), a correspondingly sensitive A.F. or R.F. thermocouple ammeter is readily obtained.

Figure *16a* shows the working principle of a thermocouple ammeter. Two short, fine pieces of wire, one steel and the other constantan, are twisted together as shown. High frequency current is led to the terminals T_1 and T_2. The resistance of T_2JT_1 is perhaps 1 or 2 ohms and heats up due to the I^2R loss in it. The heat developed is concentrated at point J. Wires G_2J and G_1J act as a thermocouple with J as the heated point.

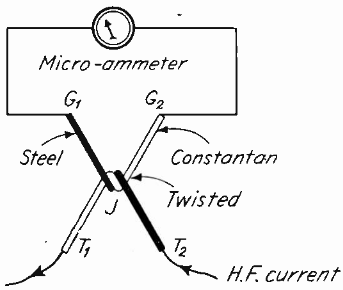


FIG. 16a

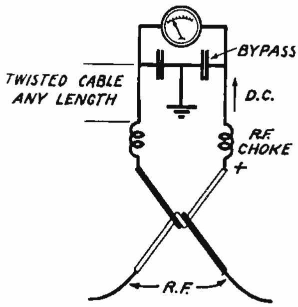


FIG. 16b

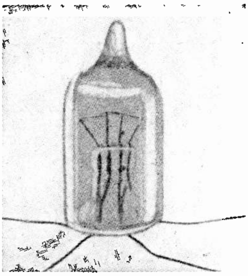
(Note. The H.F. current does not flow through meter)

In one type of thermocouple, a 25 ma. flow of high frequency current from T_2 to T_1, results in a .5 ma. of D.C. through G_2 and G_1 when an ordinary 0 to .5 ma. D'Arsonval meter is used.

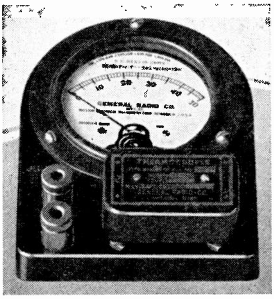
In using a thermocouple meter, it is essential that no R.F. currents get into the D.C. meter. Even though an R.F. current will not produce a meter deflection, enough R.F. current will burn out the coil. For ordinary laboratory work where low R.F. currents are measured, no precautions are generally required, provided reasonable care is taken to shield the D.C. meter from stray R.F. currents. In transmitters where the couple and the meter may be many feet apart, the following precautions are taken. The couple, of course, is located at the point where the current to be measured is present. A twisted cable connects the couple to the meter. To prevent R.F. from the source measured from getting into the cable leads, R.F. chokes are used. Quite often the D.C. meter is shunted with two low loss condensers and the center tapped to ground, as shown in Fig. *16b*. When one R.F. terminal to the couple is at ground

R.F. potential, the chokes and by-passes may be omitted, as the meter will be at a low R.F. potential.

A typical thermocouple unit is shown in Fig. *16c*, the elements held by a glass press and in a vacuum. The couple is then mounted in a moulded box with four prongs as terminals. Figure *16d* shows a D.C. galvanometer (0 to 500 microamperes) designed to take any of several thermocouples. Calibrations are required for each couple used and thermocouple ammeters, although intended for R.F. or A.C. uses, may be calibrated on D.C. That is, a circuit similar to Fig. *5* or Fig. *12* may be used, the standard resistors and the source being D.C. devices, but the meter to be calibrated a thermocouple ammeter. In calibrating a thermocouple ammeter it is wise to reverse the battery connections, as a difference in contact resistance of the joint may cause the readings to differ. An average value is taken. Several points on the scale should be so checked and a calibration curve drawn, as a thermocouple meter is not a linear indicator.



COURTESY GENERAL RADIO CO.
FIG. 16c



COURTESY GENERAL RADIO CO.
FIG. 16d

MAGNETIC VANE AMMETERS

For power line frequencies, that is commercial A.C. power, which we obtain at the outlet in our homes, offices and factories, more substantial types of current meters are available. One of them is the magnetic vane ammeter. Its low cost of construction, its ruggedness and its fair precision have led the serviceman to accept this type of ammeter for line current measurements of 25, 40, and 60 c.p.s. current as well as D.C. The principle of operation is rather simple.

Suppose a solenoid is fed with D.C. current. If a *soft, annealed* iron plunger is placed near an open end, it will be sucked in, even against the action of a spring which may tend to pull it out. The greater the current in the solenoid, the greater the pull. What happens is that the plunger becomes a magnet under the influence of the solenoid electromagnetic action. Now, if the D.C. current is reversed, the sucking-in action will continue. The polarity of the plunger reverses with the polarity of the solenoid. So, even by feeding low frequency A.C. to the solenoid wires, the action of pulling in the plunger continues in spite of the comparatively rapid reversal of current. However, there is a limit to increasing the frequency, and at a high audio frequency the current in the solenoid would have no effect on the plunger. Magnetic vane ammeters which employ this principle are usually designed to read current correctly with frequencies below 133 c.p.s. They are inaccurate at higher frequencies or may not deflect at all.

Some of the inexpensive meters—D.C. as well as A.C.—use the principle applied in the manner illustrated in Fig. *17a*. From our previous explanation, no trouble should be experienced in understanding how this simple ammeter acts. A scale is attached to the instrument, and by comparing to various known values of A.C. current, the instrument may be calibrated. The coil should be shielded from heavy magnetic fields of dynamo-electric machinery, dynamic loudspeaker fields and power choke coils; and this shield is built into the meter.

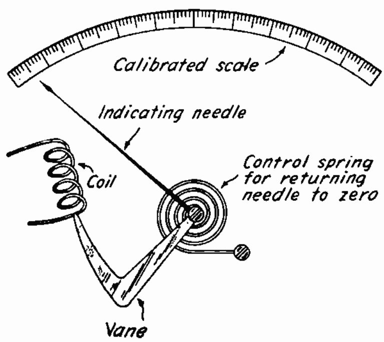


Fig. 17a

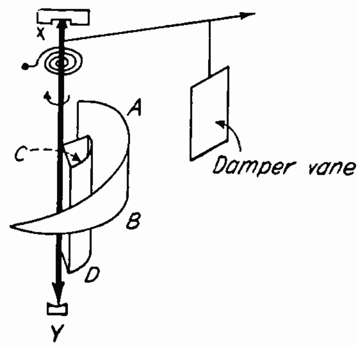


Fig. 17b

The original magnetic vane instrument invented by Weston is shown in Fig. *17b*. A thin piece of soft iron, *AB*, of triangular shape, is bent to cylindrical form, and placed firmly within a solenoid. Another piece of thin iron, *CD*, rectangular in shape but bent into a slightly smaller cylinder, is centered coaxially within *AB*, that is, having the same axis *XY*. The vane *CD* is rigidly attached to *XY*, which has a pointer also controlled by a restoring spring. When a direct current flows through the solenoid, both pieces of iron become magnetized. Edges *A* and *C* are of the same polarity and edges *D* and *B* are alike in polarity. Naturally they repel, and the only motion possible is in the direction of the arrow. The twist continues until balanced by the restoring spring. It will take a greater flux strength and more current in the solenoid to force a greater rotation. The fixed element *AB* is shaped to give as nearly as possible a uniform meter scale.

Figure *17c* shows the internal construction of an actual meter. Rigidly affixed to the needle is a flat rectangular aluminum damping vane which rotates in, but without touching, an airtight box. This air friction damper keeps the needle steady, on much the same principle as a tight-rope walker uses a large fan or umbrella to steady himself. As the current rises, falls and reverses, the damper keeps the needle pointing to the r.m.s. or effective value of current.

Because the current flows through a solenoid, a magnetic vane ammeter will have inductance as well as resistance. If the inductance is sufficiently large it will have a definite effect on its frequency range, and the method of extending its current range. For example, a typical high grade 0 to 1 ampere magnetic vane meter has a resistance of 1 ohm and an inductance of .0001 henries. At 60 c.p.s. its inductive reactance will be about .038 ohms. This is about 3 per cent of the resistance. For ordinary radio use this may not seriously upset the meter calibration. At 600 c.p.s. the reactance becomes .38 ohms, sufficient in itself (not considering the magnetic field response at this frequency) to throw the

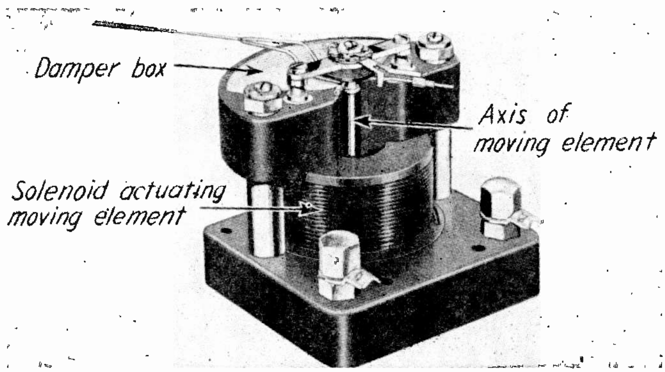


FIG. 17c

calibration off a considerable amount. An ammeter of the type shown by Fig. *17a* would have more of this inductive effect.

With these facts in mind, a shunt may be used at any low frequency, determined in a manner identical for a D'Arsonval unit, provided the inductive reactance is less than 4 per cent of the resistance and high precision is not required. Of course, a shunt may be used at any frequency with any ammeter, provided a special scale is supplied for that frequency and shunt. But in general, it is wiser to use step-down or so-called current transformers where the original scale times a multiplying factor is to be used in current range extensions. In general, a magnetic vane ammeter may be used on D.C. and A.C. up to 133 c.p.s. without much change in the calibration. As there are many modified magnetic vane ammeters in daily use, it is wise to follow the maker's limits of frequency and current range. However, they are all made to read correctly for 25, 40, and 60 c.p.s. currents.

ELECTRODYNAMOMETER A.C. AMMETERS

Although the electrician and radiotrician will generally, for high current measurements, use the magnetic vane type of instrument for commercial frequencies, at times an electrodynamometer ammeter may be of advantage. A typical construction is shown in Fig. *18.* Wattmeters operate on a similar principle, as well as the better grade of meters used for direct measuring of capacity and inductance. It is the laboratory A.C. meter. The principle of its action is quite simple.

The coil *A,* in Fig. *18,* which may be either circular or rectangular, is fixed. Within it is a similar coil, smaller, of course, so that it may rotate without touching, but yet quite close. Both coils are in series. When a current flows through coil *A*, a magnetic field is set up; the same current flowing through coil *B*, whose magnetic field is in the opposite direction, causes the movable coil to swing away. The larger the current, the greater the repulsion and the more the turning torque. Naturally the pointer moves until the magnetic twist is balanced by the back torque of the spiral springs. A damping vane, enclosed in a damper box, prevents the pointer from vibrating to and fro when a measurement is made.

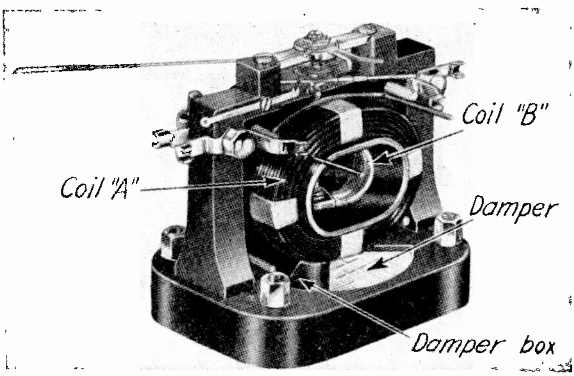


FIG. 18

When an A.C. current flows, the magnetic field will first be in one direction and then in the other. But the coils are in series, and the same current flows through each and repulsion always exists. Consequently, the turning torque is always in the same direction. Electrodynamometer ammeters *always* read r.m.s. values. Like the magnetic vane ammeter, they are only for commercial frequencies of 0–133 cycles and almost always are calibrated for 60 cycles per second. They must also be shielded from outside magnetic fields and be kept away from large steel construction work.

No iron is used in the moving system, consequently no magnetic hysteresis or eddy current losses take place. No magnetization of iron is necessary and fairly sensitive ammeters may be built. One manufacturer will supply electrodynamometer ammeters from 15 milliamperes to 10 amperes in semi-precision models. A 0–1 ampere model may have a resistance of ½ ohm and a 0 = 15 ma. meter a resistance of 1,400 ohms. As these ammeters are generally of the precision type, only current transformers may be used to extend their range. A typical current transformer is shown in Fig. *19,* and they do not differ in construction from ordinary transformers. They are merely designed to have negligible effect on the current to be measured, that is, have a definite turn ratio.

COPPER OXIDE RECTIFIER AMMETERS

Perhaps the copper oxide rectifier, plus a D.C. ammeter, is the most widely used device by servicemen and radio technicians, for A.C. measurements. You are well acquainted with the fact that half- and full-wave rectifiers will convert A.C. to pulsating D.C., and a D.C. meter will

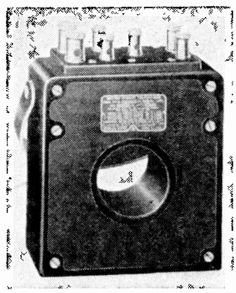


FIG. 19. A portable current transformer. Designed to be used on any A.C. 0 to 5 ampere ammeter with errors of less than ½% in the range of 25 to 60 c.p.s. Ammeter connects to the upper right two terminals. In the group of five posts, one is a common terminal of an internal tapped primary winding. The other four posts also connect to this primary winding and permit current extensions of 10, 20, 50 and 100 amperes. The internal primary winding is not used for currents greater than 100 amperes but by running one external loop of wire through the center opening which is carrying the current to be measured, the range is extended to 1,200 amperes; two turns extend it to 600 amperes; three turns extend it to 400 amperes; four turns extend it to 300 amperes; six turns extend it to 200 amperes.

record the average D.C. value. The tube is commonly used for this purpose, and the vacuum tube meter will be considered in another lesson. A crystal detector, of the fixed carborundum type, may also be used. But as the crystal is very unstable, these types are used without calibrated scales as A.C. current indicators rather than as accurate current meters. The copper oxide rectifier, which is used extensively in converting A.C. to D.C. for low voltage D.C. sources, is readily designed to have fair stability and similar sizes are readily duplicated in quantities. Typical meter rectifier units are shown in Fig. *20.* Of course, rectifiers can be obtained to handle any amount of A.C. current, but the usual radio practice is to design them for low current (1 to 5 milliamperes) and use them in combination with a sensitive D.C. microammeter for use as low current A.C. meters. For example, with the rectifier shown, when 1 milliampere of A.C. is fed to the rectifier, sufficient D.C. current is obtained to make a 0–500 D.C. microampere meter read full scale. The combination then is useful as a 0–1 milliampere A.C. meter. In fact, this is the usual set-up for basic milliammeters used in radio work, higher ranges obtained by the use of shunts.

The most commonly used connection is the full-wave arrangement shown in Fig. *20c*. During each alternation of the A.C. cycle, two elements allow current to pass, while one of the other two block the current flow in that portion of the rectifier. It is important that every element has the same resistance, otherwise unequal half waves will be rectified. The practical connections are shown in Fig. *20b*. The end and center terminals are the D.C. meter connections, the two terminals off center are for the A.C. connections. Extreme care must be exercised in soldering to lugs if supplied as in Fig. *20a*. Heating the elements destroys their resistance and rectifying characteristics.

A copper oxide rectifier may be made to work on any frequency, and if it were not for its capacity (capacity between adjacent elements) frequency would have no effect, that is, it would not introduce meter errors. In fact, elements as small as $\frac{1}{8}$-inch diameter have been made which work well at 2,000 k.c. For radio work, the copper oxide rectifier meter is generally used for power frequencies (25 to 133 c.p.s.) and audio-frequencies (35 to 10,000 c.p.s.). The unit shown in Fig. *20a* has been

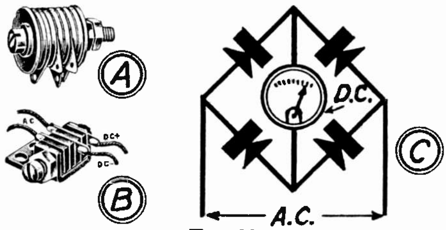


Fig. 20

designed for power line frequencies, but may be used at audio frequencies if only comparative readings are desired. The unit shown in Fig. *20b* is only about $\frac{1}{4}$-inch square and an ammeter calibrated on 60 c.p.s. may be safely used on any frequency up to 10,000 c.p.s. if 5 per cent accuracy will suffice.

The instrument must be used at ordinary room temperature. As heat has an appreciable effect on the calibration, it must be kept away from parts radiating heat. As the rectifier merely changes A.C. to pulsating D.C., and the D.C. meter reads average value, the copper oxide rectifier meter must be used to measure current of the same wave form used in its calibration. Sine wave currents are used in calibration, and if you measure A.C. currents with distorted wave forms only, rough measurements are provided. Correct readings are possible on commercial power currents, as they are invariably sine wave. Copper oxide rectifier meters, if used for measurements, should be checked at least twice a year, and the correction required noted and used in subsequent measurements. If too far off, it should be returned to the maker for correction. For precision measurements of A.C. power currents where precision of 2 per cent or better is required, magnetic vane and electrodynamometer meters should always be used.

As you probably know, the basic instrument in the multimeter used by servicemen is a 0–1 A.C. or D.C. milliammeter. A single D'Arsonval needle type microammeter and a copper oxide rectifier may be used. Using shunts and series resistors, extended current ranges and various voltage ranges are possible. The 0–1 D.C. milliammeter may also be used in the ohmmeter. Figure *21* shows a basic A.C.-D.C. milliameter circuit. A double-pole double-throw switch is used to change from A.C. to D.C. measurements, and one of the test leads is changed. When changing from A.C. to D.C., the full current passes through the meter, and a shunt, R_1 is used to reduce the sensitivity of the D.C. meter. This is done to have both A.C. and D.C. scales nearly alike and equal in range, a matter of simplicity in use. Resistor R_2 is used to prevent the low resistance of the D.C. meter placing too much of a load on the copper oxide rectifier, and reducing the load tends to make the A.C. scale more uniform. As all rectifiers of similar make do not have the same resistance when assembled, resistor R_3 is used in practice to make up for any

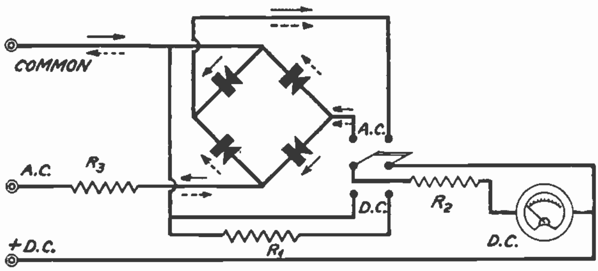


FIG. 21. Arrows show current flow

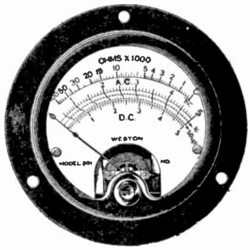


FIG. 22

difference in the desired total ohmic value of the entire meter circuit. A typical universal meter is shown in Fig. *22*, the meter incorporating only the copper oxide rectifier, with the associated resistors and controls provided in kit form.

The Cathode Ray Oscillograph

It is well to remember that the D.C. milliammeter, in fact, all D.C. meters measure average current; A.C. meters, such as the hot wire, the thermocouple, the magnetic vane and the electrodynamometer ammeters, are calibrated to read root mean square (that is effective) current values; and the rectifier type ammeters read average values of the rectified A.C. current they are intended to measure, but are calibrated to read in root mean square values. In radio work, there are conditions where it is equally as important to know the current wave form, as its average, root mean square and peak values. For this purpose the cathode ray oscillograph is perhaps the most useful and the most flexible instrument for use by the radio servicemen, laboratory or design technician. It is important that you know how it works.

It is a well-known fact that electrons are readily controlled by an electric field, and when electrons are in motion they may also be controlled by a magnetic field. Furthermore, it is well known that when a screen made of such material as calcium tungstate (a chemical also called willemite) is bombarded with high-speed electrons, the spot hit will emit light, simply because the energy of impact readily causes the electrons in the atoms on the screen to vibrate and emit by its own accord light peculiar to the material used (usually a green light). The screen is said to be fluorescent. Braun, prior to the year 1900, suggested a tube having a source of free electrons, which are sped up by an electrode, into a beam, and directed to a fluorescent screen. The beam is made to move over the screen influenced by the voltage to be analyzed,

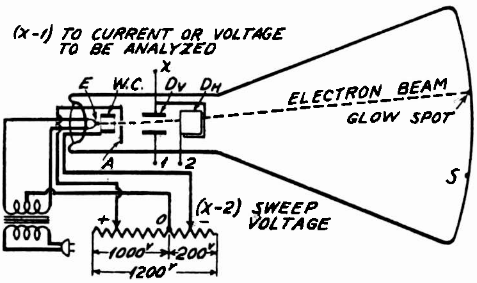


FIG. 23

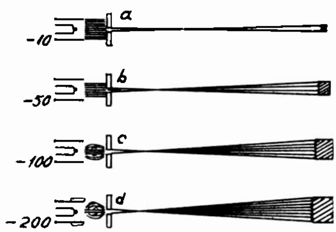


FIG. 24

and thus the wave form is traced. The beam will follow practically any variation regardless of its frequency, because it has negligible mass. In other words, the beam is a pointer of negligible weight. A modern cathode ray tube is nothing like the original Braun tube, even though the basic idea remains the same. Let us study the action of two modern cathode ray oscillographs.

The tube itself looks like a large glass funnel, totally closed, the air removed to a reasonable vacuum and in some cases a little argon gas introduced. Thus we have gas and vacuum type cathode ray tubes. The reason for the gas will be shortly explained. Although there are many types of cathode ray tubes, those used in the testers designed for servicemen may be considered as having: *1,* an electron emitter E (see Fig. *23*); *2,* an electron beam concentrator $W.C.$; *3,* an accelerating electrode or anode A; *4,* a vertical (up and down) set of deflecting plates D_V; *5,* a horizontal (side to side) set of deflecting plates D_H; and *6,* a fluorescent screen S. Although Fig. *23* shows one type of tube made and extensively used in the U. S. A., another popular make will shortly be considered in Fig. *27*.

The electron emitter E in Fig. *23* is a regular filament with its tip twisted or coiled, the tip covered with barium or strontium oxide which you should know emits electrons when heated. These small negative particles are drawn out by the anode A which is at a high positive potential, and the intensity of the beam (the space current) is increased by raising the anode or plate voltage. If the two sets of deflecting plates have no voltage difference applied, the beam will pass straight through the tube, impinge on the fluorescent screen (usually calcium tungstate) which then emits a green glow. The spot will be quite large and means are provided to control its size and brilliancy. This tube has a small amount of argon gas, which is ionized by the passage of the electrons. The freed electrons join the stream, leaving the heavy positive gas ions. Any of the electrons that stray from the beam combine with the positive ions, making neutral argon. Thus the beam is concentrated or held in a close bundle. The gas effect is fixed by the tube designer.

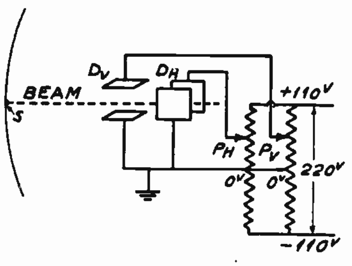


Fig. 25

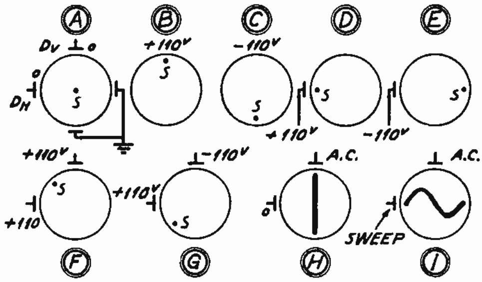


Fig. 26

The intensity of the beam may be increased by raising the anode voltage and such a control is often provided. To adjust the size of the spot a special electrode *W.C.* is introduced. It is a little cylinder which surrounds the electron emitters; its ends are open. Technicians call it a "Wehnelt" cylinder after its originator. This tube is made negative and the greater the negative charge the larger the spot and the greater the spot brilliancy. The negative charge converges the beam through the hole in the anode, as illustrated in Fig. *24*.

It was previously said that the deflecting plates are used to move the spot on the screen. Everything else said so far is primarily to obtain a sharp distinct spot on the screen. The deflecting plates do the work that makes the cathode ray tube so useful. Suppose a circuit as suggested by Fig. *25* is connected to the deflecting plates. If variable contacts P_V and P_H are placed at *0*, the electron beam will suffer no attraction or repulsion and the beam will impinge at the center of the screen as shown in Fig. *26A*. As P_V is adjusted to +110 volts, the spot will move upward and reach a maximum as shown in Fig. *26B,* because the electrons in the beam are attracted by the positive charged plate. If the upper plate is made negative by sliding P_v below *0*, then the spot will move down. Various positions are shown in Figs *26A to 26G* for various potentials on D_v and D_H, and the effects produced should be perfectly clear.

On the other hand, if a 60 c.p.s. voltage, 110 volts peak is connected to the D_v plates while no voltage is connected to the D_H plates, the spot will rapidly move up and down and appear as a line, as shown in Fig. *26H*. Because the up and down action is rapid, 60 complete cycles per second, a band or line instead of a movable spot as you might expect is seen. This condition exists because the eye cannot follow a change of more than 8 per second, although at least 15 changes per second are best for no flicker. This phenomenon is called persistence of vision. Now, with the 60 c.p.s. voltage applied to D_v, if you were to rapidly swing P_H from +110 to —110 in an irregular manner, by wiggling the knob, the spot which previously formed a straight line would also move sideways, and you would observe a series of confusing waves. But if you would produce a voltage that would rise uniformly from +110 to — 110, exactly 60 times a second, a single stationary cycle would appear

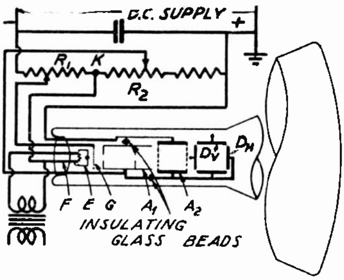


FIG. 27

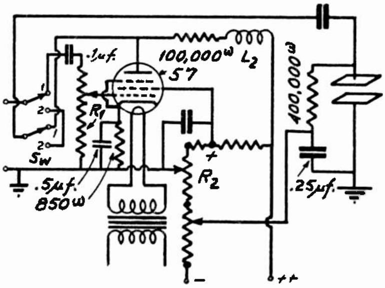


FIG. 28

on the screen as shown in Fig. *26I*. This uniformly rising voltage which is applied to D_H for the purpose of moving the spot sideways is called the sweep voltage and when the pattern stands still you have synchronized or locked the sweep voltage with the analyzed voltage which is applied to D_v. The method of producing the regularly changing sweep voltage will be discussed shortly, but now for a description of the other popular cathode ray tube.

Figure *27* shows a high vacuum cathode ray tube and the basic electrodes and controls. Again an electron emitter is used, but in this case a small ferrule with a recess covers the filament. Barium and strontium oxides are placed in the recess at *E*. The electrons are drawn out of the emitter by two anodes lettered A_1 and A_2. The latter are of special construction. They are two cylinders placed end to end. A_2 is larger than A_1. The first anode has two circular discs, one near each end. When these anodes are positively charged, they create an electrostatic field which bends the beam into a close bundle, and if either voltage is regulated the bundle of electron rays converge to a point on the fluorescent screen. This is referred to as electrostatic focusing and is quite often compared to a camera lens in action. Hence the anodes accelerate the electron stream and focus it to a point on the screen. Either anode voltage could be regulated, although A_1, which operates at a lower voltage than A_2, is usually controlled. R_2 in Fig. 27 is the focusing control.

The brilliancy of the spot is varied by the voltage applied to a circular disc with a centrally located hole called a grid placed near the electron emitter and between the latter and the first anode. By varying the negative bias (R_1 in Fig. 27) the space charge surrounding the cathode is aided or neutralized and the amount of electrons drawn over by the anode is under control. The vertical and horizontal deflecting plates are the same in action as for the first tube described.

Clearly the deflection of the spot on the screen from its center position is dependent on the voltage applied to the deflecting plates. In the average cathode ray tube made for service work the deflection is one

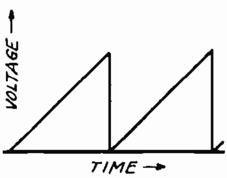


FIG. 29

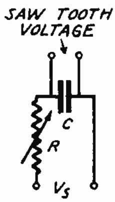


FIG. 30

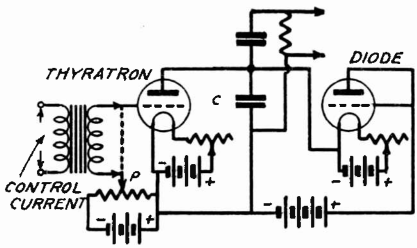


FIG. 31

inch for every seventy-five volts applied. As a matter of fact, this is the sensitivity rating of a tube. If the screen of the tube is about 1½ inches in radius, then voltages of 1.5×75 or 112.5 volts may be measured. If the spot could be initially moved down to the bottom by applying an initial 112.5 negative bias, then a voltage of 225 could be measured. As a rule, we want to measure A.C. voltages so we are limited to only one-half the total swing, or a peak value of 112.5 volts. Of course, deflections of ⅛-inch would be just about distinguishable, and this corresponds to about 10 volts. When we come to measuring the R.F. voltages in the I.F. stages, and the A.F. voltage at the output of the second detector of an ordinary receiver, especially when a small receiver input signal is applied, 10 volts is a large value. So some amplifying device is required in conjunction with the regular cathode ray tube.

To increase the sensitivity of the ordinary cathode ray tube, an amplifier for each pair of plates is needed. It is referred to as the horizontal or vertical amplifier, depending on which set of plates it feeds.

The usual amplifier is of the type shown in Fig. *28,* and contributes a voltage gain of about 40. With this amplifier the sensitivity of the cathode ray tube becomes 2 volts per inch, and voltage peaks of .25 volt are readily detected.

The circuit shown is one that is used in a popular cathode ray oscillograph tester. As you will recognize upon tracing the circuit, a resistance-capacitance coupler is used, the circuit designed to have linear amplification from 20 to 90,000 c.p.s. When switch *S.W.* is placed on contacts *1–1,* the amplifier is employed; when placed on contacts *2–2* the amplifier is not used. The potentiometer controls the degree of amplification, while R_2 is one means of shifting the spot for centering it on the screen.

To sweep the spot horizontally from left to right we need: *a,* a bias set the spot to the left (this is the usual practice); and *b,* a constant varying potential, as shown in Fig. *29,* which will rise in a regularly increasing manner from 0 to about 215 volts, then return to zero value immediately. Such a sweep voltage is called a saw-tooth voltage. The frequency of this saw-tooth wave should be variable from 15 to 20,000 c.p.s. for analyzing audio frequencies. Furthermore, whatever system is selected to produce this saw-tooth voltage should have some means of keeping it in step (synchronizing it) with the voltage or current we are analyzing.

A simple way of getting a fairly true saw-tooth voltage is to connect a condenser C and a resistor R, as shown in Fig. 30 to a D.C. supply. The condenser charges up, the process limited in time by the presence of resistor R. The rising voltage is tapped off of C. The time to reach about 60 per cent of the applied voltage is determined by the time constant of RC (C in microfarads times R in megohms). By varying either R or C the time to reach this value may be controlled. Now we must introduce an automatic condenser shorting switch to stop and start the process over and over again.

The solution to this problem is to be found in the modern gas triode, otherwise known as the thyratron or grid glow tube. When shown in a circuit diagram this tube is not distinguishable from an ordinary heater type triode, although the cathode is designed quite differently to withstand heavy bombardment of the gas ions produced. What is its unusual behavior which permits it to be used as an automatic switch? Assume first that it is connected in the usual way and with a fixed C bias. As the plate voltage is raised from zero, the plate current remains at zero until a critical plate voltage is reached. Then the plate current rises sharply and the plate-cathode resistance becomes very low. Now when the plate-cathode of a gas tube is connected to the charging condenser, the latter will be shorted at the critical voltage which is supplied by the condenser. What has the grid bias to do with this critical voltage? An important effect. If the grid bias is raised, so is the critical breakdown plate voltage; if it is lowered, then the critical breakdown voltage is lowered. Furthermore, once the breakdown takes place, the grid has no further control on the plate current until the next cycle starts.

A basic control and sweep circuit is shown in Fig. *31*, following the ideas just outlined. Condenser *C* is charged by battery *B* (or some D.C. supply) through the diode which is nothing more than a variable resistor, whose ohmic value is controlled by its filament current. The diode and the condenser control the basic frequency of the sweep. If the bias control *P* is varied so the negative bias is increased, it takes a larger plate voltage to break the tube down, consequently, the amplitude across *C* is increased and the frequency of operation is reduced. The peak voltage is limited by the D.C. supply. Furthermore, if the gas tube circuit is only

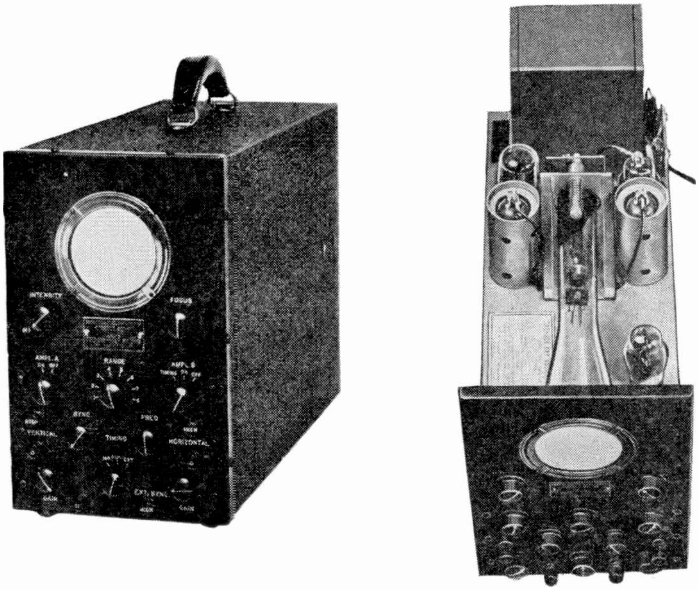


Fig. 32

adjusted for an approximate frequency (usually by adjusting its bias and plate voltage and altering the condenser capacity, the plate load resistor), the frequency of oscillation of the saw tooth voltage may be stabilized or synchronized exactly, by introducing into the grid bias circuit a small amount of the signal voltage to be analyzed. The sweep frequency is then controlled by the applied signal, all other factors essentially controlling the sweep voltage amplitude.

It should be mentioned that the diode in Fig. *31* is used as an automatic variable resistor that serves the same purpose as *R* in Fig. *30* to make the sweep voltage curve more linear than using a wire wound resistor. Usually an R.F. pentode is employed, the cathode and plate acting as the terminals of what is called a saturated tube resistance, and

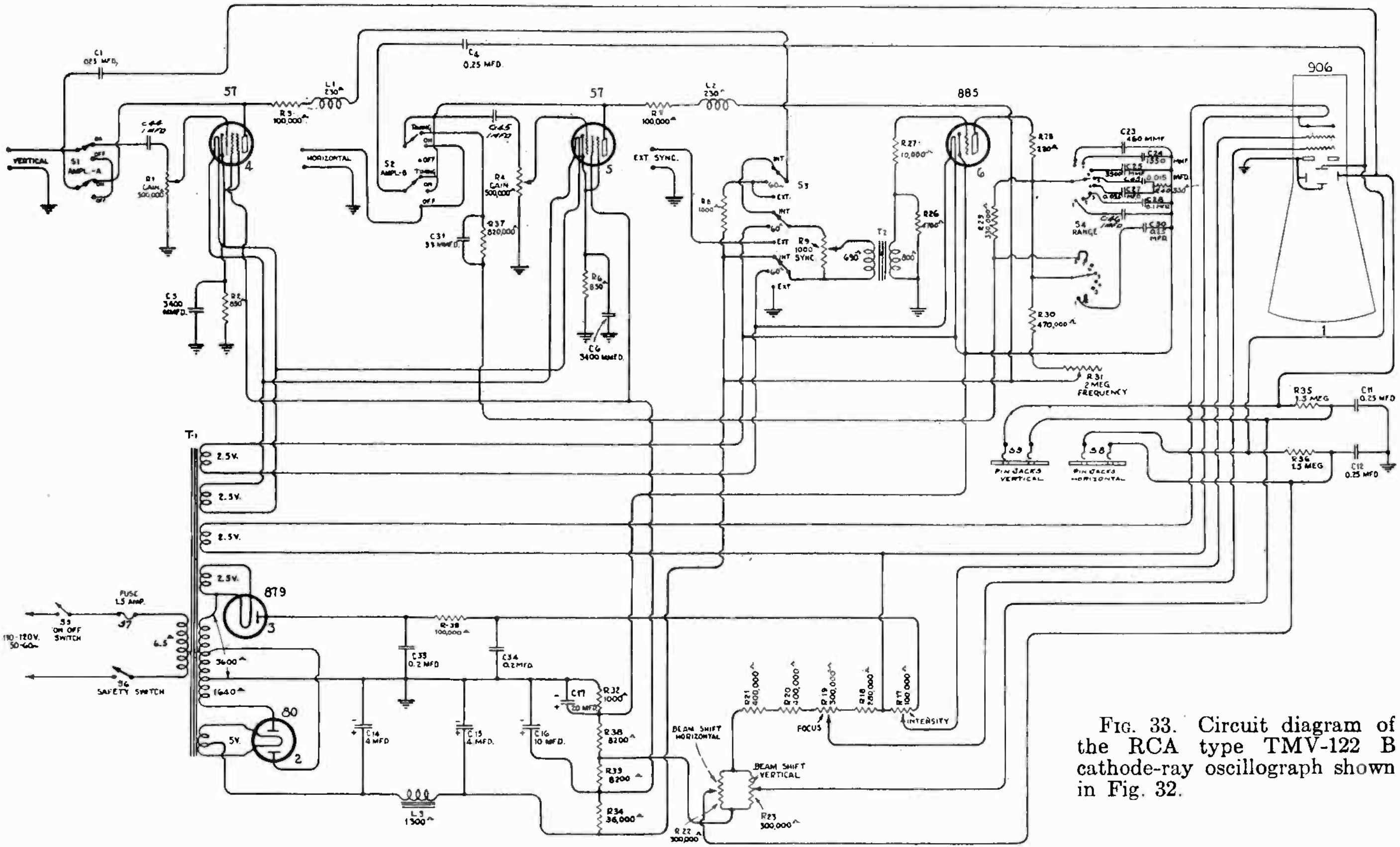


FIG. 33. Circuit diagram of the RCA type TMV-122 B cathode-ray oscillograph shown in Fig. 32.

its value of resistance controlled by varying the C bias applied to its grid. In other cases a tube type resistor and a regular resistor are used together, the latter variable.

The modern cathode ray oscillograph, a practical portable type as shown in Fig. *32,* is nothing more than a compact assembly of the cathode ray tube, amplifier and sweep circuits each with the essential controls, as in Fig. *33.* The AC voltage, or voltage obtained across a series resistor representing the current to be analyzed, is *connected to the vertical deflecting plates,* and when synchronization is obtained a true picture of the wave form is seen. By using a wire or transparent ruled paper screen over the end of the cathode ray tube, AC current and voltage measurements are readily made.

TEST QUESTIONS

Be sure to number your Answer Sheet 28FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your course, and the best possible lesson service.

1. How is a practical measuring instrument calibrated?
2. What is an ammeter made to indicate 1/1000 of an ampere called?
3. How may the range of an ammeter be extended?
4. If a meter has been extended five times, how would you mentally read the meter scale?
5. Would you use a hot-wire or thermocouple meter to measure R.F. currents of less than 20 milliamperes?
6. For measurements of A.C. power currents where precision of 2 per cent or better is required, would you use a copper oxide rectifier or magnetic vane ammeter?
7. Draw the circuit diagram of a basic A.C.-D.C. milliammeter circuit incorporating a copper oxide rectifier.
8. If a copper oxide rectifier meter is calibrated on sine wave currents, what accuracy would you expect when measuring A.C. currents having distorted wave forms?
9. What instrument is used when it is important to see the current wave form?
10. If a cathode ray oscillograph is to be used to analyze the wave form of an AC voltage, is the AC voltage applied to the vertical or horizontal deflecting plates?

VOLTAGE MEASURING DEVICES AND THEIR USE

29 FR-1

NATIONAL RADIO INSTITUTE

EST. 1914

WASHINGTON, D.C.

"WISHERS" AND "DOERS"

How often have you said, "I wish I had more money?" Thousands of times, possibly. But do you realize that if you are living in a town of, let us say, 5,000 inhabitants, there are exactly 4,999 others in your town who have said exactly the same thing about the same number of times?

And yet of these 5,000 "wishers," only about 100 are going to do something about it. The others are going to continue being "wishers."

Now, any man who shows enough "get-up-and-go" spirit to undertake this Course proves that he is not a mere "wisher." When you enrolled you showed that you wanted to be a "go-getter." Your job now is not to yield to the temptation to relax. You must spur yourself to new efforts every day—to new achievements. You must keep going forward on the Road you have mapped out for yourself.

Every lesson in this Course, every Radio job you have to work hard to get, is a step along this Road. So don't let yourself wish that the lessons were easier, or that you could become successful without studying, or that Radio jobs would come looking for you.

Stay out of the class of the "wisher" and stay in the class of the "Doer."

Don't forget that the "wisher" is a very unhappy individual because he is constantly thinking and worrying about what he does not have. The go-getter is so busy getting what he wants that he doesn't have time to be unhappy.

J. E. Smith.

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WASHINGTON, D. C.

1941 Edition

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Voltage Measuring Devices and Their Use

VOLTMETERS

The voltage across any resistance can easily be determined if we know the current through the resistance and the value of the resistance. From Ohm's law, voltage is equal to current multiplied by the value of the resistance. Thus we have a direct method of calculating the potential difference (P.D.) between any two points in a circuit, regardless of the kind of voltage, D.C., or A.C. of any frequency, provided always there is no source of e.m.f. connected within the two points.

From all of this we can derive a very simple method of measuring voltage—that is, by placing a known resistance in series with a calibrated milliammeter, across the voltage difference to be measured.

Fig. 1 shows a supply delivering current to a load. It can be any kind of a supply delivering current to any kind of a load—a motor, a resistance or a resonant circuit. Naturally there is a voltage across the load. Let us say we want to measure it. Its resistance or impedance is not known; therefore an ammeter in series with it would not enable us to compute the voltage. However, by placing between the two terminals whose P.D. is to be measured, a known high resistance in series with a milliammeter, we can obtain sufficient information to compute the P.D. Of course a D.C. milliammeter must be used for D.C. voltages and an A.C. milliammeter for A.C. voltages.

We know that the voltage across the load is the same as the voltage across the resistance R in series with the milliammeter. But we know the value R, and our meter will indicate the value of the current I. The voltage is simply $I \times R$.

A voltmeter is nothing more than an arrangement of this sort. Sometimes you hear a voltmeter referred to as a "potential galvanometer" because all it amounts to is an ammeter used to measure potential differences.

Any milliammeter may be used as a voltmeter, provided the combined resistance of the meter and the external known resistance is high enough to prevent all but a negligible amount of current flowing between the two terminals from being "side-tracked" through the meter. When measuring D.C. potentials, a D'Arsonval type of ammeter is used. When measuring A.C. voltages, an electrodynamic ammeter is usually used, although magnetic vane types of instruments may be used. For audio frequency voltages, a thermocouple or oxide rectifier ammeter is frequently used, while for measuring R.F. voltages a hot wire or thermocouple milliammeter is commonly used. These various types of voltmeters will be discussed separately in the following pages.

D.C. VOLTMETERS

One of the most important things to remember in connection with voltmeters is that, when a voltmeter is connected across two terminals, the voltage across them is not the same as it was before the voltmeter was connected. A consideration of a resistance load with a definite value of current flowing through it as in Fig. 2 will show why this is true. Let us say the load is a 1,000 ohm resistance and there are 100 milliamperes flowing through it—that is, the meter A indicates .1 amp. The P.D., from Ohm's law, should be $.1 \times 1{,}000$ or 100 volts.

But suppose a voltmeter having a resistance 5,000 ohms

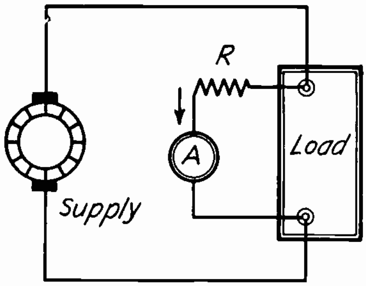


Fig. 1

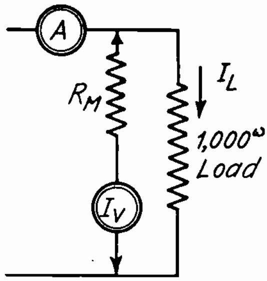


Fig. 2

is connected across this load. What will be the voltage across the load? We are going to assume that the current has not changed—that A still reads .1 amp. This current divides between the voltmeter and the load, 5/6 of it going to the load and 1/6 through the voltmeter. Then $V = 1/6 \times 5{,}000 \times .1 = 83.3$ volts—and our reading is approximately 17 per cent off.

On the other hand, if the voltmeter had a resistance of 100,000 ohms, the part of the total current going through the load would be equal to $100 \div 101$ and the part through the voltmeter would be $1 \div 101$. In this case $V = \frac{1}{101} \times 100{,}000 \times .1$ or 99.1 volts and the error is less than 1 per cent.

Now what does all this mean to us? It means simply that for close voltage measurements, our voltmeter should have an extremely high resistance in comparison to the resistance of the circuit in which the potential difference is being measured.

A voltmeter of the type commonly used by Radio-Tricians for measuring D.C. voltages is shown in Fig. 3a. This is a portable type of voltmeter. The panel type of voltmeter is illustrated in Fig. 3b. Meters of this sort are designed for use in measuring voltage across voltage dividers of power packs and C bias resistors and are designed to have a resistance of 1,000 ohms for every volt on the scale.

You will note in Fig. 3c that the voltmeter has four terminals, one marked minus (–), one +10 volts, one +250 volts and the other +750 volts. The (–) terminal is a common terminal. Thus connecting two points of a circuit whose potential difference is to be measured across this terminal and the +10 terminal, we can read voltages up to 10 volts. Between (–) and +250, we can measure up to 250 volts. And between (–) and 750 we can read up to 750 volts.

FIG. 3a

FIG. 3b

When the 0–10 volt scale is used, the voltmeter resistance is 10 × 1,000 or 10,000 ohms; when the 0 – 250 volt scale is used, the resistance is 250,000 ohms and, for the 750 volt scale, the resistance is 750,000 ohms. For every volt in the range there is a resistance of 1,000 ohms. By using Ohm's law we can immediately see that the meter is a 1 milliampere (.001 amp.) meter, for:

$$.001 \times 250{,}000 = 250 \text{ volts, etc.}$$

The voltages read with a meter of this type would be only 2 per cent off if the resistance of the load across which measurements are taken was 1/50 the resistance of the meter. Therefore, to maintain this degree of accuracy for the various scales, the 0–10 scale should not be used when measuring across loads greater than 200 ohms; the 0-250 range should not be used when measuring across loads greater than 5,000 ohms and the 0–750 range should not be used on loads greater than 15,000 ohms. Incidentally, a typical, well-made, modern voltmeter is guaranteed to be accurate within 2 per cent when measuring voltages of the order of 100^v—that is, if the meter reads 98 or 102 volts, the meter is as accurate as it is guaranteed to be.

Even though voltages measured across very high resistances, such as detector resistors, C bias and plate resistors, with a voltmeter of this type will be in error, the indications are still useful in radio service work, for variations up to 10% in voltages are often permissible in radio circuits.

Anyone can adapt a milliammeter for use as a voltmeter by the use of the proper external resistance.* For best results a 0–1 milliammeter is used, having a resistance between 10 and 15 ohms. Its scale should preferably be divided into 100 divisions. Now suppose we wish to read 0–10 volts. What is the value of the resistance we shall have to use with it?

When placed across 10 volts a current of 1 milliampere must pass through it for full scale deflection. Then the required voltmeter resistance will be calculated from the formula $R = \frac{E}{I}$

In this case $R = \frac{10}{.001}$ or 10,000 ohms. As the meter has only 10 or 15 ohms resistance, this can be overlooked and the external resistance may be made exactly 10,000 ohms. However, should the meter resistance be above 15 ohms, say for example 500 ohms, it would not be negligible and the external resistance would have to be in this case (10,000-500) 9,500 ohms.

If the voltmeter is to read from 0–250 volts, the external resistance would be (neglecting the meter resistance) $R = \frac{250}{.001}$ or 250,000 ohms. If we already have a 10,000 ohm resistor connected to the 10 volt terminal, we can connect a 240,000 ohm resistor in series with this as shown in Fig. 3c (resistor R_{250}.) Then the additional resistor is called a *multiplier*. In Fig. 3c, three multipliers are shown — R_{10} = 10,000 ohms; R_{250} = 240,000 ohms, and R_{750} = 500,000 ohms. All these resistors are standard precision devices. With the use of these multipliers the meter has three scales, a 0–10 scale in which case each main division represents 1 volt, a 0–250 volt scale in which case each main division represents 25 volts, and finally a 0–750 scale in which each main division represents 75 volts.

* By the use of the proper shunts and multipliers, a single 0–1 milliammeter can be made to measure various ranges of current and voltage.

It is essential when using multipliers to measure high voltages that the resistance be not concentrated in one bobbin as in Fig. 4, but that it be spread out—and for this purpose several bobbins in series are used. This makes it easier to insulate the resistance wires from each other.

In order to prevent moisture from entering the coils, they are boiled in wax. And to prevent sparking when the terminals of the voltmeter are removed from the circuit under test, the resistances are non-inductively wound. This is accomplished by winding two wires, side by side, from two different spools. The resistance is started by cleaning the insulation from the end of both wires at one end and soldering them together. Then the correct amount of wire is wound on the form and the two open ends form the terminals of the multiplier. The resistance, of course, is twice the resistance of one length of wire.

Very similar construction methods are used in building non-inductive resistance units for A.C. voltmeters.

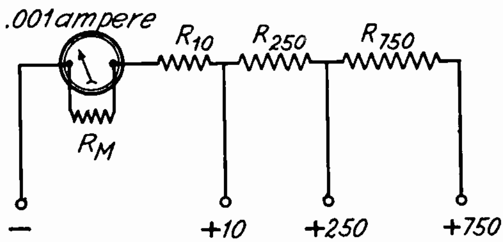


FIG. 3c

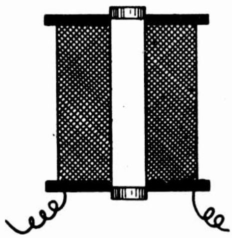


FIG. 4

ELECTRODYNAMOMETER VOLTMETERS (A. C.)

The A.C. voltmeter is basically an A.C. milliammeter. There are several types of A.C. milliammeters that may be used, but the most desirable for accurate measurements is of the electrodynamic type. Here we meet new problems, for the electrodynamic meter has inductance besides resistance and this must be taken into consideration in calculating the series resistance required.

When a resistance is placed in series with an inductance, the voltage across the system is equal to:

$$V_M = I_M \times \sqrt{R^2 + (2\pi f L_M)^2}$$

where V_M is the voltage across the arrangement

I_M is the current through the voltmeter indicated by the milliammeter

L_M is the inductance of the meter
R is the resistance of the voltmeter and the multiplier's resistance (non-inductive)

In the formula the expression $2\pi f L_M$ is the reactance of the milliammeter, and, if it can be made small in comparison with R, we can neglect it. In the design of an A.C. voltmeter, this is always made as small as possible.

An electrodynamometer milliammeter designed to have very little inductance may be connected in series with precision multipliers. However, instruments of this kind are expensive and are not used for ordinary radio work. They are generally used in laboratories and wherever precision is essential.

In radio work for measurement of A.C. power supplies, A.C. voltmeters having comparatively low sensitivity are used. The D.C. permanent magnet voltmeter discussed in the previous pages has a sensitivity of 1,000 ohms per volt. A typical precision electrodynamometer voltmeter designed to read from 0 to 300 volts has a total resistance of approximately 6,600 ohms—that is, a sensitivity of 22 ohms per volt. And so measurements cannot be made on high resistance loads without considerable error. While satisfactory for measuring filament and line voltages, these instruments are not sufficiently accurate for high voltage measurements across power pack transformers.

Electrodynamometer voltmeters are suitable only for low frequencies—up to about 150 c.p.s. Beyond this frequency the inductance, the resistance, eddy currents and capacity effects in the coils alter the calibration and readings are not reliable.

Fig. 5 shows a typical electrodynamometer voltmeter of the precision type. This instrument is shielded from external magnetic disturbances and the needle is damped. The moving coil system is attached to a fan-shaped aluminum disc which revolves between two permanent magnets. The eddy currents that are induced in it tend to keep the needle deflection steady.

A.C. voltmeters are built to measure up to 750 volts r.m.s. Where higher voltages must be measured, a step-down "potential" transformer is universally used.

MAGNETIC VANE VOLTMETERS

A magnetic vane voltmeter is nothing more than a magnetic vane milliammeter in series with a known resistance. However, the presence of iron in the center of the solenoid affects the inductance of the milliammeter considerably. Therefore instruments of this type are calibrated at known A.C. voltages of a certain frequency and are designed only for use at that frequency. In general, however, it is true that a 60 c.p.s. meter may be used with frequencies from 25 to 130 c.p.s. with little error.

Moving vane voltmeters for high voltage measurements are

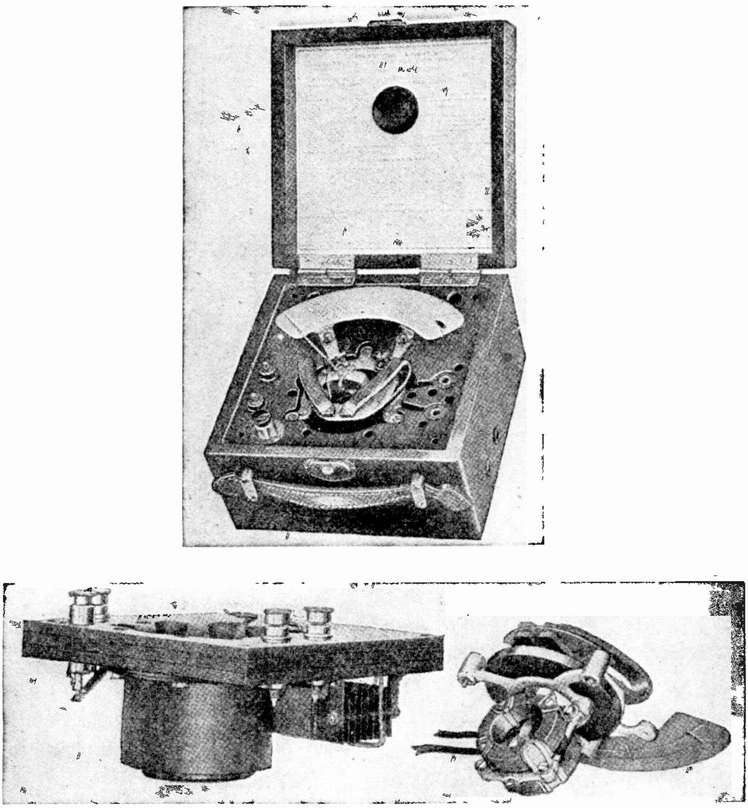


FIG. 5

fairly sensitive. A typical A.C. voltmeter of this type commonly used in radio work is shown in Fig. 6. A 0–4 A.C. voltmeter has a sensitivity of 10 ohms per volt; a 0–300 voltmeter has a sensitivity of 166 ohms per volt.

In cases where meters of this type are designed for sensitivity at large voltages, the exciting solenoid is wound with many turns of wire. For very high voltages a step-down transformer is used.

The A.C. voltmeters in most set analyzers are of the magnetic vane type. It should be remembered that they are not intended for use as D.C. voltmeters. Furthermore, they are intended to measure voltages only at commercial power frequencies.

COPPER OXIDE A.C. VOLTMETERS

A copper oxide milliammeter, in series with one or more known resistances, provides a valuable A.C. voltmeter. This type of instrument is used chiefly for measuring A.C. voltages where great sensitivity is desired. It consists of the copper oxide rectifier system arranged in a diamond (bridge) formation, feeding a sensitive D.C. microammeter connected across the bridge. The other two ends of the diamond, in series with a

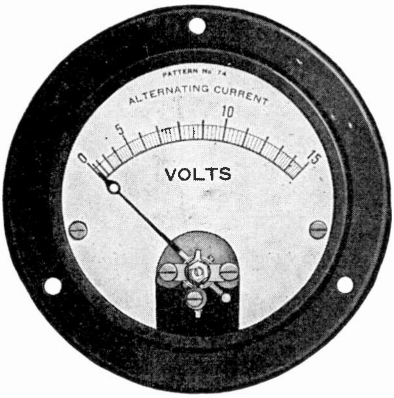


FIG. 6

resistor or resistors, connect across the load whose potential difference is to be measured. A typical arrangement is shown in Fig. 7. With properly chosen multipliers connected as shown, the device would measure voltages from 0–900 in convenient steps. For radio work this type of A.C. voltmeter is replacing all other types.

For ordinary frequencies, 25 to 500 cycles, the impedance of the milliammeter system is negligible and the series resistances merely serve to drop the voltage across the milliammeter bridge arrangement to a given value. As the A.C. current being measured is full-wave rectified as shown in Fig. 8, the D.C. microammeter reads the average value of the half sine wave. Therefore calibration should be made with the use of pure sine wave generators and not on ordinary A.C. unless it is known to have a sine wave. Voltages read with an instrument of this sort are always r.m.s.

Although instruments of this type are very sensitive, they are subject to considerable error. As they are calibrated on pure sine waves, the presence of harmonics in the current being measured will tend to throw the readings off. Then, too, the rectifying property of the copper oxide element decreases with increasing frequency at the rate of 1 per cent for every 2,000 c.p.s. And the rectifier is affected by room temperature. However, if the wave form of the current being measured is a fairly pure

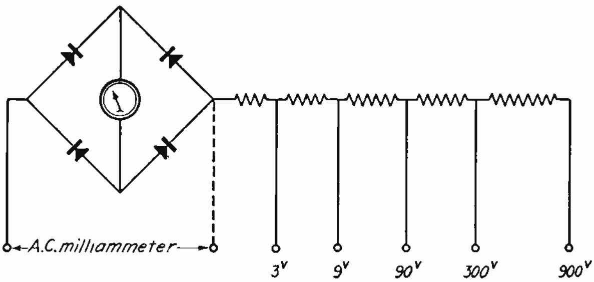


FIG. 7

sine wave, accuracy will be within 5 per cent of full scale reading.

A sensitivity of 1,000 ohms per volt is possible with this type of meter.

By a simple switching arrangement the D.C. meter can be disconnected from the rectifying system and used for D.C. measurements. In this case a different scale will have to be used, or a

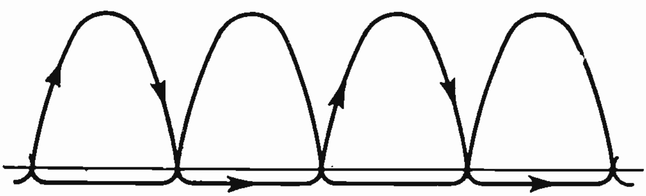


FIG. 8

resistance must be placed in shunt with the meter to compensate for the r.m.s. calibration.

THERMOCOUPLE VOLTMETERS

When it is required to make exact measurements of A.C. voltages at audio or radio frequencies, the thermocouple voltmeter is the best device to use. A voltmeter of this type is simply a thermocouple milliammeter in series with a non-inductive, non-capacitive resistance which limits the current flow through the meter to a value sufficient to provide full scale deflection.

For R.F. and A.F. measurements, a thermocouple milliammeter is generally used without any multipliers and the voltage is measured in the following manner: The meter is placed in series with the resistance load across which the voltage drop is to be measured—the value of the resistance must be known. By multiplying the value of current flowing by the resistance of the load, the voltage can be determined. If the square of the current measured is multiplied by the resistance, the power output is obtained.

The meter is calibrated in milliamperes for convenience and voltages must be calculated. A meter of this sort is especially useful for measuring hum output or the signal output of power audio tubes. The connections for this purpose would be as shown in Fig. 9.

Radio men who do considerable experimental work usually find it advisable to invest in a thermocouple milliammeter having a range of 0–120. There are available several instruments of this type that are accurate to within 2 per cent on all frequencies ranging from commercial A.C. to radio frequencies. The resistance of these instruments is around 5 ohms. Then an r.m.s. voltage of .6 volt ($.120 \times 5 = .6$ volt) will give full scale deflection.

For exact laboratory work where R.F. voltages of the order of a few millivolts must be measured, microammeters must be used. Fortunately, suitable microammeters are available, and these, too, work on the principle of the thermocouple.

HIGH VOLTAGE MEASUREMENTS

Where potentials of 2,000 volts and more are to be measured, it is general practice to use capacity (electrostatic) voltmeters.

Although voltages this high are seldom used in ordinary radio work, it is well worth understanding the underlying principles of the devices used to measure them.

As you know, when a condenser is charged, one plate is positive and the other is negative. You also know that opposite charges attract. And here you have the principle of the electrostatic voltmeter, as illustrated in Fig. 10.

The force existing between the two plates, one fixed, the other movable and attached to the indicating needle, depends on the voltage and the capacity of the attracting system.

Voltmeters of this type are calibrated by means of voltages whose r.m.s. values are known.

In Fig. 10, terminals T_1 and T_2 are for low range readings. The multipliers used to extend the range are condensers. For each multiplier a separate calibration is necessary.

One big advantage capacity voltmeters have is that they

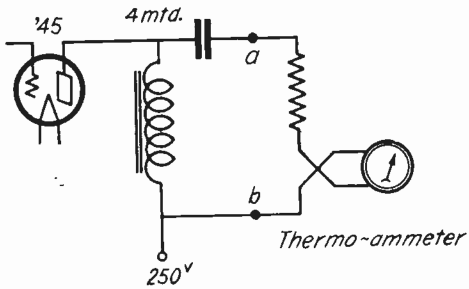


FIG. 9. For exact power measurements the resistor in series with meter should equal the recommended load for the tube whose output is measured. For relative output indication a value of 2 to 4 thousand ohms will suffice in most cases.

require little or no current after the initial deflection and they eliminate the necessity for step-down potential transformers. They may be used for A.C. or D.C. measurements over wide frequency ranges.

It might be mentioned that extremely delicate capacity voltmeters for low voltage work have been built, but their use is confined to laboratory work.

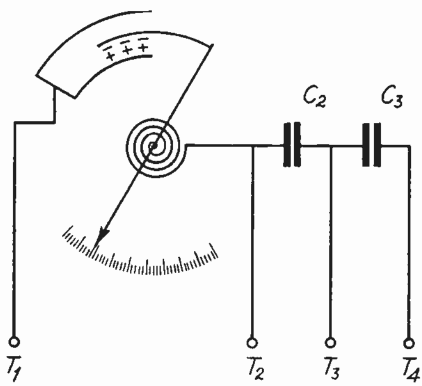


FIG. 10

Another device for the measuring of extremely high voltages, of the order of 10,000 to 200,000 volts (10 to 200 kilovolts), makes use of a spark gap. For voltages from 50 kv. to 200 kv. the spark gap consists of two spherical brass electrodes. The distance between the spark gap at the break-down point can be measured and the voltage determined from a calibration curve.

Then corrections for certain weather conditions, temperature, and humidity should be made for closer results.

Devices of this sort fill a practical need in the making of insulation tests. Extremely high voltages are required—higher than can be measured by the ordinary voltmeter. In practice the gap is adjusted so that it will break down at a certain high voltage. Then the voltage is stepped up by means of transformers until the gap breaks down, which is then an indication that the voltage is sufficiently high for use in testing insulation and dielectric resistance.

The spark gap breaks down at the peak voltage and not the r.m.s. Remember that the peak voltage is 1.41 times the r.m.s. value.

For voltages between 10 and 50 kv., a spark gap of which the electrodes are two No. 00 sewing needles may be used. When these are 11.9 millimeters apart, the gap will break down when 10 kv. are impressed across it. When break-down occurs with the electrodes 41 millimeters apart, 30 kv. are indicated; and when 118 millimeters apart, 60 kv. are indicated.

HOT WIRE AND OSCILLOGRAPH VOLTMETERS

The universal practice of using non-reactive resistors in series with a milliammeter for voltage measurement applies also to the hot wire milliammeter and the oscillograph milliammeter when used for voltage readings. When the reactance is negligible, the voltage V is always equal to $I_a \times (R_m + r_a)$—that is, the sum of the ammeter and the multiplier resistance multiplied by the current through them. Remember this fundamental rule and you will never have any difficulty in determining the proper type of voltmeter to use for any particular purpose.

The hot wire milliammeter in a voltmeter arrangement is used for the same purposes as the thermocouple voltmeter—for audio and radio frequency measurements. Voltmeters of the hot wire type, however, are much less expensive than thermocouple voltmeters, and for this reason they are used much more extensively in ordinary servicing work.

Voltages can be photographed or actually "seen" by the use of a sensitive oscillograph galvanometer in series with a pure resistance.

Neither the hot wire nor the oscillograph voltmeter requires a more complete discussion here than has been given, for in a previous lesson we studied the hot wire ammeter and the oscillograph galvanometer in detail. Their adaptation for use as voltmeters requires merely that they be connected across the potential difference, in series with a known resistance.

It should be perfectly clear by this time that most voltmeters and ammeters are current indicating devices; the only difference is that one is calibrated to read in volts, the other in amperes.

VACUUM TUBE VOLTMETERS

One of the most valuable devices for use in radio laboratories and at the service bench is the vacuum tube voltmeter, often called the "thermionic" voltmeter. It is as important a piece of equipment as the thermocouple milliammeter.

The great advantage of the vacuum tube voltmeter is that it draws negligible current from the circuit in which a potential difference is being measured, which makes it especially valuable for measuring voltages in the grid circuits of R.F. ampli-

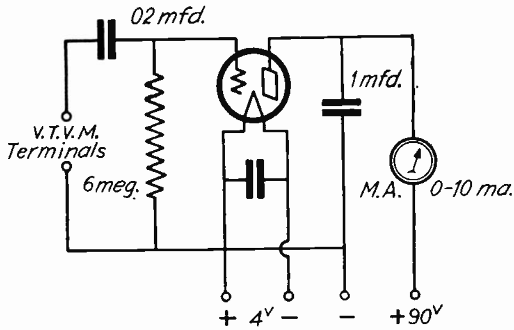


Fig. 11a

fiers, or voltages across resonant circuits having extremely small current outputs. The ordinary V.T.V.M. (vacuum tube voltmeter) will read A.C. voltages over a range of 0 to 12 volts. On the other hand, voltmeters of this type can be made to read 1 or 2 microvolts, and by the use of shunts they can be used to indicate current values. Just recently announcement was made of the development of a V.T.V.M. that will measure a current flow as small as 60 electrons per second. The sensitivity of this device can be appreciated if we recall that 6.3 million, million, million electrons flowing through any cross-section of a wire per second constitute only one ampere of current flow.

Basically the V.T.V.M. is an A.C. detector tube operated with a *C bias* or a *grid leak-grid condenser* control. The grid leak type is more sensitive than the C bias type of V.T.V.M.—it may be adjusted to read from a few microvolts to 7 or 8 volts.

Fig. 11a shows the schematic diagram of a typical *grid leak-grid condenser* V.T.V.M. In operation the filament is kept at 4 volts in order to prolong the life of the tube. The filament voltage is kept constant by means of a filament ballast or by manual adjustment (a rheostat and a D.C. voltmeter).

While the V.T.V.M. circuit shown in Fig. 11a is not extremely sensitive, it is quite rugged and extremely useful.

A V.T.V.M. is usually calibrated on 60 cycle current by the drop wire method. A toy transformer with a 110 to 10 volt step-down is used to supply the calibrating potential. Across the secondary is connected a low resistance potentiometer. Between the slider contact of the potentiometer and one of the other terminals is connected a 0 to 10 volt r.m.s. 60 cycle voltmeter. See Fig. 12. The V.T.V.M. to be calibrated is connected to the two free terminals. Then by adjustment of the potentiometer arm, the voltage fed to the V.T.V.M. can be changed in known steps, and for each voltage, the plate current of the tube is noted and recorded. A calibration curve is then made from the recorded values as shown in Fig. 11b.

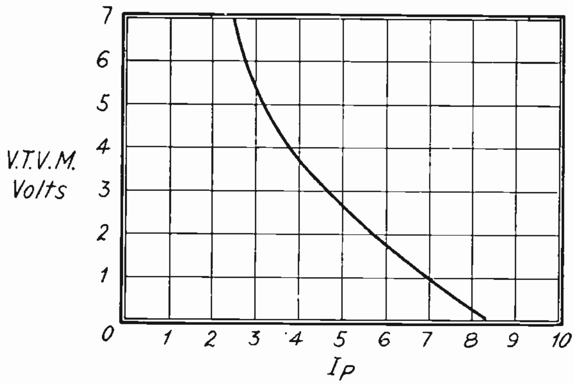


Fig. 11b

Notice the low plate current when high A.C. voltages are measured. The explanation of this is that as the A.C. voltage applied to the grid swings positive, electrons are drawn to the grid. During the negative swing the electrons which have not escaped make the negative swing greater than it would be normally. This causes the plate current to drop and results in a decrease in the average plate current. The grid leak is provided to allow the extra electrons to leak off.

In very sensitive V.T.V.M.'s, microammeters are used to measure the plate current. In this case it is very important that the D.C. component of the plate current be balanced out so that the microammeter records only current changes. The manner in which this is accomplished is shown schematically in Fig. 13. The meter used is a 0 to 100 microammeter. A shunt should be used in connection with this meter to make it less sensitive until the steady plate current is exactly balanced out.

A 0 to 8 D.C. voltmeter is necessary for checking the filament voltage which should be kept always at constant rated value. A 45 volt *B* supply is used, connected through the meter in the plate return. Between the *B*— and the *A*+ connections there are a variable 10,000$^{\omega}$ resistor, a 10,000$^{\omega}$ fixed resistor and a 400$^{\omega}$ variable resistor. This arrangement supplies a voltage which bucks the plate voltage and provides a means of balancing out part of the D.C. plate current.

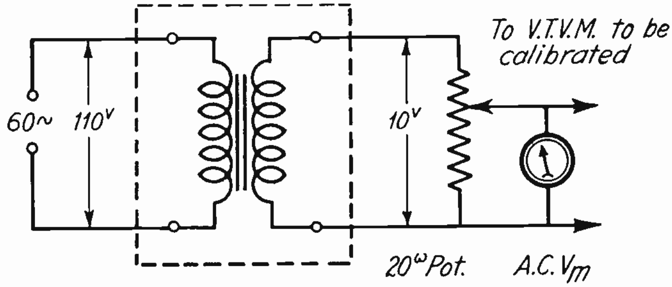


FIG. 12

The variable resistors are adjusted so that with no A.C.

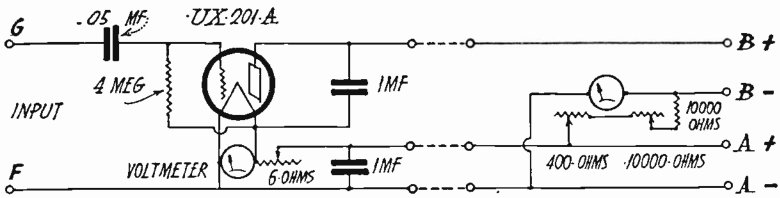


FIG. 13

applied to the input of the device and with a shunt connected across the meter, approximate zero microammeter reading is obtained. Then the shunt is removed from the meter and the 400$^{\omega}$ variable resistor adjusted so that the microammeter reads exactly full scale, in this case 100 μa.*

* If the meter is adjusted originally to zero, actual calibrations and readings should be made with the meter terminals reversed. Otherwise the meter will read down-scale.

After most of the D.C. plate current has been balanced out in this way, the V.T.V.M. is ready for calibration. This should be done by the use of known A.C. voltages. The same arrangement is used as in Fig. 12 except that a fixed drop wire is connected between the vacuum tube voltmeter and the low voltage side of the transformer. Fig. 14 shows the details. Notice the 100 ohm resistor in series with a 900 ohm resistor. Of course the voltage across the smaller resistor will be 1/10 the total voltage—that is, 1/10 of a volt if the total voltage is 1 volt. A 1 ohm resistor in series with a 999 ohm resistor will (a 1000^{ω} resistor will be satisfactory) reduce the voltage to .001 volt.

Naturally, as the grid swings positive, some grid current will flow and the measurement of terminal voltages will be slightly affected. For ordinary purposes, however, the current drawn is negligible. The calibration curve will be like Fig. 11b.

Where it is absolutely essential that the grid shall draw no

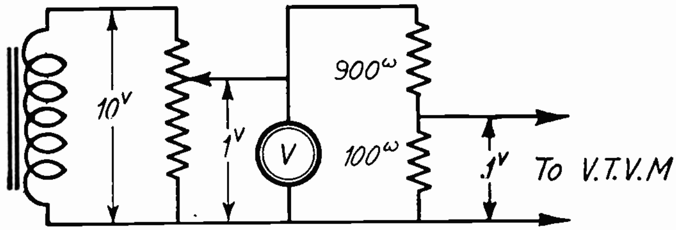


FIG. 14

grid current, the *C bias type* of tube rectifier is used. Fig. 15 shows how the apparatus used in Fig. 13 can be adapted for use as a C bias V.T.V.M. In order to prevent grid current flow, the bias must always be greater than the peak value of the voltage being measured. It is always safe to assume that the C bias should be 1½ times the r.m.s. value of the measured voltage. For example, if we want our V.T.V.M. to measure up to 4 volts r.m.s., the C bias should be 1.5×4 or 6 volts. In this case the bucking adjustment is made so the meter reads *zero* when no A.C. voltage is applied to the V.T.V.M. The calibration curve will show increased plate current as the applied measured voltage is increased.

Higher voltages may be measured by using larger grid biases and larger plate voltages. The relation of C bias voltage to plate voltage should always be such that the tube operates at the point of greatest curvature of its E_g-I_p characteristic. The use of less sensitive meters as shown in Fig. 11a will increase the range up to the limit set by the bias voltage.

The range of a V.T.V.M. may be extended by using a drop wire * as shown in Fig. 16. A 99,000 ohm non-inductive, non-capacitive resistor is placed in series with another resistor of 1,000 ohms. The V.T.V.M. is connected across the 1,000 ohm resistor while the terminals 1 and 2 are connected to the termi-

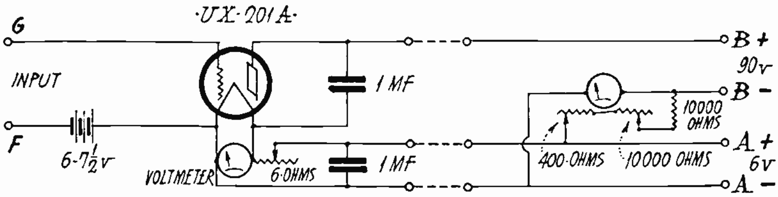


Fig. 15

nals at which the voltage is to be measured. If the V.T.V.M. normally reads up to 10 volts, with the drop wire the range will be extended 100 times (100,000 ÷ 1,000) ; that is, it will now read up to 1,000 volts.

If in any A.C. circuit there is a resistance, whose ohmic value is known, the current through that circuit may be measured with a V.T.V.M. by measuring the voltage across the resistance

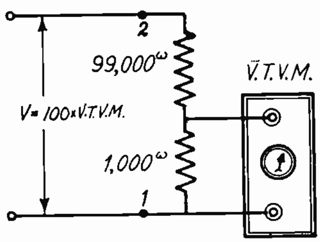


Fig. 16

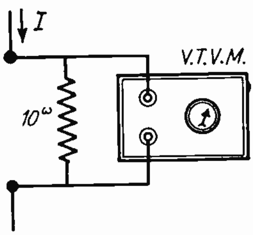


Fig. 17

in the circuit and calculating the current by Ohm's law. A known resistance may be introduced if it does not materially alter the circuit condition. For example, if a sensitive V.T.V.M. is shunted across a 10 ohm resistor in the circuit, as in Fig. 17, and a reading of .01 volt obtained, the current in the circuit will be from Ohm's law I = .01/10 or .001 ampere.

If vacuum tube voltmeters are properly by-passed, they can be safely used to measure voltages at either audio or radio frequencies with little error, even though they were originally calibrated at 60 cycles.

* Another expression for a voltage divider.

MEASURING RESISTANCE

If a voltage of known value is connected across a resistor whose value is not known, and the current through the resistance is measured, the resistance in ohms can be calculated from Ohm's law. See Fig. 18a for the set-up. A D.C. supply is used, and the meters are also D.C. instruments. It is not essential that the voltmeter have a very high resistance or that the ammeter have a very low resistance if the proper corrections are made.

It should be noted in Fig. 18a that the voltmeter does not read the true voltage across the resistance although the ammeter does read the correct value of current flowing through it. The true voltage across the resistor is equal to $V - (I \times R_1)$; that is, the voltmeter reading minus the current through the meter multiplied by the meter resistance. Of course, if the meter

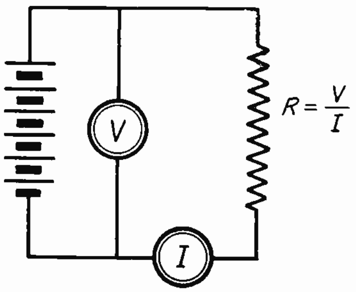


FIG. 18a

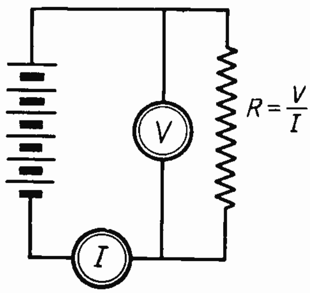


FIG. 18b

resistance is known, it is possible to measure the total voltage drop across R and the meter, calculate the total resistance, and subtract the resistance of the ammeter. To make the necessary corrections the resistance of the ammeter will have to be known or measured. Then the value of the unknown resistor will be the total resistance, calculated from the voltmeter reading, minus the ammeter resistance.

An alternate method of measuring resistance is shown in Fig. 18b, where the voltmeter is connected directly across the unknown resistance and the ammeter is placed next to the voltage supply. In this case the voltage reading will be the true voltage across the resistor, but the ammeter will not read the true current through the unknown resistor for the voltmeter is in parallel with it. That is, the ammeter will read the current through the resistor plus the current through the voltmeter. To find the true current, subtract the voltage reading divided by the voltmeter resistance from the ammeter reading. In other words, the true $I = I_{AM} - \frac{V}{R_{VM}}$.

Most voltmeters have a resistance of from 200 to 1,000 ohms per volt. If you are using the 10 volt scale of a 200 ohm per volt meter, the voltmeter resistance will be this factor multiplied by 10—in the case mentioned, 200 × 10 or 2,000 ohms.

The resistance is always the true voltage across the resistor divided by the true current through it.

In Fig. 18a, if a low resistance ammeter is used, the error is negligible and correction is not necessary. In Fig. 18b, if a high resistance voltmeter is used, the error will be negligible and correction unnecessary. When both low resistance ammeters and high resistance voltmeters are used, either connection 18a or 18b may be used and corrections are unnecessary.

For measurement of widely varying values of resistance,

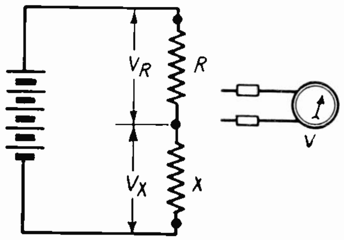


Fig. 19a

Fig. 19b

multi-range meters are necessary. In this case, the range which permits ¾ to full-scale deflection should be used.

Fig. 19a illustrates what is known as the double voltmeter reading method of measuring resistances. A single high grade multi-range 1,000 ohm per volt voltmeter is used in conjunction with precision resistors of various values—1, 10, 100, 1,000, etc., ohms. The known resistor *R* and the unknown resistor *X* are connected in series across the voltage supply. Voltmeter readings are taken across both resistors. Let these readings be represented by V_R and V_X. Then the value of the unknown resistor is:

$$X = R \times \frac{V_X}{V_R}$$

For exact measurement, R should be chosen as near the value of *X* as possible—that is, V_X and V_R should be approximately equal.

Fig. 19b shows an external view of a typical non-inductive precision resistor, commonly used by service men when measuring resistors by this method.

Often in practical work it is sufficient to determine only the approximate values of resistances. For example, at the service work bench it is not often necessary to be able to measure resistances exactly, but a means of making rapid measurement is desirable. For this purpose ohmmeters are used. As shown in Fig. 20, an ohmmeter is simply a milliammeter calibrated to read directly in ohms. Incidentally, any milliammeter can be used as an ohmmeter by means of a calibration curve made by plotting meter readings against known values of resistances.

The ohmmeter shown in Fig. 20 consists of a 0–1 milliammeter of the D'Arsonval type in series with a 3 volt source of e.m.f. (usually a flash-light battery) and a 4,000 ohm rheostat. Two test prods are included.

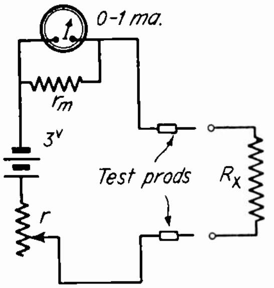


FIG. 20

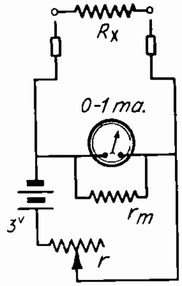


FIG. 21

When the test prods are held together, the meter, the variable resistor and the 3 volt battery are all in series. With the variable resistor adjusted for 1 mil.* of current flow, assuming the battery voltage is exactly 3 volts, the combined resistance of the circuit, including that of the resistor, the meter and the battery, will be 3 ÷ .001 or 3,000 ohms. Now when the prods are connected across a resistor to be measured, the current that flows will be equal to 3 ÷ (3,000 + R_X). and as we are interested in computing the resistance R_X, we may arrange this in formula form:

$$R_X = \frac{3}{I} - 3{,}000$$

For example, if I is .8 mil. (.0008 amp.), a 750 ohm resistor is indicated. If I is .5 mil. (.0005 amp.), 3,000 ohms are

* Milliampere.

indicated. If .2 mils. (.0002 amp.), 12,000 ohms; .1 mil., 27,000 ohms, etc. With this information we can plot a calibration curve or the scale of the meter may be calibrated directly in ohms.

Because of the circuit arrangement, the ohmmeter in Fig. 20 is called a series type ohmmeter. It is an ideal ohmmeter for measuring large resistances.

For measuring low resistances rapidly and with a fair degree of accuracy, a shunt type of ohmmeter is used, shown schematically in Fig. 21. The meter used is a milliammeter.

Assuming that a 0–1 milliameter is used, when the prods are separated the resistor r should be so adjusted that 1 mil. of current flows and the meter needle deflects full scale. As r will

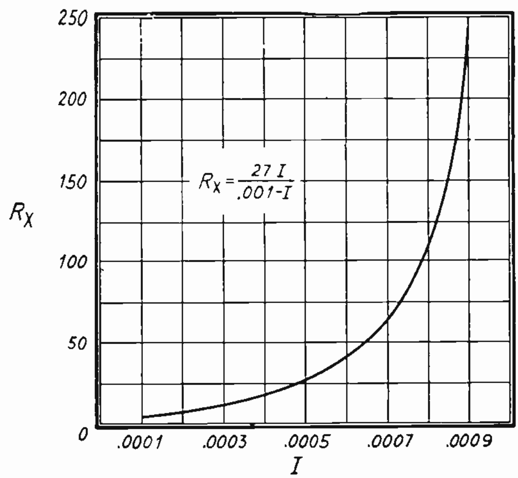


FIG. 22

be about 3,000 ohms and r_m, the meter resistance, will be about 25 ohms, it is evident that the prods can be held together, shorting the meter, without affecting the current flowing in the circuit—it will still be .001 amp.

Knowing this, we can work out the principle of the operation of our shunt-ohmmeter. The voltage across the meter will be $r_m \times I$—that is, the resistance multiplied by the current indicated by the meter. This voltage will also act across the unknown resistor R_X which is connected between the prods of the ohmmeter and will be equal to the resistance R_X multiplied by the current flowing through R_X. Knowing that the main line current is .001 amp., the current through R_X will be .001 less the current through the meter. Therefore its voltage is

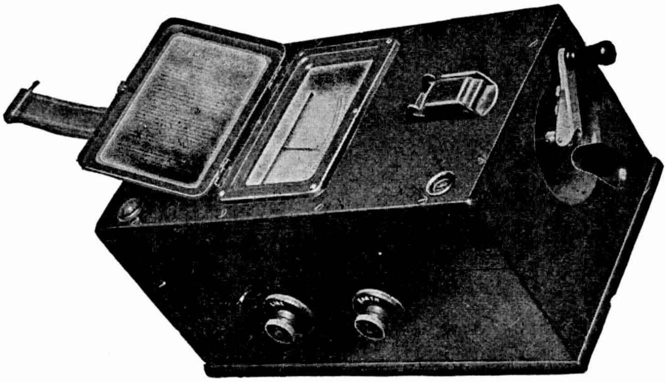
$(.001\text{-}I) \times R_X$, and this is, of course, equal to $I \times r_m$. From this we develop the formula:

$$R_X = \frac{r_m \times I}{.001 - I}$$

A calibration curve for an ohmmeter using a Weston 0–1 ma. type 301 panel milliammeter which has a resistance of 27 ohms, is given in Fig. 22.

MEGGERS

The name "megger" is simply a contraction of "megohm meter." Thus meggers are devices for measuring resistances in terms of megohms—that is, extremely high resistances such as leakage resistances and resistances of insulating material.



COURTESY OF THE JAMES G. BIDDLE CO., PHILA., PA.

FIG. 23

These measurements are often extremely valuable as in the case of paper condensers, in which the measurement of the leakage resistance is an indication of the useful life of the condenser. The windings of power chokes must be well insulated from the iron cores. In transformers the primaries must be well insulated from the secondaries. The leakage resistance of an insulating bushing on a variable condenser is an indication of the efficiency of the support.

The "megger" insulation testing and high resistance measuring instrument shown in Fig. 23 consists essentially of a special direct reading ohmmeter of the permanent magnet-moving coil type, mounted in a suitable case along with a hand driven generator.

The diagram in Fig. 24 shows details of the magnetic circuit and electrical connections. *M* represents permanent bar magnets. Between the poles at one end is the armature *D* of the hand-driven generator, and between the poles at the other end is the moving system of the ohmmeter.

There are three coils, *A*, *B* and *B′* (in Figs. 24 and 25), fastened rigidly together. The assembly is free to rotate about the axis. There are no controlling springs, but current is led to the coils by flexible copper leads having the least possible torsion, so that the pointer "floats" over the scale when the generator is not in operation.

Coils B and B' are connected in series with resistance R across the generator potentials. They constitute the "control" element of the ohmmeter and give the instrument the property of indicating correctly, regardless of the exact value of the generator potential or the strength of the permanent magnet. These coils are so connected that when a potential is applied they tend to turn the axis in a counter-clockwise direction until they assume a position where their rate of cutting the magnetic flux is zero—that is, directly opposite the gap in the C-shaped iron core about which B' moves. The pointer then indicates infinity on the scale. This is the reading obtained when a megger is operated with nothing connected across the terminals marked *earth* and *line*.

The moving coil A, which for the most part is in a uniform electromagnetic field, is in series with the generator, the ballast resistor R' and the unknown resistance which is connected to the terminals earth and line. The electrical connections are such that this current tends to turn the axis in a clockwise direction, in opposition to that of B and B'. When the earth and line terminals are

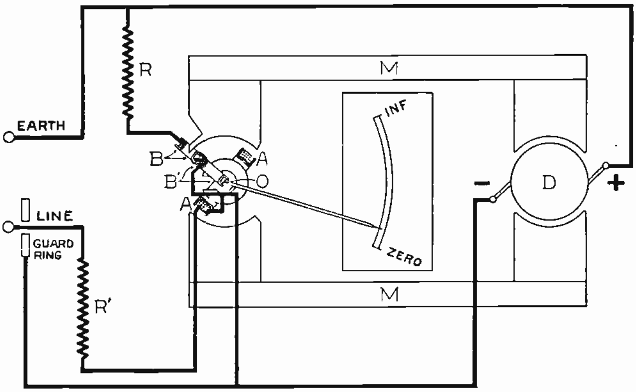


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FIG. 24

short circuited, the current produced by A overpowers that of B and B' and the pointer stands over the point marked zero.

Now if a high resistance is connected across the external terminals, the current from the generator has two paths over which it can flow. Therefore it divides, part passing through the control coils B and B', and part through coil A in series with the resistance under test. The result is that the opposing currents of the two elements balance one another at a point on the scale corresponding to the value of the resistance under test. In this way, also, by using known values of resistance, the scale can be calibrated.

The ordinary megger operates at a voltage of 500^v, which is kept fairly constant even though it is supplied by a hand driven generator, by means of a special control. When necessary, the voltage supply to the device under test may be reduced by increasing the resistance of R' (by means of a rotary switch). However, with each change of R', the scale readings change. For simplicity, these scales are usually arranged so that readings are 1/10 and 1/100 of the original scale values. A typical megger reads from 2 to 1,000 megohms with alternate scales from .2 to 100 megohms or 20,000 ohms to 10 megohms.

There is on the market a small portable megger which has been proven highly useful in the installation of centralized radio systems, sound recording and amplifying systems, public address and sound picture equipment. In many cases, proper testing of insulation resistances will mean a saving of considerable time and trouble.

MEASURING POWER

Determination of the power delivered to a load in a D. C. circuit is a comparatively simple matter. All we have to do is to measure the voltage across the load, the current through it, multiply these two values together, and we have the power in watts. Of course the voltmeter used should have a very high resistance as compared with the resistance of the load of which measurements

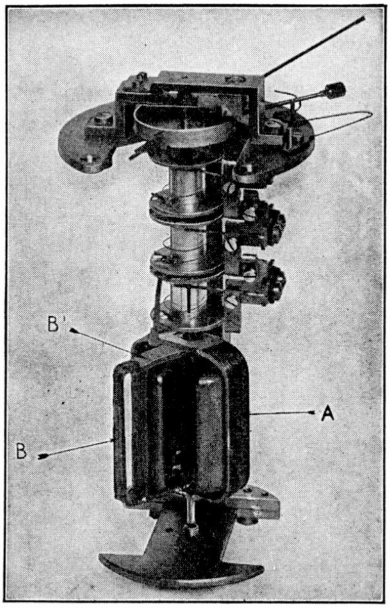

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FIG. 25

are taken, and the ammeter must have a very low resistance so that the values read are true values. Thus power in watts is always equal to the true I multiplied by the true V.

In A.C. circuits, however, the determination of power is not so simple. The volts multiplied by the amperes as measured between two terminals do *not* represent the power used by a load or delivered by two terminals because the *power factor* must be taken into consideration. As you know, the power factor is a measure of the phase condition.

If you measure the A.C. voltage across a load in an A.C. circuit, and the current through the load, the product of the two ($I \times V$) is the *apparent* power—not in watts but in volt-amperes (V.A.) or kilovolt amperes (KV.A.). For example, if a voltage of 110 was measured and the current was found to be 1.5

amperes, the apparent power delivered to the load or absorbed by the load would be 1.5 × 110 or 165 volt-amperes (.165 KV.A.).

To find the power in watts, the apparent power must be multiplied by the power factor. That is, $P = V \times I \times$ P.F.

In Fig. 26 the voltage V leads the current I by a certain number of degrees which we call θ. The actual power is $I_E \times V$. I_E, you will observe, is obtained

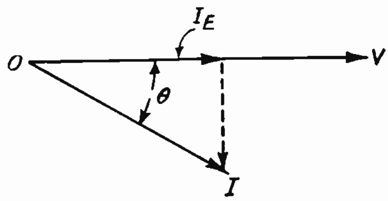

Fig. 26

by drawing a perpendicular line from the end of line I to the line OV. The ratio of I_E to I is the power factor; that is, P.F. $= I_E \div I$.

Unless we know the power factor exactly, to measure the real power we must use a wattmeter, an instrument almost identical in appearance and construction to an electrodynamic ammeter.

Fig. 27 illustrates the working principle of the wattmeter. There are two coils, one within the other. These coils are only inductively coupled. The

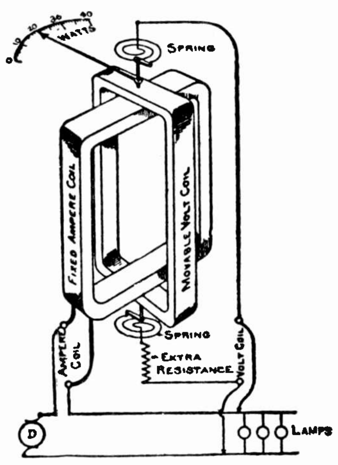

Fig. 27

inner coil is made of very few turns of relatively heavy wire. The outer coil is made of many turns of fine wire and is in series with a high resistance. When a device of this sort is used to measure power delivered to a load, the inner coil is connected in series with the load and its magnetic field will be proportional to the current through the load. The current that flows through the outer coil will be proportional to the voltage of the load and its magnetic field will be proportional to the load voltage.

The two coils are set at right angles to each other. When current flows through them, their magnetic fields interact. The outer coil is free to move and, when the magnetic fields about both coils interact, the outer coil is twisted; that is, it is given a mechanical torque, to a degree depending on the relative intensity of the two fields. The twist is balanced by a coil spring and the deflection of the outer coil is indicated by a pointer moving over a graduated scale.

As the "twist" is proportionate to the product of the magnetic field of one coil and the magnetic field of the other, and as these fields are determined by the voltage across and the current through the load, naturally the amount of the twist indicates power in watts.

The device is so designed that only *effective* current and voltage contribute to the twisting effect. Therefore the wattmeter is a true power indicator. When an instrument of this sort is magnetically shielded and provided with air or magnetic eddy current dampers, it can be used to measure either D. C. or A. C. power up to 150 cycles with little error.

The wattmeter is hand calibrated against known powers. These instruments are obtainable in ranges of a few watts to many kilowatts. Milliwatt meters are also available for the measurement of small powers. Of course any wattmeter must be designed to carry the voltage and the current of all loads to

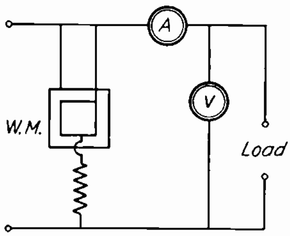

FIG. 28

be measured. For testing the A.C. power delivered to a radio receiver, a wattmeter capable of withstanding a voltage of 150 and capable of carrying 3 amperes maximum current is required.

Sometimes it is necessary to determine the power factor of an A.C. supply. To find the power factor, a set-up as shown in Fig. 28 must be used. There is a wattmeter, an A.C. voltmeter and an ammeter connected as shown. The voltmeter and ammeter will enable us to calculate the apparent power and the wattmeter will tell us the true (effective) power. Then the power factor will be found from the formula:

$$\text{P.F.} = \frac{\text{effective power}}{\text{apparent power}} = \frac{W}{V \times I}$$

OUTPUT INDICATORS

Often in testing at the service work bench or in the laboratory it is necessary to measure the power output of a radio receiver. In the early days of Radio about the only check on the power output was obtained by listening to the output of the loudspeaker. But since then Radio has advanced to become an extremely exact science, and exact methods of measuring the power output were developed.

Along with A.C. receivers came the problem of hum, and in the development of means to reduce the hum output it became necessary to have accurate means of measuring the amount of hum in the receiver output.

We will now explain to you how power output and hum measurements are taken. Let us work with a typical output stage—a pair of '45 type tubes in push-pull. As a loudspeaker is not a constant impedance device, we disconnect it and connect in its place a suitable resistor.

As the total tube impedance is 2 × 1,750 or 3,500 ohms, a 3,500 ohm resistor connected across the output will result in maximum power output. It is this output we want to measure.

A single 45 tube will deliver a maximum of 1.6 watts of power and two in push-pull deliver about 4.0 watts. The current through the load resistance may be calculated from the formula $P = I^2R$—the power to be wasted as heat. With a maximum output of 4 watts,

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{4.0}{3,500}} = .032 \text{ amp., approximately (32 ma.)}$$

From this we can see that a 0 – 50 milliampere thermocouple ammeter in series

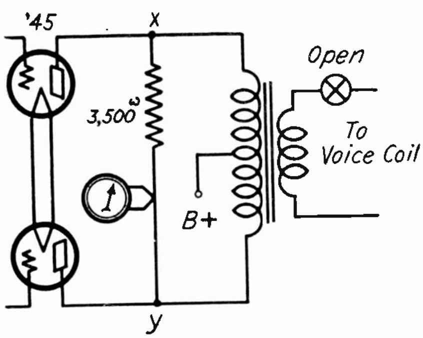

FIG. 29a

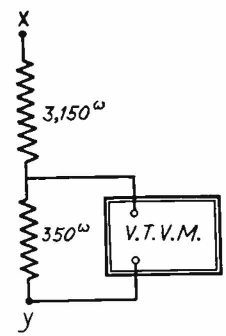

FIG. 29b

with the load resistance or a vacuum tube voltmeter will indicate the current through it and enable us to calculate the actual power output up to the maximum value.

The output voltage is $I \times R$; and the power output will be I^2R. A thermocouple ammeter or a V.T.V.M. should be used as these are the only instruments that can be used with precision on low and high frequencies and in this case the frequencies may be as low as 60 cycles or as high as 10,000 cycles.

When measuring hum output a 0–1 milliampere meter should be used as the amount of hum that should be present is less than .15 volt. When hum measurements are taken, it is absolutely essential that the antenna and ground be disconnected so that no R.F. signals are picked up.

Thermocouple ammeters are expensive and extremely delicate. For this reason the vacuum tube voltmeter is a more practical device for measuring output powers. Fig. 29b illustrates the use of a V.T.V.M. which may be connected across the output of two '45 tubes in push-pull (terminals x and y). With a V.T.V.M. connected as shown across only 350 ohms of the 3,500 ohm load resistor, the V.T.V.M. will read 1/10 the entire voltage across the resistor. Our vacuum tube voltmeter will be of the type that will read from 0 to 15 volts, and its readings will have to be multiplied by 10 to give the true voltage.

The power lost in the load will be equal to $E^2 \div R$.

A vacuum tube voltmeter is accurate at any audio or radio frequency.

Often it may be desired to get a rough approximation of the power output with the receiver in operation. In this case a vacuum tube voltmeter can be connected directly across the voice coil of the speaker. A 0–5 volt instrument may be used.

Another simple method involves the use of a fixed carborundum detector in series with a 0–10 milliammeter. When this method is used, a high variable resistance should be connected in series with the meter to prevent the meter needle from flying off scale. A device working on this principle serves only as an output indicator, and measurements are not accurate.

A copper oxide voltmeter may also be used, but here, too, results will not be very accurate, due to the presence of harmonics. A device of this sort used in laboratory testing where single frequencies are measured will be accurate to within 5 per cent.

TEST QUESTIONS

Be sure to number your Answer Sheet 29FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. How can a milliammeter be used to measure voltage?
2. Suppose you have a 0-5 milliammeter having a resistance of 200 ohms and you want to use it to read 0-10 volts, what value of *external* resistance (in ohms) would you use?
3. What do we call an external resistance used with a voltmeter to increase its range?
4. Explain why an Electrodynamometer voltmeter is not suitable to measure high A.C. frequencies.
5. Show by a diagram how a thermocouple voltmeter is connected in a circuit for output power and hum voltage measurements.
6. Name the two types of V.T.V.M.'s.
7. How can the V.T.V.M. be used to measure current in an A.C. circuit?
8. What is an ohmmeter?
9. What type of ohmmeter would you use for measuring low resistances?
10. What instrument would you use to find the true (effective) power in an A.C. supply circuit?

RESISTANCE, CAPACITY, INDUCTANCE AND FREQUENCY MEASUREMENTS

30FR

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE VALUE OF HAVING VARIED INTERESTS

Don't go stale! Keep a fresh, active interest in everything you do. Only by doing this can you get your full measure of benefit from your work, from your play, from exercise, from study.

When you work or when you play—work hard, play hard. When you study, throw your whole brain, every part, into your studies.

Then when you stop working, or playing, or studying—let go. Drop it. Forget about it. Turn to something else.

Not everybody knows that the best vacation is merely a complete change from what you have been doing. Loafing is not a vacation—it is merely boredom.

There is nothing better for an office worker after hours than a brisk walk, a swim or a round of tennis. There is nothing better for an outdoor worker than a quiet hour with a book or a good newspaper, or listening to the Radio.

Exactly *what* you do is not important provided it is *different*. Change your pace. Don't do the same thing all the time. Vary your life as much as you can. Vary your interests. Cultivate a general, intelligent interest in the world of which you are a part. You will find it helps you to keep a fresh and alert outlook on life.

Keeping alert keeps you young. Keeping interested keeps up your energy. Interest creates energy in you. A curious mind learns more readily than one with a narrow outlook. The more you learn, the more easily you learn.

Study your Course—but keep room in your mind for other things. Concentrate on Radio—but concentrate on your regular work, on your play, on your other desirable or necessary activities when it is time for them. Keep a fresh outlook. Keep growing. Don't go stale.

J. E. Smith.

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Resistance, Capacity, Inductance and Frequency Measurements

WHEATSTONE BRIDGE

Where precision is desired in measuring resistance, methods more exact than the ohmmeter or the voltmeter-ammeter methods are needed. A "differential" arrangement of comparing resistances has been known for over a century and today it is applied not only to the measurement of resistance, but inductance and capacity, for conditions of direct current flow, as well as A.C. of high and low frequencies. There are many successful adaptations of the basic Wheatstone Bridge, as the original method is called.

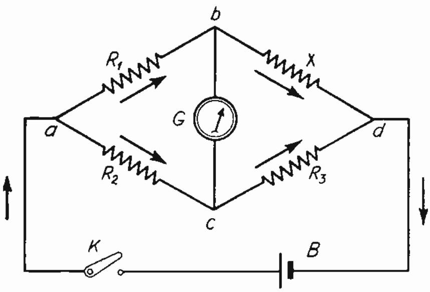


FIG. 1

Study closely Fig. 1. Four resistances are arranged in diamond or elongated rectangular formation. Three of these resistances are precisely known values which we shall refer to as R_1, R_2 and R_3; the fourth is the unknown which is to be measured. Resistances R_1, R_2 and R_3 are variable resistors but are not like rheostats which are so common in practical radio work. We shall see how these are constructed and arranged shortly. One or more dry cells, B, are in series with a key K, and connected to terminals a and d of the diamond formation. Between b and c, a sensitive D.C. galvanometer or microammeter of the portable or laboratory type is connected. For the sake of convenience and as a protection, various adjustable shunts (not shown in Fig. 1) are connected across the galvanometer so that the latter may be made less or more sensitive.

When key K is depressed, a current flows from a through R_1, through X, to d and into the battery line again. Likewise a current flows from a through R_2 to c through R_3 to d and joins the other current when entering the battery line. A potential difference, or a voltage drop if you prefer, exists across R_1 and across R_2. If they are of different values, a current will flow through the galvanometer G. Resistance R_3 is now adjusted until the galvanometer reads zero, when the key is closed, thus indicating the Wheatstone bridge is perfectly balanced, because at zero reading the voltage across R_1 equals that across R_2 and the voltage across X is equal to that across R_3. No current flows through G and the current I_{ab} through R_1 is equal to that which flows through X; while the current I_{ac} flowing through R_2 is equal to the current flowing through R_3.

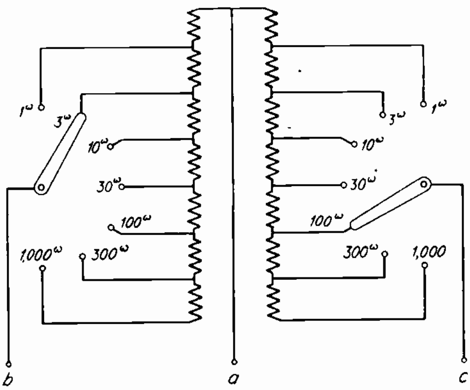


Fig. 2

The voltage across each resistance is the current multiplied by the resistance in ohms. Therefore,

$$I_{ab} \times X = I_{ac} \times R_3 \qquad \text{(a)}$$

also

$$I_{ab} \times R_1 = I_{ac} \times R_2 \qquad \text{(b)}$$

With the aid of simple algebra, we divide equation (a) by equation (b), and with the current cancelled out, the equation of the Wheatstone bridge when *balanced* is obtained. For those who are not familiar with algebra, the following equation (1) should be memorized along with Fig. 1.

$$X = R_3 \times \frac{R_1}{R_2} \qquad (1)$$

For example, if at balance, which is indicated when there is no deflection on the galvanometer, R_3 was 227 ohms, R_1 was 10 ohms and R_2 was 100 ohms, the unknown resistance X would equal

$$227 \times \frac{10}{100} = 22.7 \text{ ohms.}$$

You may have already observed the possibility of measuring extremely large and small resistances in a single bridge. Notice that the unknown resistance is always R_3 multiplied by the ratio of R_1 *to* R_2. This reveals the possibility of making a convenient variable bridge by changing the ratio of R_1 to R_2, as for example, 1/1, 10/1, 100/1 and 1000/1 and 1/10, 1/100, 1/1000. By the use of a simple 1 to 1 ratio of R_1 and R_2 the value of X can be approximately obtained. Then X will be equal to R_3 at the proper setting of R_3. Afterwards, for more exact measurement, a ratio of 1/10, 1000/1 or 1/100, or any ratio that allows a more complete

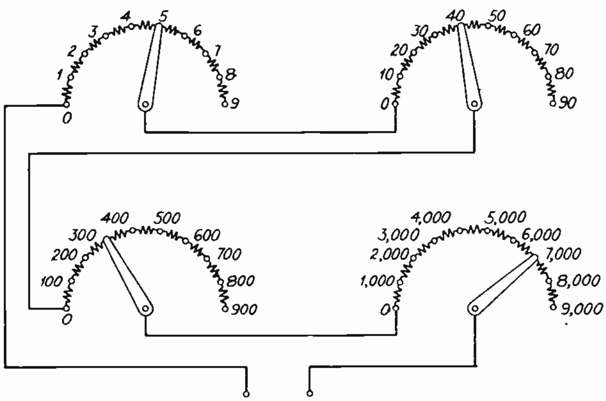


FIG. 3

use of R_3 may be used. Figure 2 shows how these ratios may be prearranged. The important factor in connection with R_1 and R_2 is not their exact value, but rather the ratio of R_1 to R_2.

The value of resistance R_3 must be known exactly for every setting, and it must be variable in a very simple and convenient manner. What is known as a "decade" arrangement is used as R_3 in Fig. 1. A *decade resistance* arrangement is shown clearly in Fig. 3. Each switch arm moves over ten contacts which make connection with nine equal resistors in series. There are usually four variable tap-arm arrangements, the first for the nine equal 1000^{ω} resistances, the second for the 100^{ω} section, the third for the 10^{ω} section, and the fourth for the 1^{ω} section. They are all in series, so that a value of resistance up to 9999 ohms may be readily obtained by setting the four switch arms at maximum. Thus at maximum setting of the switch arms and with the ratio arms set at 1000/1, a resistance measurement up to 9,999,000 ohms—practically 10 megohms—is possible, and at the minimum setting, a low value of .001 ohm can be measured. However, the lowest resistance measurable with any precision is ½ ohm.

A typical portable Wheatstone bridge is shown in Fig. 4. It is surprising how quickly a resistance can be measured with it. The unknown resistance is connected to the binding posts provided for quick connection and a single dry cell is connected to $B+$ and $B-$. When the approximate resistance is known, the

FIG. 4
Leeds and Northrup Type S Portable Wheatstone Resistance Bridge

procedure is simple. For example, if you know the resistance to be measured is somewhere near 250 $^{\omega}$, R_3, the decade group is set as follows. The "thousand" section would be set at 2000, and the hundred section at 500. The ratio switch at the extreme rear left of the bridge $\frac{R_1}{R_2}$ would be set at 1/10 (.1), which will reduce the measured values by one-tenth.* The key in this instrument (a contact button) would be pressed and the decade switches (0–10 and 0–1) adjusted until the galvanometer needle reads zero or as near to zero as possible. At first the shunt

*Of course, the decade box could have been set for 250$^{\omega}$ and a ratio of R_1 to R_2 of 1 to 1 used. However, under these circumstances, the full sensitivity of R_3 would not be utilized.

across the galvanometer would be used and then entirely removed. This precaution is essential in order to protect the meter. Further sensitivity can be had by the use of 2 or 3 dry cells in series as the source of e.m.f.

When the resistance to be measured cannot be estimated, the ratio arm is set at 1 and the decade resistor section adjusted, using a shunt across the meter until the change of a small resistance value will cause the needle to read first to the right and then to the left of zero. This gives a close approximation to the final value.

This bridge is intended for close D.C. resistance measurements and must be made with great care. Each unit, whether 1000 ohms or 1 ohm, is non-inductively wound in the form of a bobbin. Fig. 5 shows a typical construction. A layer of silk is

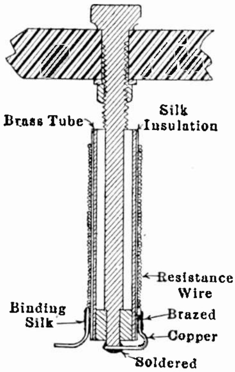


FIG. 5

wound on a brass tube. This is then shellacked and baked. The insulated resistance wire, usually "manganin," is doubled, and the looped end used as the starting end. The two wires are wound side by side, usually in a single layer. The two free ends are brazed to metal terminal lugs. The coil is then shellacked and baked for about 10 hours at 140° Centigrade, after which it is paraffined to exclude moisture. Thus the resistance unit is made moisture proof and is free from temperature effects.

THE A.C. WHEATSTONE BRIDGE

For ordinary purposes the A.C. resistance of a device used in commercial and audio frequency circuits may be assumed to be the same as the D.C. resistance as measured in a D.C. bridge. No hard and fast rule can be set, however, and we must be guided by the design and use of the device. Quite often the device may have associated with it an inductance or a capacity or it may really be an inductance coil with an associated resistance. The A.C. resistance of such parts will vary with frequency and may involve varying power losses. Then an A.C. bridge is required for precise measurement.

An A.C. bridge used to measure A.C. resistance would be arranged in the same manner as the D.C. bridge in Fig. 1. Instead of a battery, an A.C. source of e.m.f. would be used, that is, an audio oscillator with a range of 400 to 10,000 c.p.s. The D.C. D'Arsonval microammeter would be replaced naturally by an A.C. indicating device. A sensitive thermocouple microammeter or a microvolt V.T.V.M. would be an appropriate indicator for bridge balance, and well adapted for use at all frequencies.

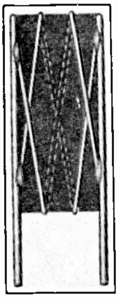


FIG. 6

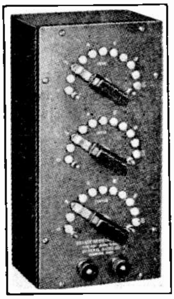


FIG. 7

Considerable testing is done at audio frequencies, particularly at 1000 c.p.s. Therefore a telephone headset can be used in place of an A.C. meter, a balance being obtained when minimum or no sound signal is heard through the phones.

The resistances R_1, R_2 and R_3, if used at frequencies from zero to 1,500,000 c.p.s., for any degree of precision, must be made with an absolute minimum of distributed capacity and inductance and their ohmic resistance values must not change with temperature.

An alloy wire, manganin, is used as it is practically unaffected by normal room temperature changes, and its resistance will not change with age. As a matter of fact, some laboratory instrument manufacturers age resistance units six months before adjustment for final exact value.

To make the resistance units independent of frequency changes, special methods of construction are employed to eliminate capacity and inductance effects. The Ayrton-Perry method is a common one. A thin bakelite form is used. A single wire is first wound on with a space between turns equal to the diameter of the wire. In parallel, electrically, a second wire is wound on the form in the spaces between the turns of the first winding. The winding direction of the second wire is opposite to that of the first, so that the currents result in two magnetic fields which cancel each other. This method of winding keeps down the distributed capacity to that of a single layer coil, which is quite negligible. A schematic of the winding is shown in Fig. 6.

A precision of .1 per cent on D.C. to 5 per cent at 1,500,000 cycles is possible, with a bridge of this kind. An error of only

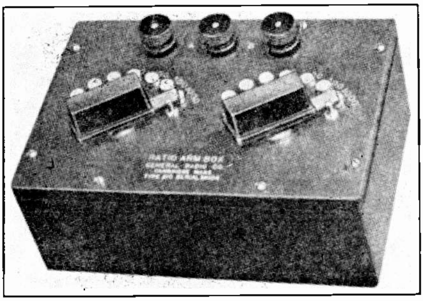


FIG. 8

5 per cent is quite good as R.F. measurement tolerances of 10 per cent are common.

A typical decade resistance box is shown in Fig. 7 (forming R_3 in Fig. 1) and a ratio arm box is shown in Fig. 8 (constituting R_1 and R_2 in Fig. 1). They both use the high frequency resistance feature just described and are valuable in radio and audio frequency bridge measurements.

CAPACITY BRIDGES

There are innumerable capacity bridges, each having its particular value. The most commonly used is the one shown in Fig. 9, having a diamond arrangement of two A.C. resistance decade boxes, a known fixed metal-plate mica-dielectric condenser and the unknown capacity to be measured. R_1 and R_2 are 0 to 10,000$^{\omega}$ decade resistance boxes of the kind illustrated in Fig. 7. C_s is the standard condenser and for measuring ordinary radio capacities of .001 to 10 mfd., it has a capacity of .050 mfd. Notice that the audio oscillator supplies A.C. voltage through a coupling transformer. This is good practice, as it prevents any D.C. current from flowing through any leak that may be present in either condenser. It is also advisable to use a coupling transformer ahead of the phones, having a large primary impedance and secondary turns to match the impedance of the phones.

R_1 and R_2 are adjusted until minimum hum is heard in the phones and the capacity X is found from equation:

$$C_x = C_s \times \frac{R_2}{R_1} \qquad (2)$$

If the unknown capacity of C_x is near the value of C_s, the

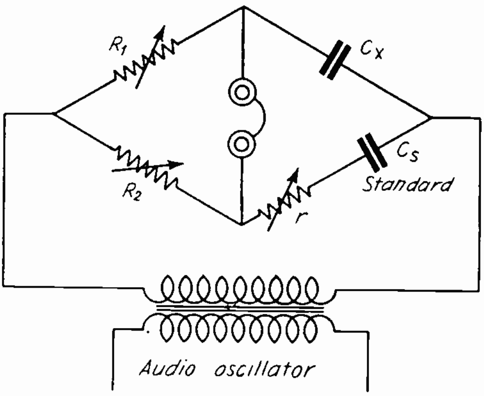


Fig. 9

standard, the settings of R_1 and R_2 will be practically the same. The greater the value of R_1 and R_2 used, the greater will the precision of measurement be. If C_x is small in comparison to the value of C_s, R_1 will be much higher than the value of R_2. Likewise, when C_x is large, R_2 will be larger than R_1 for balance. In permanent capacity bridges the arm R_1 is not always a variable decade box but may be a group of resistances which can be adjusted in steps of 10 ohms by means of a tap switch. Values of 10, 100, 1,000 and 10,000 ohms are all that are needed. This allows capacity measurements of 20 microfarads down to .005 mfd. with fair precision by setting R_1 and adjusting decade box R_2.

It is not possible to reduce the hum in the phones to nothing merely by adjusting R_2. We must not overlook the fact that C_x and C_s have inherent resistance and this must be balanced out. The standard C_s is usually selected with great care for low losses, and in general its series resistance will be much lower than the series resistance of C_x. A calibrated variable rheostat r of 0 to

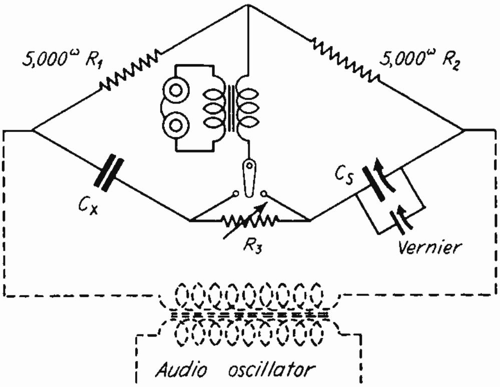


FIG. 10

200 ohms is placed in series with the standard condenser. This is adjusted for no hum by balancing out the series resistance of C_x. It may be necessary to readjust R_2 and then r again before absolutely no signal is heard in the phone. This last value of R_2 is used in calculating C_x.

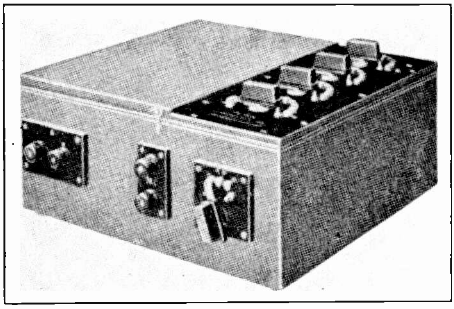


FIG. 11

The equivalent series resistance of the unknown condenser can be measured and will be $R_x = r \times \frac{R_1}{R_2}$. This method is very valuable in testing by-pass, filter, and coupling condensers for equivalent series resistance. The power factor of the condenser is then quickly calculated from the formula:

$$\text{P.F.} = 2\pi f R_x C \tag{3}$$

Where the service man or laboratory technician builds most

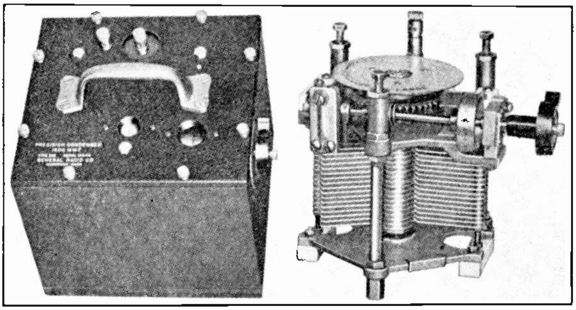


FIG. 12

of his own apparatus, the condenser bridge merits a prominent place along with an audio oscillator, an R.F. signal generator, and other laboratory equipment.

When measuring radio condensers of small capacities hav-

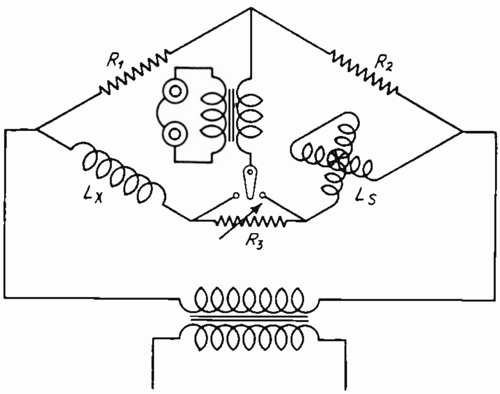


FIG. 13

ing low losses, considerable care must be exercised. All parts of the bridge must be shielded—each section from the other.

Fig. 10 shows the usual bridge arrangement when the resistance arms, R_1 and R_2, are fixed and equal. A precision variable condenser is connected at C_s and the unknown is placed at C_x. An audio oscillator feeds an A.C. e.m.f. across the bridge and C_s is varied until minimum hum signal is heard. R_s—a decade resistor box—is connected in series with either C_s or C_x for final hum balance. Using equal arms of resistance—that is, with R_1 equal to R_2—the unknown capacity equals the known value of C_s. R_1 and R_2 are shown as $5{,}000^{\omega}$ each. C_s may be a 1,500 micro-microfarad direct reading variable standard. If R_2 is 500 ohms, the values of C_x will be 1/10 of C_s and the largest capacity that can be measured is 150 $\mu\mu f$; if R_2 is 50 ohms, the value of C_x will be 1/100 of C_s and the largest capacity that can be measured is 15 $\mu\mu f$.

Fig. 11 shows a typical capacity bridge with fixed ratio arms, using a precision variable condenser like the one shown in Fig. 12. A tuning fork oscillator emitting a 1,000 c.p.s. sine wave is used as oscillator.

INDUCTANCE BRIDGES

Inductances are also measured by means of a bridge circuit only they must have at least two inductance arms. Fig. 13 shows

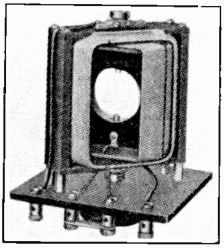


FIG. 14

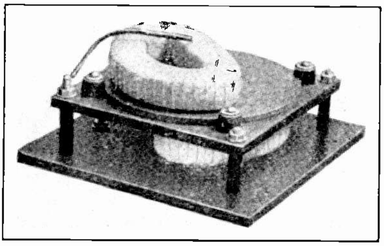


FIG. 15

an ideal inductance bridge arrangement. L_s, a standard inductance, is used, and the unknown inductance L_x takes the place of C_x. If the resistance arms are equal, L_x will be equal to L_s, which is usually a variable inductance (variometer). A typical laboratory instrument is shown in Fig. 14. It is obtainable in sizes from .02 to .4 millihenry; .10 to 4 mh.; and .4 to 18 mh. Obviously, varying the ratio of R_1 to R_2 allows larger or smaller inductances to be measured.

The bridge shown in Fig. 13 can be used as a universal bridge for measuring resistance, capacity and inductance. R_1 is a decade box having .1, 1, 10, 100^{ω} sections and R_2 is a tapped resistance with values of 1, 10, 100 and 1,000 ohms in individual sections. The ratio arm box shown in Fig. 2 may be used as R_1 and R_2. R_3 is a 4 section decade box of .1, 1, 10 and 100^{ω} sections. A standard resistor, condenser or inductance is connected at L_s, and the unknown is placed at L_x. R_3 is shorted when measuring resistance, included in the right arm when measuring capacity, and it may be necessary to insert it either in the right or left arm when measuring the inductance of a coil. The formulas by which exact values are calculated are:

(4) $L_x = \frac{R_1}{R_2} \times L_s$

(5) $C_x = \frac{R_2}{R_1} \times C_s$

(6) $R_x = \frac{R_1}{R_2} \times R_s$

(where L_x, C_x and R_x will be in the same units (microfarads, henries, millihenries, megohms, ohms) as L_s, C_s and R_s).

When measuring inductance or capacity, R_3 is thrown into the right or left arm for minimum signal response. Standard

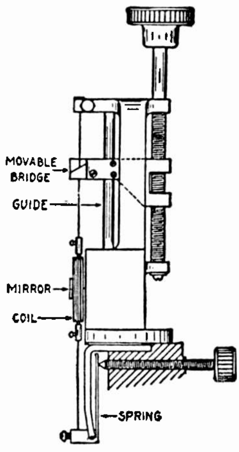
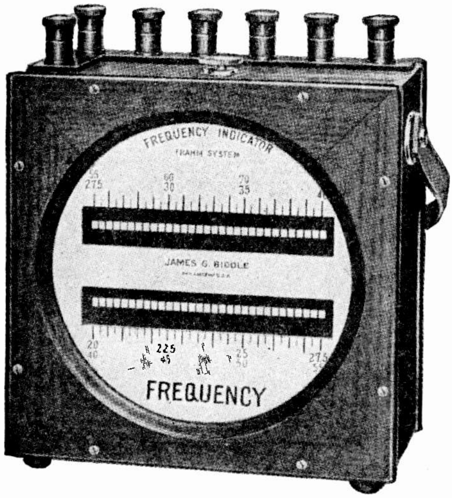


FIG. 16

fixed inductances are shown in Fig. 15. They are to be had in values of .10, 1.0, 10.0, and 100.0 millihenries. The very same bridge may be used for measuring D.C. resistance, with a galvanometer and battery, as well as R.F. coils and condensers at high frequencies. If R_1, R_2 and R_3 are designed for D.C. to high frequency use, the only precaution necessary is to have the standard calibrated for the frequency at which measurements are to be made and to use an e.m.f. of that frequency. For high frequency use the phones can be replaced with a V.T.V.M. of sensitive construction, a thermogalvanometer, or a vacuum tube detector followed by a stage of audio and then phones. In the latter case the R.F. signal must be modulated.

For some laboratory work where the utmost precision is required a *vibration* galvanometer is used as shown in Fig. 16. It is nothing more than a tuned oscillograph element in which a powerful permanent magnet supplies the flux. The element is tuned to the frequency of the source of audio e.m.f. used in balancing the bridge. A mirror and scale indicating method is used similar to that of a laboratory D'Arsonval galvanometer,



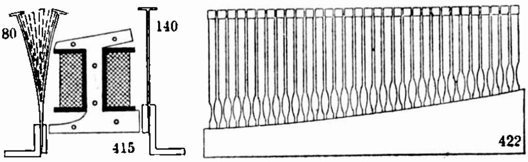
Vibrating Reed Frequency Meter

but, instead of the light deflecting, the width of a band of light becomes less as the current decreases.

FREQUENCY MEASUREMENTS

Commercial frequencies (frequency of the current supplied at the wall sockets) can be assumed to be fairly constant. With the growing popularity of electrically operated clocks and with the advent of local television programs, power companies are compelled in their efforts to please the consumers to maintain absolute frequency throughout the day. A precision clock carefully monitored against Naval Observatory time is used as the power house standard. A synchronous motor, a motor which will not change its speed of rotation when a load is added, and whose speed is dependent solely on the frequency of the supply current, operates a clock mechanism. This clock must not deviate at any time from the naval standard. The speed of the power house generators is so regulated that they maintain absolute agreement with the standard.

Where no attempt is made to supply power for electric clock operation, the power company may use several methods of keeping fairly constant frequency. Each alternator will deliver rated frequency at a definite speed of rotation. It then remains to maintain the speed at that specific value. Small automobile magnetos are often used for this purpose. In general, they produce 10 volts when driven at 1,500 r.p.m. They consist of a small armature such as used in D.C. generators, but have a magnetic field produced by 4 to 6 large, well-aged, permanent magnets.



B

Fig. 17

The magneto is connected to a variable speed motor and the output of the magneto connected to a suitable range voltmeter (a low resistance type will do). Next the magneto-voltmeter combination is calibrated. At various speeds of rotation the voltage is recorded; a curve is drawn between voltage and speed in revolutions per minute. Likewise a plot of cycles per second against voltage could be drawn for use when the combination is permanently attached to the A.C. generator.

The speed of the calibrating motor which is directly coupled to the magneto is determined by means of a stop watch and a revolution counter. The latter is usually set at a simple number such as 0000, or 1000 or 3000 and, holding the stop watch in one hand and the counter in the other, the stop watch is started at the same moment the counter is inserted into the countersunk center of the motor shaft. After exactly one minute the counter is removed—the counter reading is the r.p.m. Several readings are taken and the average of them all used. A watch with a second hand can be used by a careful observer.

The calibrated magneto and voltmeter are connected to the main generator. If the latter is running at the proper speed, the voltmeter connected across the magneto will read a constant correct value. Should the voltage increase or decrease, it is an indication that the speed of the generator has changed and consequently its frequency. Then the main driving motor is adjusted to drive the generator at the proper speed.

Another method of keeping a check on frequency in the power house, and one that is used even more often than the magneto method, involves the use of a low frequency meter.

It is well known that a tuning fork (an instrument which sends out a definite frequency of sound when tapped) goes into violent vibration when brought near a solenoid having an A.C.

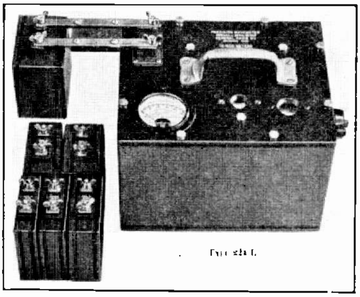


FIG. 18a

current flowing through it whose frequency is the same as the frequency of the tuning fork. This principle is made use of in the Hartmann and Braun frequency meter. In this instrument, there are small steel reeds (*B* in Fig. 17) firmly anchored in the base. Each reed is of a different length and therefore has its own period of vibration. On the top of each reed is a rectangular cap painted white. These caps are weighted so that the reeds will vibrate at exactly the proper frequency.

The electromagnet of the meter, which has a high resistance winding, is connected across the supply whose frequency is to be measured. As the reeds do not retain magnetism, they will be attracted twice during each cycle and the A.C. power will cause that reed to vibrate violently whose frequency is twice that of the current measured. If the reeds have been previously calibrated, we have a direct reading frequency meter. A variation of 50 per cent in the amplitude of reed vibration will result if the supply frequency is altered one-half cycle. Thus if two reeds vibrate, let us say the one marked 60.5 quite prominently and the one marked 61.0 less prominently, the indication is that the frequency is between 60.5 and 60.7 c.p.s.

There are various other types of frequency meters, but they cannot all be discussed here. In many cases the principles are too involved for elementary study. However, all are as simple to use as a voltmeter should you at any time need to use them.

HIGH FREQUENCY METERS—WAVEMETERS

The use of a radio frequency coil shunted by a variable condenser to form a resonant circuit is not new to us. We have met resonant circuits many times in our study of radio principles. When excited by a buzzer or an A.C. power source a

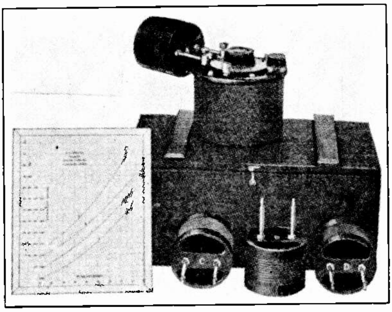


FIG. 18b

modulated high frequency is obtained; when connected into a tube oscillating system an A.C. tube generator is available. The resonant frequency is $f = \frac{1}{2\pi\sqrt{LC}}$, where f is in c.p.s. and L and C are in henries and farads respectively. Thus A.C. can be generated or measured from commercial to high frequency values.

The measurement of radio frequencies is important and a simple radio frequency meter consists primarily of an R.F. coil shunted by a variable condenser. Two commercial radio frequency meters are shown in Figs. 18a and 18b, the former a precision device, accurate to ¼ of 1 per cent and the latter accurate to 1 per cent.

These instruments can be calibrated by comparison with standard known frequencies. We should bear in mind that frequency meters and wavemeters are one and the same, the only difference being in the calibration. In order to find the wavelength corresponding to a definite frequency in cycles, divide the latter into 300,000,000—the velocity of radio waves—and the wavelength in meters will be known.

Now let us see how a frequency meter indicates when its natural frequency is in resonance with the source being measured. We require an indicating device in addition to the coil and variable condenser. The simplest device is a thermocouple galvanometer (see Fig. 19a) connected in series with *L* and *C*. The meter may be a 0-100 ma. milliammeter; a more sensi-

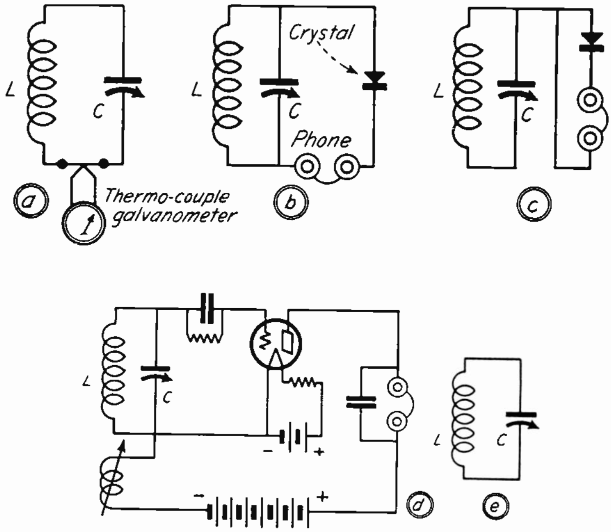


Fig. 19

tive meter of course means that less powerful sources can be measured. The coil is coupled by bringing it near to the circuit where the current is to be measured for frequency. The condenser *C* is varied until the meter shows maximum deflection. In place of the galvanometer a small flash-light bulb having a low resistance can be used. Lamps having more than one or two ohms resistance should not be used because of broad tuning effects, so that exact resonance is not easily determined. At exact resonance the bulb lights up most brilliantly. These arrangements are for use with transmitters, and powerful signal generators, *not* radio receivers. The method can be applied to modulated or continuous R.F. currents.

Various other types of frequency meters are shown in **Figs.** 19b to 19e. In the circuits shown in Figs. 19b and c, you will note that phones are used in conjunction with a crystal detector. These methods can be used only to measure the frequency of modulated radio frequencies.

The connections shown in *b* result in a more sensitive device than that in *c;* in fact the first is about 8½ times as sensitive as the second. In both cases the condenser *C* is a precision calibrated condenser. In practice *C* is adjusted for maximum earphone response. Then the frequency is calculated from the condenser setting, or, if the condenser is calibrated in kilocycles, it can be read directly.

The frequency meter shown in Fig. 19d has a regenerative detector. Thus it can be used with unmodulated as well as modulated R.F. This is also a rather sensitive frequency meter.

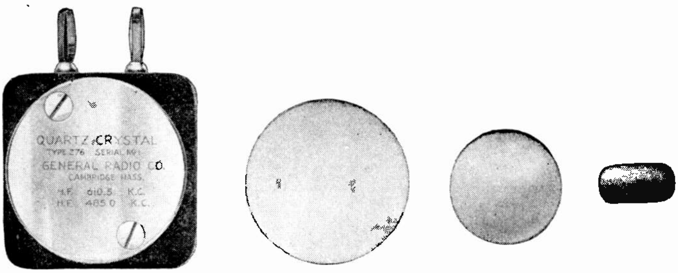


FIG. 20a

Surprising as it may seem, the coil and condenser alone as in Fig. 19e form quite an efficient frequency meter. Suppose the circuit containing the unknown frequency has an R.F. indicator, a meter in the case of an oscillator, a loudspeaker in the case of a receiver. When the coil of the frequency meter is brought near the circuit to be investigated and the capacity is varied, a sharp drop in meter reading or a decrease in sound output will be evident when the two circuits are resonant, that is, at the same frequency. The frequency meter is then read.

PIEZO OSCILLATORS

Various crystals such as Rochelle salts, tourmaline and quartz have what are known as "piezo electric properties," that is, properties involving the production of electricity by pressure. If any piezo electric crystal is mechanically pressed, an e.m.f. will be developed across two of its sides. Then when the pressure is removed, the crystal naturally expands, but, acting as though it were resilient, it expands beyond its normal size and again an e.m.f. is developed across two of its faces, this time, however, of opposite polarity.

If we cause a piezo electric crystal to vibrate in some way or other, it will generate an A.C. e.m.f.—*at a constant frequency,* determined by the size, shape, structure, and temperature of the crystal.

Piezo electric effects can be obtained electrically, and in practice the crystal is always made to vibrate by electrical means. Suppose we placed a rectangular shaped, carefully faced piece of quartz crystal between two metal plates and we applied a source of D.C. to them. The crystal would actually con-

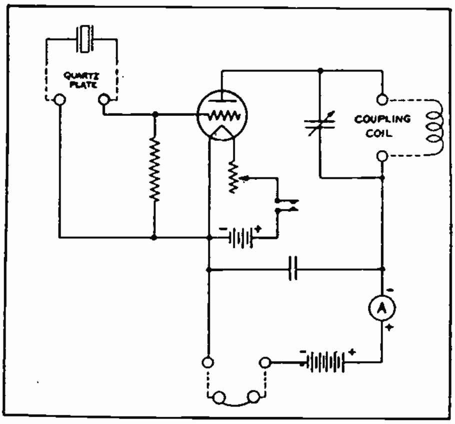


Fig. 20b

tract and expand (vibrate) for a short while immediately after the D.C. was applied, each vibration being smaller than the preceding one.

What effect does this have on current flow? Of course the only D.C. current that flows is that required to charge the condenser formed by the two plates. But the vibration of the crystal results in an A.C. e.m.f. having a damped wave form—each cycle smaller than the preceding cycle—and a small A.C. current will flow through the circuit. The frequency of this A.C. will be determined by the size, shape and structure of the crystal.

Now if an A.C. e.m.f. of the same frequency as the crystal is impressed across the plates holding the crystal, the crystal will maintain oscillation indefinitely, at its own frequency. The crystal frequency will not deviate by more than a fraction of one per cent from its natural frequency, provided the temperature of the crystal does not vary.

Fig. 20a shows typical quartz crystals of the kind used in radio work. Quartz is always used, as Rochelle salts are fragile and tourmaline is expensive. These crystals are placed in regular crystal holders consisting essentially of two plates, which, with the crystal as the dielectric, form a condenser.

A typical crystal oscillatory circuit is shown in Fig. 20b. Here the crystal tunes the grid and the *LC* circuit in the plate is tuned to exact resonance with the crystal. Oscillation is maintained in this circuit by the energy fed back from the plate to the grid through the tube capacity. The crystal keeps the frequency of oscillation practically constant. Without it or with a regular *LC* circuit in its place, oscillation could be maintained in the circuit over a considerable frequency variation. With it in the circuit, should the *LC* constants change in any way and the feed back frequency be affected by even a small amount, oscillation will stop.

Crystal frequencies are confined, in practice, to a band between 100 and 2000 kc. High frequencies are obtained by using the harmonics of the crystal frequency; lower frequencies are obtained by using multi-vibrators (frequency reducing devices).

Quartz crystals are used in Radio, for the purpose of maintaining the carrier frequency of broadcasting stations at an absolutely constant level. They are also used in standard oscillators and signal generators because of their excellent frequency stability. In the next paragraphs we shall see how a crystal controlled oscillator operates.

STANDARD AUDIO AND RADIO FREQUENCY SOURCES

In an earlier lesson we studied various devices for producing R.F. and A.F. current—signal generators and oscillators. When well built and properly calibrated, these are valuable tools for the service man and the laboratory technician. For ordinary purposes, signal generators are calibrated by means of frequency meters. But this leads us to the question, "How are the frequency meters calibrated?" Of course, you might say that these are calibrated from other frequency meters, but for the original calibration we must always go back to a primary standard.

While you may never come in contact with a primary frequency standard, you should know, and you will be interested to know, how this standard is obtained and maintained. Standard frequency devices are to be found in the Bureau of Standards at Washington, D. C., and in a few of the larger experimental laboratories throughout the country.

The device consists primarily of a 100 kc. crystal oscillator controlling a couple of multi-vibrators one working at 1,000 cycles. This thousand cycle current is used to operate a synchronous motor type of clock. The time kept by this clock is checked against an absolute standard of time, as, for example, the time signals sent out at 10 P. M. and 12 o'clock each mid-day by the government station NAA.

If the synchronous clock keeps exact time over a period of twenty-four hours, to the second, it is shown that the crystal is oscillating at exactly 100 kc. Thus the multi-vibrator system and the synchronous clock provide an exact check of the crystal.

As we said, two multi-vibrators are used. The first multi-vibrator operates at 10 kc., the other at 1 kc. or 1,000 cycles. The first or 10 kc. multi-vibrator is controlled at its 10th harmonic by the 100 kc. crystal oscillator, and the 1 kc. multi-vibrator is controlled by the first multi-vibrator at 10 kc. How this is done is explained as follows:

A multi-vibrator is nothing more than a resistance coupled amplifier circuit with its output connected to the input. It has no *LC* circuit but its frequency of operation is determined mainly by the values of *R* and *C*. The oscillation thus is comparable to motor-boating in the audio system of a receiver.

A multi-vibrator will supply a signal rich in harmonics, but the frequencies are not constant. If a constant signal of the same frequency as the fundamental or any harmonic frequency of the multi-vibrator is fed to the multi-vibrator, the latter will assume the stability of the introduced signal. Usually in primary signal sources, a piezo crystal oscillator is used to provide the controlling signal, and is usually of a frequency equal to the tenth harmonic of the multi-vibrator.

After the crystal is known to generate a frequency of exactly 100 kc., various standard frequencies can be obtained from it. Directly from the multi-vibrators can be obtained frequencies in steps of 10 kc. and 1 kc. A third multi-vibrator is supplied in commercial units, whose fundamental frequency is the fundamental frequency of the crystal oscillator. Thus accurate frequencies above 1,000 kc. are obtained.

Higher frequencies could be obtained by an ordinary *LC* oscillator carefully monitored by the harmonics of the crystal oscillator, or the multi-vibrator.

It is interesting to know that this very same elaborate frequency standard may be made to give standard audio frequencies. It is to be realized that the synchronous motor driving the clock mechanism revolves exactly in step when fed with 1000 c.p.s. If two synchronous motors were operated as synchronous generators by reduction gears, one 10 to 1 and the other 100 to 1, the generated frequencies would be 100 and 10 c.p.s. If these frequencies including the 1000 c.p.s. driving source are amplified by an amplifier having a large bias, harmonics up to the 10th may be obtained. Again audio frequencies from 10 to 10,000 can be obtained in steps of 10 c.p.s.

Primary standards of this sort are extremely costly and, for general calibration purposes, secondary standards calibrated from the primary standards are used. Fig. 20b shows the diagram of a piezo oscillator extensively used in laboratories as a secondary standard. A complete commercial oscillator of this type is shown in Fig. 21. The tube in this circuit is a type '12A. Large tubes are not advisable as quartz crystals cannot handle large R.F. powers. All A and B batteries are housed within the cabinet.

A milliammeter (D.C.) indicates when the circuit is in oscillation. The phone jack permits connection to other apparatus or to amplifiers or, if the device is used as a frequency meter and coupled to the source to be measured through the coil, a pair of phones is inserted to enable the operator to hear the beats. The crystal and coils may be replaced with ones of different values by a convenient plug-in arrangement and a complete calibration in small steps within the fundamental or harmonic band can be made.

In order to obtain useful power at a harmonic frequency, it is general practice to set up a local oscillator whose fundamental frequency is the same as the desired harmonic frequency of the crystal. That is, its fundamental is adjusted for zero beat with the crystal harmonic, and the oscillator is at exactly the desired frequency and will deliver the required output power.

MAGNETOSTRICTION OSCILLATORS

In much the same way as a small, carefully cut disc of quartz will vibrate when an alternating e.m.f. is applied to its faces, rods of certain metals vibrate when subjected to a varying magnetomotive force. Such metals are said to have magnetostrictive properties.

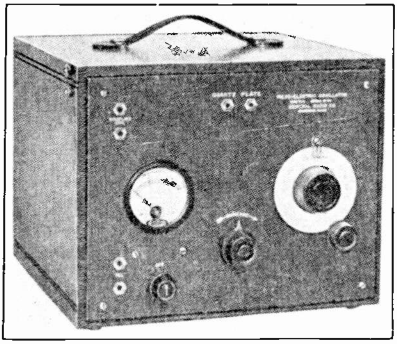


Fig. 21

Surprisingly enough, the more magnetic metals do not show magnetostrictive properties to as great an extent as metals that are less magnetic. For example, iron and steel which are highly magnetic show only feeble magnetostrictive properties. Pure nickel, alloys of nickel and iron, such as invar metal which is 36 per cent nickel and 64 per cent iron, cobalt and iron,

1000 c.p.s. Synchronous Clock

chromium, nickel and iron, all of which are practically non-magnetic, show large magnetostrictive effects.

Suppose we have a magnetostrictive bar and we inserted it into a solenoid. Current flowing through this solenoid would cause the bar to extend its length. When the current was removed the bar would return to normal length. If the current through the solenoid were reversed, the bar would also be extended in length. Accordingly, if an A.C. current is made to flow through this solenoid, the bar will vibrate at a frequency twice that of the exciting current.

Of course we have been assuming that the shape and size and structure of the magnetostrictive bar are such that the frequency of the exciting current will cause the rod to vibrate.

If a magnetostrictive bar is placed within a double solenoid, one part of which is fed with an A.C. current and the other with a D.C. current in such a way that the e.m.f. never actually reverses its direction, the frequency of the A.C. can be made the same as the frequency of the bar.

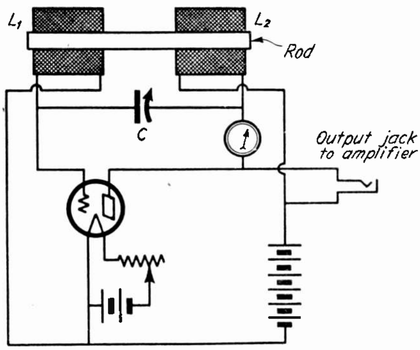


FIG. 22

An arrangement of this sort can be connected in a "hi mu" vacuum tube circuit to provide a standard frequency generator. In this case one of the coils is connected across the grid and cathode of the tube and the other across the plate and cathode of the tube. When the circuit oscillates at the frequency of the magnetostrictive bar, this frequency will remain constant within very narrow limits.

The magnetostriction oscillator is shown in Fig. 22 and a commercial standard frequency generator of this type is shown in Fig. 23. The coils are shunted by a variable condenser so that the *LC* constants can be adjusted to the fundamental frequency of the rod used.

As the condenser *C* is tuned to resonance with the rod, the milliammeter current rises rapidly. When this current is at a maximum it can be used as a signal power control without affecting the circuit frequency. Changes in filament current and plate voltage have extremely small effect on the circuit frequency, which depends solely on the length and structure of the rod. The longer the rod the lower the frequency.

An oscillator of this kind is a valuable secondary source of standard frequencies from 5 to 50 kc. and, as it is a rich producer of harmonics, frequencies of several million c.p.s. are easily obtained. Various fundamental frequencies are obtained by replacing the rod with others of various sizes. Thus the device may be used as a frequency generator or meter.

R.F. COIL MEASUREMENTS BY RESONANCE METHODS

Special resonance methods are used in measuring the inductance, R.F. resistance and distributed capacity of R.F. coils.

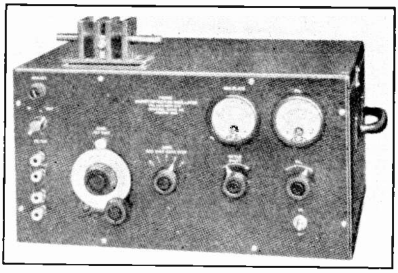


FIG. 23

For making these measurements, the resonance method is best because this is the only method by which actual operating conditions can be gauged, as the various quantities differ greatly at high and low frequencies.

From the formula $L = \frac{1}{39.5f^2C}$ $\left(\text{derived from } f = \frac{1}{2\pi\sqrt{LC}}\right)$ it can be seen that, knowing the value of f and C, it will be a simple matter to calculate the inductance of a coil in a resonant circuit. We can use this formula as the basis of a simple inductance measuring device.

The coil whose inductance is to be measured is connected in series with a precision variable condenser having negligible R.F. resistance, and a thermocouple milliammeter. Then the coil is weakly coupled to an R.F. signal of known frequency, which should be very close to the frequency the coil is to handle. The next step is to adjust C for maximum milliammeter reading.

At this setting of C, its capacity value is read and as the frequency is known, we have sufficient information to calculate L.

Now suppose we want to find the R.F. resistance of L. If we knew the voltage across L at resonance we could find r from Ohm's Law, for the current I is read on the milliammeter. Unfortunately only I is measurable. But we can insert a known R.F. resistance, as shown in Fig. 24. Now the current through the milliammeter is reduced by the resistance of the standard resistor (R) as well as by the resistance of the coil (r). Then the new current is I_1 and:

$$I_1 = \frac{E}{r + R} \qquad \text{(a)}$$

Of course we still do not know the value of E, but we do know that it is equal to $I \times r$. Therefore we can restate formula (a) as follows:

$$I_1 = \frac{I \times r}{r + R} \qquad \text{(b)}$$

Solving formula number (b) for r we get the working formula:

$$r = R \div \left(\frac{I}{I_1} - 1\right) \qquad \text{(7)}$$

It is obvious now that as we know R and we can measure I and I_1, we can easily calculate the value of r, the R.F. resistance of the coil.

Suppose, for the sake of a practical example, that we used a standard resistor of 20 ohms and we measured I as 110 ma. and I_1 as 55 ma. Substituting in formula (7) we get:

$$r = 20 \div \left(\frac{110}{55} - 1\right)$$
$$= 20 \div (2 - 1)$$
$$= 20 \div 1$$
$$= 20 \text{ ohms}$$

If we have a decade box available, it is a much simpler matter to measure the R.F. resistance of a coil. We merely insert the decade box at R, and adjust it so that the current through the milliammeter is reduced to exactly one-half. Then we would read the value of R and the coils R.F. resistance (r) would be exactly equal to R.

We have thus far determined two important factors of an R. F. coil; its inductance and its R.F. resistance. Another important factor is its distributed capacity. With the circuit shown in Fig. 24 this may also be quickly obtained.

Tune the condenser C to resonance with the fundamental frequency produced by the signal generator. This we have already done when we measured L. Let us call the value of the precision condenser at this setting C_1. The generator no doubt

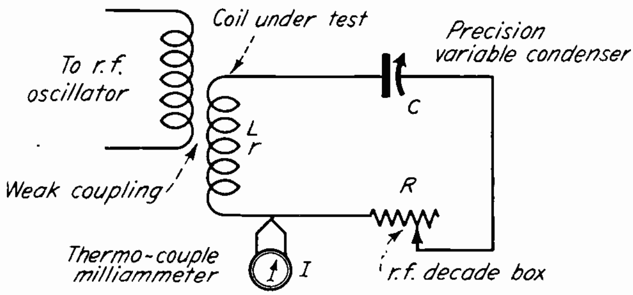


Fig. 24

has a prominent second harmonic and with the original coil it will require a condenser setting about ¼ of C_1 to bring L and C to resonance with it. Call this setting C_2. If it were not for the distributed capacity of the coil, C_1 would be four times C_2. The distributed capacity C_o is then found from the formula:

$$C_o = \frac{C_1 - 4C_2}{3} \tag{8}$$

and if C_1 and C_2 are measured in microfarads, the formula will give C_o in microfarads.

APPROXIMATE CAPACITY OF FILTER CONDENSERS

The usual radio service bench is equipped with a low range A.C. milliammeter, either of the thermocouple, moving vane or electrodynamometer type. A step-down transformer is connected to the 110 volt 60 cycle power supply. To its secondary terminal are connected the condenser to be measured and the A.C. milliammeter, in series. If there is any doubt about the secondary voltage, measure it with a voltmeter, then the capacity in microfarads will be:

$$C = \frac{1000}{2\pi f E} \times I \qquad \text{where } I \text{ is in milliamperes}, \; 2\pi = 6.28, \; f = 60, \; E \text{ is in volts.}$$

The method is only for approximate measurements, as the transformer may distort the wave form and the current reading will not be true. The impedance of the ammeter will be included in the measurement. If the voltmeter is placed across the capacity, the ammeter will read both the current through the capacity and the voltmeter. Correction should be made for the latter. If an electrodynamometer milliammeter of low resistance and inductance is used, or a V.T.V.M. is used as the ammeter, or a thermocouple meter is employed, the arrangement in Fig. 25 will be fairly accurate.

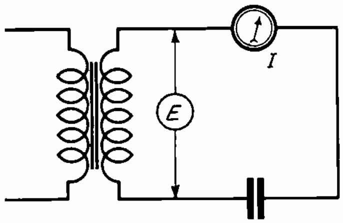


FIG. 25

A permanent set-up can be made and the ammeter dial actually made to read in microfarads, in which case we have a capacity meter. The ammeter may have several shunts so as to measure a wide range of capacities. In general the system is good for ranges of .01 to 10 mfd. However, it is usually far more satisfactory to measure capacity in a bridge measuring circuit.

TEST QUESTIONS

Be sure to number your Answer Sheet 30FR.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is a decade resistance?
2. When a Wheatstone bridge is perfectly balanced, what will the galvanometer reading be?
3. If you placed an *LC* resonant circuit as shown in Fig. 19e, near the antenna coupling coil of a receiver, carrying signal current, how would you know when the *LC* circuit resonated to the frequency of the incoming signal?
4. Draw a diagram of a bridge circuit for measuring inductance, using a standard variable inductance (variometer).
5. Would you use the frequency meter shown in Fig. 19b for measuring an unmodulated R.F.?
6. What particular advantage does the piezo crystal oscillator have as a signal generator?
7. What precautions must be taken when making precision resistors for frequencies from zero to 1,500,000 c.p.s.?
8. How can a 1 kc. standard frequency be obtained from a 100 kc. crystal oscillator?
9. Draw a diagram of a simple capacity meter having a range of .01 to 10 mfd.
10. What is the difference between a wavemeter and a frequency meter?

TUNING INDICATORS AND AUTOMATIC FREQUENCY CONTROLS FOR RADIO RECEIVERS

31FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

COURTESY

Truly big men are always courteous. It is only "small" men, men with inferiority complexes, who are rude or thoughtless. And smaller than small are those who are over-courteous to their superiors and intentionally rude to those over whom they have some authority.

Practice courtesy in all your contacts, business as well as social. Establish courtesy as one of your life habits. Be polite and kind to everyone you meet, rich and poor alike, and soon courtesy will become second nature for you.

The best place to test yourself is right at home. Are you always courteous to members of your immediate family, or do you shout at them on the slightest provocation? Are you considerate of their feelings or do you delight in saying things and doing things which you know will hurt them?

Many people are entirely different persons away from home. If you are among these, try treating the members of your family with the same consideration you would show strangers or ordinary friends. They might think for a few days that you are ill, but they will soon become accustomed to your new attitude and everyone will be much happier.

More than that, if you develop the habit of being courteous to your own folks, your away-from-home courtesy will ring true. It won't appear "put-on," as is so often the case when a man reserves his courtesy for only special occasions.

J. E. Smith.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

NCP3M641 Printed in U. S. A.

Tuning Indicators and Automatic Frequency Controls for Radio Receivers

Making Receivers Easy To Tune

THE tuning dial of a selective, modern receiver may require adjustments which are accurate to within one-hundredth of an inch movement of the dial pointer on its scale, if the desired signal is to be tuned in properly, free from distortion. The effects of improper tuning upon the wave form of a signal are clearly shown by the diagrams in Fig. *1*.

Receiver designers recognize the difficulties involved in tuning a receiver with this high degree of accuracy, and for this reason have provided a number of tuning aids on the receiver. Large dial scales are provided, with correspondingly longer pointers, to make small movements of the pointer more readily distinguishable. Two-speed adjusting knobs, one turning the tuning condenser assembly directly and the other through a mechanical speed-reducing or vernier mechanism, further simplify accurate tuning.

A dial designed for accurate tuning is of little value if the listener has to rely upon his ears as a guide for proper tuning. The reasons for this are quite simple; loudness is not a dependable guide because about equal loudness is secured for several kilocycles on either side of resonance, due to A.V.C. action. Clarity of reception is likewise a poor guide, for the average individual is not capable of telling immediately whether or not distortion is present. (In a receiver having A.V.C. but no tuning indicator we could, of course, tune for maximum volume with minimum background noise, but few people realize that this can serve as a guide for correct tuning.)

Tuning Indicators. The introduction of automatic volume control practically forced radio designers to develop another improvement, the visual tuning indicator. Fortunately, there is in A.V.C. receivers a voltage or current which either reaches a maximum or minimum value when the receiver is correctly tuned. This voltage or current can be made to operate a simple meter-type indicator having either a needle pointer or a shadow indicator; other types of indicators used for this purpose include a cathode ray indicator tube (often called a magic eye), a miniature electric lamp providing flash tuning, or an audio beat oscillator which provides an audible indication of incorrect tuning.

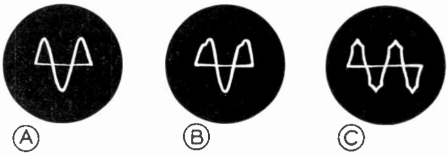


FIG. 1. These diagrams, copied from curves produced on the screen of a cathode ray oscilloscope in the N. R. I. laboratory, show what happens when a selective radio receiver is carelessly tuned. At *A* is the audio output curve secured when the receiver is correctly tuned to a carrier modulated with a single pure sine wave; there is no distortion. The slightly-distorted audio output wave form produced when the receiver is tuned about 2 kc. above the input R.F. carrier frequency appears at *B*, while the severely distorted wave form at 10 kc. off-tune appears at *C*.

Visual tuning indicators are by no means a perfect solution to this problem of tuning, for even with the best types of indicators the average broadcast listener finds it difficult to tune exactly at all times. Correct tuning requires patience and careful watching of the tuning indicator; a person who is relaxing to enjoy a radio program does not care to bother with the details of proper tuning.

Radio engineers recognize that slight mistuning is relatively unimportant during the first few moments of listening. After the radio receiver has been in operation for an hour or so, however, even small amounts of distortion become objectionable although they cannot consciously be recognized by the listener. Distortion appears to affect the nervous system, making a person tired of listening even to a good program.

Since the success of the entire Radio industry, including broadcasters and receiver manufacturers alike, depends upon having a large listening public, it is only natural that radio receiver engineers continued their search for devices and methods which would simplify the tuning of receivers. Their goal was a system which would permit even a small child to tune in the receiver just as well as could a radio expert.

Automatic Frequency Controls. As you know, in a superheterodyne receiver it is the local oscillator frequency which, more than anything else, determines the value of the I.F. signal. When this I.F. signal frequency is different from the I.F. value of the receiver, due to improper tuning, distortion will be present and sensitivity will be poor.

The superheterodyne receiver circuit is well suited for automatic tuning; even though it may be as much as 5 kc. off resonance, the tuning can be corrected merely by adjusting the oscillator trimmer condenser or by changing the inductance of the oscillator coil.

With this basic superheterodyne principle in mind, radio engineers produced a circuit for developing automatically a voltage which is proportional to the amount by which the oscillator is off resonance. This voltage is fed into a special vacuum tube circuit which is connected to the oscillator and has the peculiar ability of being able to change the inductance or capacity of the oscillator circuit just enough to produce the correct I.F. signal value. This system of automatic frequency control is commonly called A.F.C.

When a receiver is equipped with A.F.C., the listener merely tunes in the desired signal as best he can without any particular attention to accuracy of tuning; the A.F.C. system then automatically completes the tuning procedure.

Automatic frequency control systems are used chiefly in those larger receivers which have some type of automatic push button tuning system; in fact, A.F.C. is essential in a receiver having the electro-mechanical (motor-driven) type of automatic tuning system in order to *correct for slight inaccuracies in the mechanical action of the tuning mechanism and compensate automatically for oscillator frequency drift.*

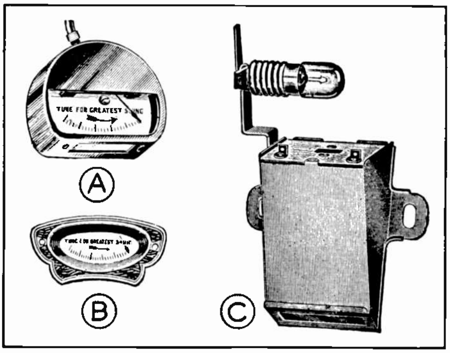


Fig. 2. Examples of current-controlled tuning indicators using an inexpensive milliammeter movement which consists essentially of a solenoid (coil) of about 1000 ohms resistance, inside which moves a long, pointed steel vane to which is attached the indicating pointer. The greater the D.C. current through the solenoid, the greater is the force which pulls the vane into the solenoid and moves the pointer. At *C* is a shadowgraph tuning indicator using a milliammeter movement; its operating principle is illustrated in Fig. *3*.

Tuning aids and automatic frequency control systems provide additional problems for the Radiotrician.

The operating principles of the devices in general use for tuning aids must be thoroughly understood before service can be rendered, so these principles will now be taken up.

Current-Controlled Visual Tuning Indicators

Meter-Type Indicator. Meter-type tuning indicators are ordinarily connected *into the plate supply lead going to one or more A.V.C.-controlled stages.* The average D.C. plate current drawn by a screen grid or pentode tube with normal C bias is about 5 milliamperes; this plate current drops practically to zero when the A.V.C. system increases this negative C bias to 40 or 50 volts. A 0-5 ma. milliammeter movement can therefore be used as a meter-type tuning indicator.

In Fig. *2A* is shown one form of a meter-type tuning indicator. This unit is attached to the receiver chassis in such a way that the face of the meter can be viewed through a hole in the receiver panel. An escutcheon plate like that shown in Fig. *2B* is often used with this meter to improve its appearance, and a pilot lamp is sometimes mounted below the meter to illuminate the scale through the window which can be seen in Fig. *2A*. The no-current position of the pointer is at the extreme right, as shown in these views. With the meter connected to indicate D.C. plate currents of an A.V.C.-controlled stage, the current through the meter is a maximum when no signal is tuned in, and the pointer will be at the extreme left. Tuning in a carrier signal causes A.V.C. action to decrease the D.C. plate current for the A.V.C.-controlled stages, and the tuning meter pointer therefore moves toward its zero position at the extreme right. The listener tunes the receiver for a maximum deflection to the right, or in other words, tunes for greatest swing to the right, for this corresponds to at-resonance conditions in the receiver circuit.

There are a number of variations of the simple meter movement just described, but all depend upon the same operating principles. In one case a small, round black disc is mounted on the end of the meter pointer; this disc moves over a series of concentric circles, alternately black and white, like those on rifle targets. The no-current

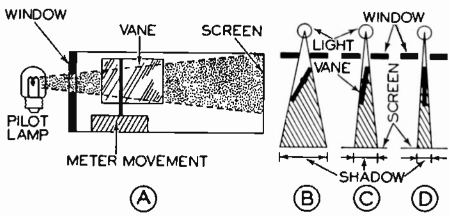


FIG. 3. In this shadowgraph tuning indicator, a large current causes the meter movement to place the vane in position *B*, giving a maximum-width shadow. Tuning in a station reduces the current, making the vane take various positions, such as at *C* and *D*; the listener tunes for minimum shadow, since this corresponds to exact resonance for any station.

position of the disc is at the center of the target, and the listener therefore tunes to get this pointer as close as possible to the center; manufacturers' instructions say: "Tune for a bull's eye."

Shadowgraph Tuning Indicator. Perhaps the most widely used variation of the tuning meter movement is the shadowgraph tuning indicator shown in Fig. *2C*. This contains a frosted glass or celluloid screen which is mounted so as to be visible from the front of the receiver panel. Behind this screen is a pilot lamp, the light from which passes through a small window and past a small rectangular vane attached to the meter movement before reaching the screen. When meter current is a maximum, this vane blocks most of the light, casting a shadow on the screen. As resonance is approached when tuning in a station, the meter movement rotates the vane towards its zero position, giving a minimum-width shadow. Details of this arrangement are shown in Fig. *3A*, and the effects of vane position upon the width of the shadow are shown in Figs. *3B*, *3C* and *3D*.

Circuit Connections. When a tuning meter is to be actuated by the D.C. plate current of only one A.V.C.-controlled stage, connections into the plate supply lead of this A.V.C.-controlled tube may be made as shown

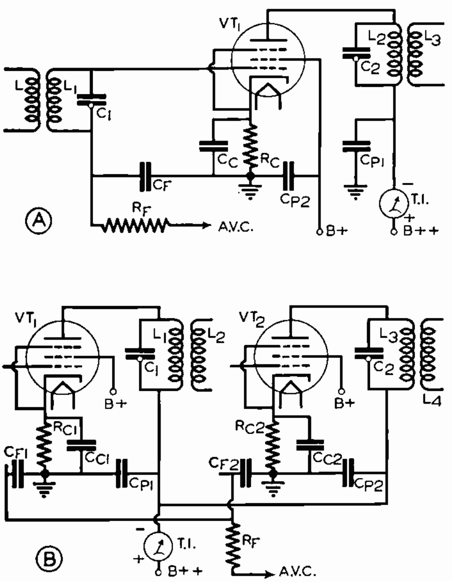


FIG. 4. Connections for a meter-type tuning indicator for a single A.V.C.-controlled stage *(A)* and for the common plate supply lead to two A.V.C.-controlled stages *(B)*.

in Fig. *4A*. Notice that by-pass condenser C_{P1} prevents R.F. and I.F. currents from passing through the tuning indicator. The resistance of the tuning indicator drops the D.C. plate voltage about 5 to 10 volts.

When the D.C. plate current to more than one A.V.C.-controlled amplifier stage is passed through the tuning indicator, connections into the plate supply lead going to these A.V.C.-controlled tubes may be as shown in Fig. *4B*. Naturally the current range for the indicator in this circuit must be greater than for the tuning indicator in Fig. *4A*. The meter movement should be selected to give nearly full-scale deflection to the left for a no-carrier-signal condition, in order to give maximum meter movement when a station is tuned in. Notice that by-pass condensers C_{P1} and C_{P2} are used in this arrangement to keep R.F. and I.F. currents out of the tuning indicator.

Voltage-Controlled Visual Tuning Indicators

Cathode Ray Tuning Indicator. A special cathode ray tube which acts essentially as a high-resistance voltmeter is used in many receivers as a voltage-controlled visual tuning indicator. The *D.C. voltage developed across the load resistor of a diode second detector-A.V.C. tube* in a receiver is used to control the cathode ray tuning indicator, since this voltage varies with carrier level.

The operating principle of a cathode ray tuning indicator tube is essentially the same as that of the cathode ray oscilloscope tube. Electrons striking a surface coated with a fluorescent material (such as willemite) cause the surface to glow with a greenish light. The diode detector load voltage determines the amount of surface which glows at any time, and thus we have a simple and highly attractive tuning indicator.

In a cathode ray tuning indicator an oxide-coated cathode, heated by a filament, is mounted in the center of a cone-shaped anode having a coating of fluorescent material on its inner surface, as indicated in Fig. *5A*. When a D.C. voltage is applied between the cathode and the anode, the electrons emitted by the heated cathode will strike the inner surface of the anode, called the *target*, and the entire inside of the circular cone or target will glow with a greenish light. In addition, a thin, vertical dart or vane is located between the target and the cathode, as shown in Fig. *5B*. This dart is known as the *control*

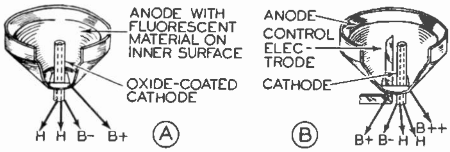


FIG. 5. Essential elements of a cathode ray tuning indicator tube.

electrode, for it determines how much of the target will glow.

When the control electrode is connected to the cathode, it has no electrical influence upon the electrons emitted by the cathode, but does have a physical blocking effect which prevents electrons from reaching that portion of the target directly behind it. We thus have a shadow in back of the control electrode, as indicated in Fig. *6A*. Making the control electrode negative with respect to the cathode, as in Fig. *6B,* widens this shadow, for the control electrode now has a repelling effect on the emitted electrons. When the control electrode is made positive with respect to the cathode, however, it serves to speed up the emitted electrons and to make them bend towards the shadow region, narrowing the shadow as indicated in

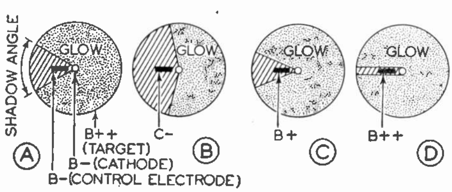
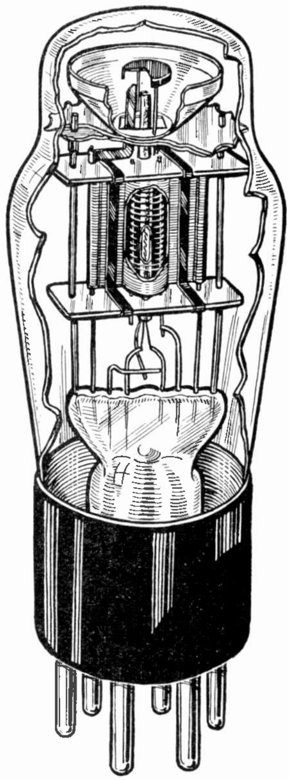


FIG. 6. Variation of shadow angle with control electrode potential in a typical cathode ray tuning indicator tube.

Fig. *6C*. When the control electrode is highly positive, as in Fig. *6D,* the shadow becomes very narrow or disappears entirely.

When a receiver having a diode detector is tuned to resonance, the diode load voltage increases in a negative direction with respect to the chassis or ground. If we want the shadow angle to close up as a station is tuned in, we must convert this increasing negative voltage into an increasing positive voltage for the control electrode of the cathode ray indicator



Courtesy National Union Radio Corp.

FIG. 7. Cutaway view showing construction of 6G5 cathode ray tuning indicator tube.

tube. This can quite easily be done by introducing a triode amplifier between the detector load and the control electrode of the indicator tube; in an actual cathode ray indicator tube like that shown in Fig. *7,* this triode amplifier is built into the same envelope as the target system.

The schematic circuit diagram in Fig. *8* gives in simplified form exactly the same information as the pictorial sketch in Fig. *7*. In addition, this diagram shows that the target connects directly to the B++ D.C. supply source, while the plate of the triode tube connects to this source through resistor R, which is usually 1 megohm. The common cathode for the two tubes is grounded to the receiver chassis, and the A.V.C. voltage is applied between the control grid of the triode section and the cathode.

When a receiver which has a cathode ray tuning indicator is tuned be-

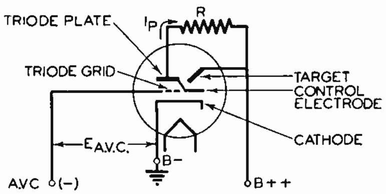


FIG. 8. Schematic symbol for a cathode ray tuning indicator tube. External resistor *R* is always used between the triode plate and the target. Circuit variations have little effect upon target current, since the target receives a constant D.C. supply voltage.

tween stations, there is no carrier signal and consequently there is no A.V.C. voltage developed across the detector load resistor. Under this condition the C bias for the triode section of the indicator tube is zero (E_{AVC} is zero) and D.C. plate current I_P for the triode section depends upon the B++ supply voltage, the value of resistor R and upon the plate-to-cathode resistance of the triode section. Since this plate-to-cathode resistance is quite low for zero grid bias, current I_P is high, and creates a high voltage drop across R. The triode plate voltage is consequently considerably less than the target voltage (because of this drop across R). The control electrode (connected directly to the triode plate) likewise has considerably less voltage than the target when no station is tuned in, and the shadow angle is therefore large.

When the receiver is tuned to a desired station carrier signal (is tuned to resonance), the A.V.C. voltage developed across the detector load increases, driving the triode grid of the indicator tube negative and increasing the D.C. plate resistance of the triode section. The result is reduced D.C. plate current and a lowered voltage drop across resistor R. The triode plate voltage and the control electrode voltage become more nearly equal to the target voltage, and the increasing positive voltage on the control electrode decreases the shadow angle on the target. This shadow angle will be a minimum when the receiver is tuned exactly to resonance for a particular station. For distant stations the minimum shadow angle will be considerably greater than for local stations.

It is possible to adjust a cathode ray indicator tube circuit to make the shadow vanish for either small or large A.V.C. voltages. With circuits designed so the shadow closes on low A.V.C. voltages, however, the tuning in of strong carrier signals will completely close the shadow before resonance occurs and an exact indication of resonance will not be possible. On the other hand, if the circuit is designed so the shadow will completely close only for strong local carrier signals, then the change in shadow angle for weak signals may be inadequate for accurate tuning. (This is not a serious drawback, however, for it is ordinarily easy to tune in a *weak* station accurately by ear.)

The A.V.C. voltage is, of course, the primary control upon the shadow angle. The angle for zero A.V.C. voltage is governed essentially by the design of the tube, but the amount which the shadow closes for a given increase in A.V.C. voltage is determined by the target voltage and by the value of series resistor R.

Curve *1* in Fig. *9* tells how the shadow angle varies with A.V.C. voltage when the supply voltage is low

(100 volts) and the ohmic value of R is low (.5 megohm). Observe that the shadow angle is 90 degrees for zero A.V.C. voltage, and the shadow is completely closed (0° shadow an-

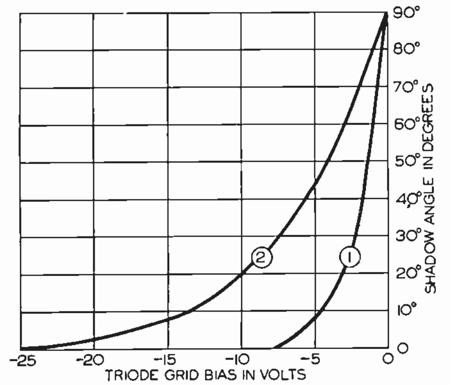


FIG. 9. This graph shows how shadow angle varies with grid voltage for a 6G5 cathode ray tuning indicator tube. Curve *1*: R = .5 megohm and B++ voltage = 100 volts; curve *2*: R = 1 megohm and B++ voltage = 250 volts.

gle) at an A.V.C. voltage of about —8 volts (the curves in Fig. *9* apply to a 6G5 tube). Curve *2* in Fig. *9* is for a high plate supply voltage and a high value of R; in this case the shadow does not close until the A.V.C. voltage has driven the triode tube grid to —23 volts.

We can draw the following conclusions from the curves in Fig. *9*: *1*, to make the shadow close at a more negative grid bias value, increase the supply voltage to the tube; *2*, to make the shadow close at a less negative value (so it will close for weak carrier signals), reduce the supply voltage to the tube. To secure the desired open shadow angle, usually about 90 degrees, adjust resistor R when no carrier signal is present. With these facts in mind, you will be able to adjust a cathode ray indicator tube for satisfactory operation on either local or distant stations. Most receivers are adjusted for a characteristic curve approximating curve *2* in Fig. *9*, for this gives a reasonable change in shadow angle at all reasonable carrier levels.

Adding a Cathode Ray Indicator Tube to a Receiver. A suitable circuit is shown in Fig. *10A*; all parts which are added to the original receiver circuit are shown in heavy lines. Note that the grid of the 6G5 cathode ray tuning indicator tube is connected through a 1-megohm resistor R_1 to the A.V.C. voltage source in the receiver. This connection could be to the minus terminal of the diode detector load, but since this terminal may furnish as much as —40 volts when a strong local station is tuned in, it is better to place voltage divider R_2-R_3 across the diode load and make a connection to this.

The larger the value of R_2 with respect to that of R_3, the lower will be the maximum A.V.C. voltage applied to the indicator tube. R_1 prevents the 6G5 tube from shorting the diode load

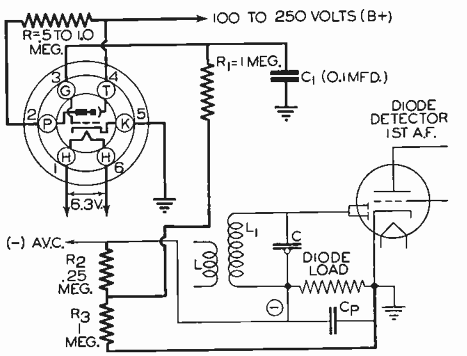


FIG. 10A. This diagram shows you how a cathode ray indicator tube would be connected between the A.V.C. supply terminal and ground in a receiver. The only extra parts required, in addition to the type 6G5 indicator tube and its standard 6-prong socket, are resistors R, R_1, R_2 and R_3, and condenser C_1. You will sometimes find the control electrode and target represented as shown here rather than as in Fig. *8*, so learn to recognize both types of diagrams.

or the voltage divider; in addition, R_1 serves with C_1 as an A.F. filter which prevents the shadow from flickering at an A.F. value.

Wide-Angle Tuning. The shadow angle for a no-signal condition in the average cathode ray tuning indicator tube is 90°, but this can be increased approximately to 180° by inserting an ordinary triode amplifier tube between the A.V.C. supply terminal and the indicator tube in the manner shown in Fig. *10B*.

When there is no carrier signal in the diode second detector circuit of a receiver, there is no A.V.C. voltage developed across the diode load, and consequently the grid of VT_1 in Fig. *10B* will be at zero bias. The plate

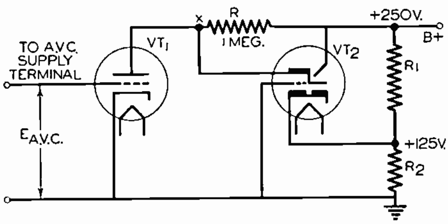


FIG. 10B. A shadow angle of approximately 180° can be secured with this cathode ray tuning indicator circuit.

current of this tube is then high, and the plate-cathode resistance of VT_1 drops so low that point x is nearly at ground potential. Since the cathode of VT_2 is +125 volts with respect to ground, the triode plate and the control electrode of VT_2 are —125 volts with respect to the cathode of this tube; under this condition the shadow angle is approximately 180°.

When a highly negative A.V.C. voltage is applied to the grid of VT_1 (tuning the receiver to a powerful local station would do this), the plate current of VT_1 drops nearly to zero; under this condition the D.C. resistance of VT_1 is so much higher than the 1-megohm resistance of R that point x practically assumes B+ potential of +250 volts. This places the triode plate and the control electrode at about +125 volts with respect to the cathode of VT_2, giving zero shadow angle. Weaker signals give shadow angles between 0 and 180°, with the change in shadow angle while tuning in a station being about twice as great as for an ordinary indicator circuit; this, of course, makes more accurate tuning possible.

Unique Tuning Aids

Although the milliammeter and the cathode ray tuning indicator tube are the most widely used tuning aids, a number of other unique methods have been developed. Three of these will be considered at this time: *1*, the G.E. Colorama indicator, using red and green lamps; *2*, the neon lamp flasher; *3*, the zero beat tuning indicator.

G. E. Colorama Tuning Indicator. The circuit diagram of the Colorama tuning indicator used in a number of General Electric receivers is shown in Fig. *11*. The A.V.C. voltage developed by the diode detector in the receiver is applied to the control grid of an ordinary type 6C5 triode tube (designated as the Colorama tuning indicator tube). In the plate circuit of this tube is the primary of the Colorama tuning reactor (an iron-core transformer) while across the secondary of this transformer is an arrangement of three green lamps in series and four red lamps in series-parallel, connected as indicated in Fig. *11*. Condenser *C52*, across the primary of the transformer, serves to filter out any A.F. components in the A.V.C. voltage; *R28* and *C53* are power pack supply filters.

When the A.V.C. voltage is low or zero, as it is when the receiver is tuned off resonance or between stations, the C bias on the 6C5 tube is zero and D.C. plate current for this tube is therefore quite high. This high plate current flowing through the primary of the Colorama tuning reactor saturates its iron core. *This core saturation lowers the reactance of the secondary winding,* so that it is practically a short-circuit path for 60-cycle alternating current. Under this condition the green lamps are in effect shunted by the 15-ohm resistor *R30*, and the current which is sent through the bank of red lamps and *R30* by secondary winding *S* on the receiver power transformer is high enough to light all of the red lamps. We thus have the red lamps glowing whenever the A.V.C. voltage is reduced by tuning between stations.

Now let us see what happens when a station is tuned in. Tuning the receiver to resonance increases the negative A.V.C. voltage applied to the grid of the 6C5 tube, and the plate current of this tube drops. The core of the Colorama tuning reactor becomes less saturated as primary current drops, and consequently the inductance of secondary winding *L28* increases. The reactance of this secondary winding at 60 cycles is correspondingly increased, reducing the shunting effect of *R30* and thus increasing the resistance of the entire circuit across transformer winding *S*. Less current now flows through the red lamps, and they begin to grow dim.

At a critical negative A.V.C. voltage, full current (.150 ampere in this case) flows through the green lamps, lighting them brightly, while the current through a red lamp is only half of the circuit current, because of the series-parallel connection. Resistor *R30* controls the maximum current which can flow through the red lamps when the receiver is off-tune, while resistor *R29* controls the current which the green lamps can draw when the receiver is tuned to a station, and also controls to a certain extent the current for the red lamps. These resistors must be properly adjusted if the red lights are to illuminate the station selector dial when the receiver is off resonance, and the green lights are to illuminate the dial when the receiver is at resonance.

Neon Lamp Flasher Indicator. A single neon lamp connected into a circuit which causes it to glow only when a station is tuned in, serves as the tuning indicator for a number of Silvertone receivers. The circuit diagram is shown in Fig. *12;* an ordinary I.F. transformer with weak coupling

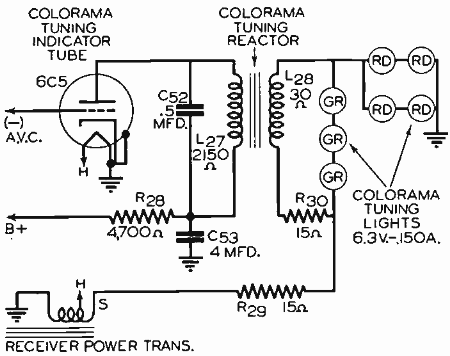


FIG. 11. Circuit diagram of the Colorama tuning indicator used in General Electric Models E-101, E-105 and E-106 receivers. The green lamps light up when the receiver is properly tuned; red lamps illuminate tuning dial whenever receiver is off tune. The reactance values given here for the primary and secondary (*L27* and *L28*) of the Colorama tuning reactor are for 60 cycles A.C. Ohmmeter measurements will therefore give considerably lower values.

between the tuned primary and tuned secondary is connected between the primary of the last I.F. transformer and the 6B7 duo-diode-pentode which is designated as the flasher tube. Primary circuit L_1-C_1 of this extra I.F. transformer forms a series resonant circuit which is connected across condenser *C* in the last I.F. transformer circuit, with the result that the small I.F. voltage drop across condenser *C* is applied to L_1-C_1. At resonance this series resonant circuit acts as a low resistance, and hence does not affect the plate load of the last I.F. stage. Loose coupling between L_1 and L_2 insures higher selectivity for resonant circuits L_1-C_1 and L_2-C_2 than could be secured in the I.F. amplifier, for we are not concerned with fidelity in the tuning indicator circuit.

The I.F. voltage developed across resonant circuit L_2-C_2 is rectified by the diode section of the 6B7 flasher tube, and a rectified voltage is developed across the 1-megohm diode load resistor. The control grid of the pentode section is connected to the negative terminal of this load resistor.

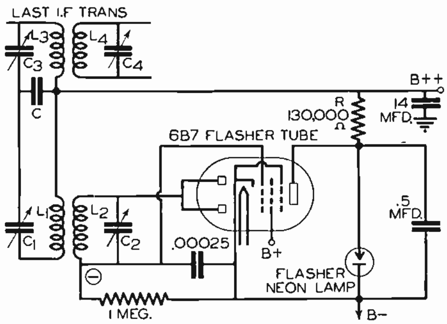


FIG. 12. Neon lamp flasher indicator circuit as used in Silvertone Models 1722 and 1732 receivers. The neon flasher lamp glows only when the receiver is tuned correctly.

The plate of the pentode section receives its D.C. voltage through 130,000-ohm resistor *R;* between the plate and the cathode is the flasher neon lamp which glows only when its terminal voltage exceeds a definite value. Furthermore, the terminal voltage of this neon lamp is equal to the supply voltage minus the voltage drop in resistor *R*.

When the receiver is tuned off resonance, little or no I.F. voltage is applied to the diode section of the 6B7 flasher tube. As a result, no rectified voltage exists across the 1-megohm resistor, the C bias on the pentode section is practically zero, and plate current of the pentode section is high. This plate current produces a large voltage drop across resistor *R*, making the neon lamp voltage too low for it to glow. Since resonant circuits L_1-C_1 and L_2-C_2 are highly selective, the receiver must be tuned exactly to resonance before enough I.F. signal can get through these circuits to excite the diode section and produce sufficient negative voltage across the 1-megohn resistor to reduce the pentode plate current to a low value. Reducing the plate current reduces the voltage drop across *R* and raises the neon lamp voltage. The lamp therefore glows when the receiver is properly tuned to a station. When the receiver is tuned rapidly from station to station, the lamp flickers each time a station is passed; this is why this particular arrangement is known as a flasher indicator.

Zero Beat Tuning Indicator. If the I.F. carrier signal produced by the mixer-first detector of a receiver is mixed with a locally-produced signal having exactly the correct I.F. value, and this mixing occurs just ahead of the second detector, an audio beat (low-frequency audio note) will be heard in the loudspeaker whenever the receiver is improperly tuned to a station.

When the receiver is properly tuned, the difference between the two I.F. signals will be less than 30 cycles, and the beat note will therefore be inaudible. When the receiver is tuned off a station, there will be no incoming I.F. signal to beat with the locally produced signal, and consequently no audio beat will be heard. A zero beat indicator of this type is entirely satisfactory provided the listener does not object to the squeal which occurs while tuning in a station. Furthermore, this indicator is effective regardless of whether the I.F. amplifier is peaked or band-passed. A zero beat tuning indicator is also of great value when tuning in continuous wave code signals, for it provides an audible tone for these signals.

The special local oscillator circuit which is used as a zero beat tuning indicator in one receiver is shown in

Fig. *13.* The oscillator tank circuit is made up of L_1 and C_1, with C_1 being adjusted to make this circuit produce a frequency exactly equal to the I.F. value of the receiver. A.C. plate

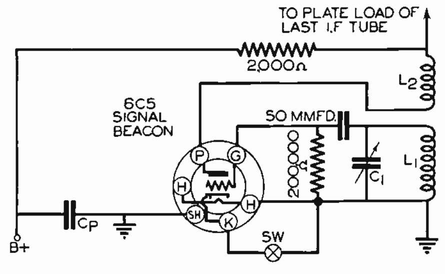


FIG. 13. Circuit of the R.F. oscillator which serves as a zero beat tuning indicator in the Grunow Model 12A-1241 receiver.

current flowing through coil L_2 induces in L_1 the feed-back voltage required for oscillation. The A.C. plate current produced by this oscillator flows through a 2,000-ohm resistor which is also in the plate supply lead of the last I.F. amplifier stage. The result is that an A.C. voltage is superimposed on the D.C. plate voltage applied to this last I.F. stage. Two signals, the exact I.F. signal produced by the oscillator and the I.F. signal produced by tuning the receiver to a station, reach the second detector. After detection, we have left the desired audio signal and a beat note equal to the difference between the two I.F. signals; when the receiver is accurately tuned to a station, this difference will be zero, the beat note will disappear, and we have what is known as zero beat.

Essential Sections of an A.F.C. System

The two essential sections of an A.F.C. system are: *1, the discriminator,* which usually produces a positive D.C. control voltage for below-normal I.F. signal frequencies, and a negative D.C. control voltage for above-normal I.F. signal frequencies with the value of this voltage being proportional to the amount of error in tuning; *2, the oscillator control circuit,* which converts the *D.C. control voltages* (produced by the discriminator) into changes in the effective inductance shunting the oscillator coil, thereby compensating for errors in tuning. The positions of these sections with respect to the other stages of a conventional superheterodyne receiver having A.F.C. are clearly shown by the box diagram in Fig. *14.* Note that the I.F. amplifier feeds both the discriminator and the second detector.

The Discriminator Circuit

Typical Discriminator Circuit. The easiest way to see how the discriminator circuit in an A.F.C. system can furnish a D.C. control voltage of suitable polarity is to consider an actual discriminator circuit, as given in Fig. *15.* We will first "get our bearings" by analyzing this circuit in a general manner, after which we will be ready to consider in detail the manner in which the D.C. control voltage is produced.

In the input circuit for the discriminator tube in Fig. *15* we find parallel resonant circuit L_P-C_P serving as the plate load for the last I.F. stage, and inductively coupled to series resonant

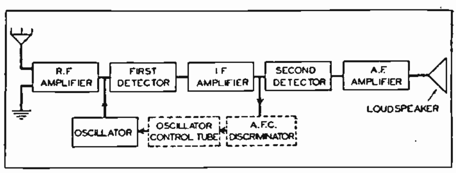


FIG. 14. The two sections shown in dotted lines must be added to a superheterodyne receiver in order to secure automatic frequency control.

circuit L_1-L_2-C. Both of these resonant circuits are tuned to the exact I.F. value of the receiver. The coil in the series resonant circuit is split into two sections of equal size, L_1 and L_2, and the plate (high R.F.) terminal of the parallel resonant circuit is connected to the common terminal of these coils through D.C. blocking condenser C_B.

The discriminator tube is a double diode rectifier tube (a 6H6 tube is most generally used), with the plate of each diode section connected to one terminal of the series resonant circuit and the cathodes connected together through equal-value resistors R_1 and R_2. Each resistor is shunted by a by-pass condenser (C_1 and C_2) and one cathode is grounded directly, hence age which we will designate as e_S. This voltage acts in series with L_1, L_2 and C in our series resonant circuit, causing a current to flow through the two coil sections. This current develops I.F. voltage e_1 across coil section L_1 and develops I.F. voltage e_2 across coil section L_2. For any condition of tuning, voltage e_1 will always be equal to e_2 *in magnitude.*

We can now see that I.F. voltage e_1 acts in series with I.F. voltage e_P on diode section D_1, and the resulting rectified electron current i_1 flows

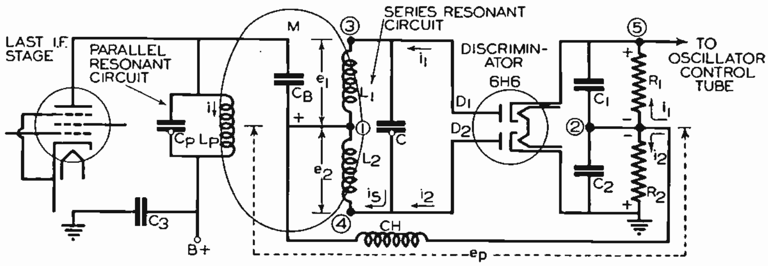


FIG. 15. Conventional discriminator circuit.

both cathodes of the discriminator tube are at ground I.F. potential.

Notice now that the I.F. voltage developed across the parallel resonant circuit in the last I.F. stage is applied across choke coil *CH*, this I.F. voltage being designated as e_P (condenser C_B provides a direct path for I.F. current from the plate end of the parallel resonant circuit to point *1* and one terminal of the choke coil, and the path from the other end of the parallel resonant circuit is through by-pass condenser C_3 to the receiver chassis, through the chassis to the grounded end of R_2 and then through by-pass condenser C_2 to point *2* and the other terminal of the choke coil). This I.F. voltage e_P developed across choke coil *CH* is in turn applied to points *1* and *2* in the discriminator circuit.

Current *i*, flowing through the coil of the parallel resonant circuit, induces into secondary coil L_1-L_2 a volt- through R_1, developing across this resistor a D.C. voltage having the polarity indicated in Fig. *15*. Likewise, e_2 and e_P act upon diode section D_2, and rectified electron current i_2 produces a D.C. voltage across R_2 with the polarity shown.

Since we are dealing with A.C. voltages in this discriminator circuit, phase must of course be taken into account when we consider their combined effects.

Correct Tuning. When the phase difference between e_1 and e_P is the same as that between e_2 and e_P, the net voltages acting upon diode sections D_1 and D_2 will be equal in magnitude; equal values of rectified current will then flow through the two resistors, making the D.C. voltage drop across R_1 equal to that across R_2. The net D.C. control voltage produced across these two resistors (between point *5* and ground) will be zero since these voltage drops are of opposite polarity, and the A.F.C. system will have no effect upon the oscillator. This is, of course, the condition for correct tuning of the receiver to a station.

Incorrect Tuning. When the frequency of the received I.F. signal does not correspond to the resonant frequency of the tuned circuits in the discriminator (because of incorrect tuning), e_1 and e_2 no longer have the same phase relationship with e_P, and consequently the A.C. voltages acting upon the diode sections are different in magnitude. Unequal rectified currents through R_1 and R_2 produce unequal voltage drops which, when combined, leave the desired D.C. control voltage to act upon the oscillator control circuit and correct for the error in tuning.

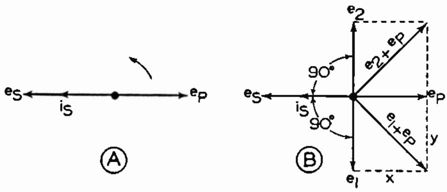


FIG. 16. Vector diagrams showing conditions in the discriminator circuit when the receiver is correctly tuned.

Since any detailed analysis of the action of an A.F.C. system must necessarily involve phase, it will be well at this time to review the fundamental facts about phase which you have already studied.

Review of Phase

All the information you need know about the phase relationships of voltages and currents for the parts in an A.F.C. circuit is given in Chart *1*, page 27. The essential facts presented by this chart, particularly by the vector diagrams in the fourth column, are:

Resistors: **The voltage across a resistor is *in phase* with the current through it.**

Coils: **The voltage across a perfect coil *leads* the current through it by 90° (the current therefore *lags* the voltage by 90°).**

Condensers: **The voltage across a perfect condenser *lags* the current through it by 90° (the current therefore *leads* the voltage by 90°).**

Transformers: **The voltage *induced* in the secondary winding of a transformer (the open-circuit secondary voltage) is 180° out of phase with the primary voltage.**

Discriminator Circuit Action

When the I.F. Signal Frequency is Correct. We will first analyze the discriminator circuit in Fig. *15* for the condition where the input I.F. signal frequency exactly corresponds to the I.F. value of the receiver. In this case parallel resonant circuit C_P-L_P and series resonant circuit L_1-L_2-C will be resonant to the incoming signal. To determine the net A.C. voltages acting on diode section D_1, we must add together A.C. voltages e_P and e_1 vectorially, so as to take into account the phase relationship of these two voltages. Likewise we must add together e_2 and e_P vectorially to find the net A.C. voltage acting upon diode section D_2. First of all, we must choose some voltage or current for reference purposes; since e_P is common to all circuits under study, we shall use it as our reference voltage. To fix this fact in mind, we draw our vector e_P along the reference line in our vector diagram, as in Fig. *16A*, using any convenient scale to determine its length.

The voltage e_S which is induced in the secondary of the discriminator transformer is 180° out of phase with the voltage across the primary (see diagram *P* in Chart *1*), and consequently we can say that e_S is 180° out of phase with e_P. We therefore place vector e_S on our vector diagram in the opposite direction from e_P, as indicated in Fig. *16A*.

Since the frequency of induced secondary voltage e_S is exactly the same as the resonant frequency of series resonant circuit L_1-L_2-C, this circuit acts like a resistance at resonance and e_S will send through the circuit a current i_S which is *in phase* with e_S, as shown in Fig. *16A*. Current i_S flows through L_1 and L_2, developing across each of these coil sections an A.C. voltage which leads the current by 90° (see diagram *H* in Chart *1*).

Rather than confuse the diagram in Fig. *16A* by adding more vectors to it, let us redraw it in Fig. *16B* and place vectors e_1 and e_2 on this new diagram. Before these vectors can be drawn, however, one other factor must be taken into account. For any direction of current flow i_S through L_1 and L_2, one of the coil voltage drops will be opposite in polarity (180° out of phase) with the other coil voltage drop in so far as e_P is concerned. This is because e_P acts in opposite directions through the two coils (it acts in the direction from point *1* to point *3* through L_1 and from point *1* to point *4* through L_2). For this reason, if we show voltage drop e_1 as leading i_S by 90°, we must show e_2 as lagging i_S by 90°, making e_1 180° out of phase with e_2. (We could just as well make e_2 lead i_S by 90° and make e_1 lag i_S by 90°, for the same results would be secured.) Now we can draw in vector e_1 and e_2, as shown in Fig. *16B*.

The next step is to find the net A.C. voltage acting upon diode section D_1 through resistor R_1. As was said before, this voltage will be equal to $e_P + e_1$ with phase taken into account. We can add these two voltages quite easily on the vector diagram in Fig. *16B*; we simply complete the parallelogram (rectangle) of which e_1 and e_P form two sides, as indicated by the dotted lines x and y in Fig. *16B*, and then draw a line from the center of our vector diagram to the intersection of these dotted lines. This line now represents the vectorial sum of voltages e_P and e_1, so we label this vector in this way. The length of vector $e_1 + e_P$ corresponds to the magnitude of the A.C. voltage acting upon diode section D_1. In a similar manner we determine that vector $e_2 + e_P$ is the net A.C. voltage acting upon diode section D_2.

These net A.C. voltages acting upon the diode sections will always be exactly equal when the I.F. signal frequency corresponds exactly to the I.F. value of the receiver. The diode sections D_1 and D_2 will consequently pass currents of equal value, and the D.C. voltage developed across R_1 by diode current i_1 will exactly equal the D.C. voltage developed across R_2 by diode current i_2. Note that these currents flow in opposite directions through R_1 and R_2, making the voltage drops across these resistors have the polarities indicated. The net D.C. voltage developed across the two resistors (between point *5* and ground) for the oscillator control circuit is therefore zero whenever the I.F. signal is of the exact value.

When the I.F. Signal Frequency is High. When the I.F. signal frequency entering the discriminator circuit is higher than the I.F. value of the receiver (higher than the resonant frequencies of L_P-C_P and L_1-L_2-C), we will naturally expect the discriminator circuit to produce a D.C. control voltage for the oscillator control circuit. Let us see how this is done.

Primary voltage e_P will again be used as our reference voltage for the vector diagram. The induced voltage e_S will again be 180° out of phase with the primary voltage e_P, so we draw the vectors for these two values as in Fig. *17A*.

Since the frequency of e_S is higher

than the resonant frequency of series resonant circuit L_1-L_2-C, the reactance of coils L_1-L_2 will be greater than the reactance of condenser C, and the entire series resonant circuit will act as an inductance whose reactance is equal to the difference between the above-mentioned reactances. We thus have voltage e_S acting upon a coil; if there were no resistance in this circuit, we could say that circuit current i_S lags the applied voltage by 90° (Chart *1*). Since this series resonant circuit has a certain amount of A.C. resistance, however, and since the net inductance is quite low near resonance, the current i_S will lag the voltage e_S by less than 90°. For explanation purposes, let us assume that series resonant circuit current i_S lags e_S by 45°. We therefore draw vector i_S lagging behind e_S by 45°, as indicated in Fig. *17A*.

Regardless of the phase relation between i_S and e_S, the voltage drops across coil sections L_1 and L_2 will lead current i_S by 90°, and since one voltage drop acts in the opposite direction from the other in so far as e_P is concerned, we can say that A.C. voltage e_1 leads circuit current i_S by 90°, and A.C. voltage e_2 lags i_S 90°. We will leave Fig. *17A* as it is, and redraw the vectors in Fig. *17B* for the complete vector diagram. Vectors e_1 and e_2 are now placed on this diagram.

Again we add e_1 and e_P, taking phase into account, to find the net A.C. voltage acting upon diode section D_1. We do this by drawing lines x and y in Fig. *17B* to complete the parallelogram having e_1 and e_P for for two of its sides. The diagonal line drawn from the center of the vector diagram to the intersection of these dotted lines now represents the net A.C. voltage, $e_1 + e_P$, acting upon diode section D_1.

In the same manner we add A.C. voltages e_2 and e_P in Fig. *17B*, getting the somewhat longer vector $e_2 + e_P$ as the net A.C. voltage acting upon diode section D_2. We can see immediately that vector $e_2 + e_P$ is longer than vector $e_1 + e_P$; this means that a higher voltage acts upon diode section D_2 than upon D_1 in Fig. *15*, and a higher rectified current therefore flows through R_2 than through R_1. The D.C. voltage drop across R_2 will therefore be greater

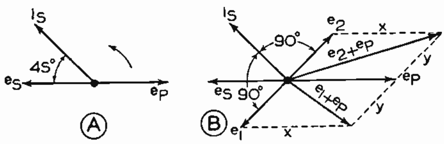


FIG. 17. Vector diagrams showing conditions in the discriminator circuit when the I.F. signal frequency is higher than the I.F. value of the receiver.

than the D.C. voltage drop across R_1, and only a part of the drop across R_2 will be canceled out by the drop across R_1. This leaves point *5* negative with respect to ground and this negative D.C. voltage constitutes the D.C. control voltage applied to the oscillator control circuit. The higher the I.F. signal is above the I.F. value of the receiver, up to a certain limit, the higher will be this negative D.C. control voltage.

When the I.F. Signal Frequency is Low. If we repeat our analysis of the discriminator circuit in Fig. *15* and draw a vector diagram for the condition where the I.F. signal frequency is lower than the I.F. value of the receiver, we would find that net A.C. voltage $e_1 + e_P$ would be larger than $e_2 + e_P$, with the result that diode section D_1 produces a higher rectified voltage across R_1 than diode D_2 does across R_2. The drop across R_2 would cancel out only a part of the drop across R_1, with the result that the D.C. control voltage between point *5* and ground would have the same polarity as the drop across R_1. The net D.C. control voltage is therefore *positive* with respect to the ground or chassis when the I.F. signal frequency is *lower* than the I.F. value of the receiver.

S Curve for Discriminator Circuit. The manner in which the D.C. control voltage produced by the discriminator varies with the I.F. signal frequency is usually expressed by radio engineers in the form of a graph like that in Fig. *18.* The curve on this graph is called an *S curve.* Note that a positive D.C. control voltage is produced for I.F. signal frequencies below the I.F. value of the receiver, and a negative D.C. control voltage is produced for I.F. signal frequencies above the I.F. value; this verifies the results of our analysis of the circuit in Fig. *15.* Observe also that the D.C. control voltage increases quite uniformly as we go above or below resonance, up to points *a* and *b*. The part of the curve between these two points is the operating range for the discriminator; slightly beyond *a* and *b*, further deviations from the resonant frequency do not give additional increases in D.C. control voltage. As a result, there is insufficient control beyond these points and A.F.C. action is not complete. From a practical standpoint, this means that I.F. signal frequencies between points *a* and *b* will be properly corrected by the A.F.C. system, while frequencies outside this range will not be "pulled in" satisfactorily.

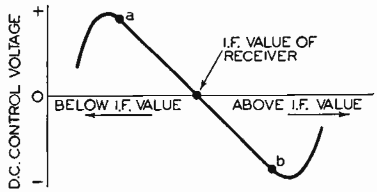


FIG. 18. S-curve showing output characteristics of a discriminator circuit.

The Oscillator Control Circuit

The D.C. control voltage developed by the discriminator (sometimes called the *discriminator voltage*) must be converted by the oscillator control circuit into an action which will increase or decrease the oscillator frequency the correct amount to make the I.F. signal frequency exactly equal to the I.F. value of the receiver. Since the frequency developed by the oscillator circuit is essentially controlled by the capacity of the oscillator tank circuit condenser and the inductance of the tank coil, this D.C. control voltage must be converted into a capacity or inductance which, when applied to the oscillator resonant circuit, will give the necessary change in frequency. In a practical oscillator control circuit, the vacuum tube is usually made to act as an inductance, for this produces a more uniform A.F.C. action over the entire band.

Before taking up an actual oscillator control circuit, let us see how we can tell when a vacuum tube is acting as a coil. We know that when a coil is connected to an A.C. voltage source, the current drawn by the coil will lag the voltage by 90°. Suppose we had a box with two terminals, and some unknown electrical device inside. If we connected this box to an A.C. voltage source and found that the current through the box lagged the voltage by 90°, we would immediately say that the box acted like a coil. As far as the A.C. voltage source is concerned, this box is behaving as an inductance.

When we increase the inductance of an ordinary coil, the reactance of the coil increases and as a result, the current through the coil is reduced. In other words, if the coil draws a low current, it has a high inductance; if the coil draws a high current, it has a low inductance. If, now, our imaginary box draws a high current which lags the voltage by 90°, we would say that this box has a low inductance; if the box draws a low current, we would say that it has a high inductance. You will soon see that we can consider the oscillator control circuit as an imaginary box having two terminals which are connected across one of the coils in the oscillator resonant circuit.

Now let us review a few fundamental facts about coils. When one coil is connected in parallel with the other, the inductance of the combination is less than that of either coil. Increasing the inductance of one of these coils increases the inductance of the combination, and likewise, decreasing the inductance of one coil decreases the inductance of the combination. An increase in inductance lowers the resonant frequency of a resonant circuit; a decrease in inductance increases the resonant frequency.

General Analysis of Oscillator Control Circuits. Now we are ready to investigate the behavior of the oscillator control circuit, to see how the D.C. control voltage produced by the discriminator can make this circuit act like an inductance and can change its effective inductance to correct for errors in tuning. A typical oscillator control circuit, along with the special superheterodyne oscillator circuit upon which it acts, is shown in Fig. *19A.*

Note that the D.C. control voltage produced by the discriminator is applied to the control grid of the type 6J7 oscillator control tube through resistor R_2. This D.C. control voltage, acting in series with the automatic C bias voltage produced by C_C and R_C, determines the average D.C. plate current for the oscillator control tube. Turning now to the oscillator circuit, coil L_O and tuning condenser section C_O form the oscillator tuned circuit, with trimmer condenser C_{PD} serving as the oscillator padder. Condenser C_g is the R.F. grid coupling condenser, and serves together with R_g to produce the rectified D.C. grid voltage for the 6K7 oscillator tube. Coil L_T is connected between the plate and grid circuits of the oscillator, and therefore provides feed-back; the upper end of this coil is grounded for R.F. current through by-pass condenser C_P. The oscillator tube receives its D.C. plate voltage through feed-back coil L_T, while the oscillator control tube receives its D.C. plate voltage through oscillator tank coil L_O.

Resistor R_1 and condenser C_1 in the oscillator control circuit are connected directly across the oscillator coil L_O in so far as R.F. currents are concerned, and form what is known as the *phase-shifting network.* This network receives the full R.F. voltage developed by the oscillator circuit, for C_P is an R.F. by-pass condenser. The resist-

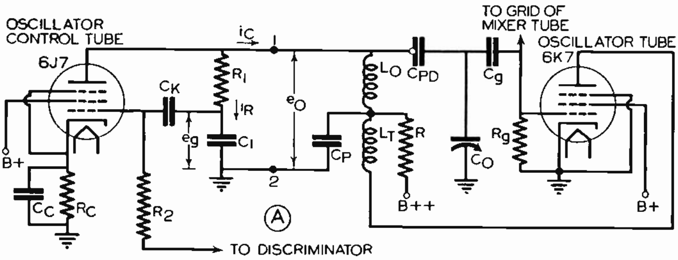


FIG. 19A. Conventional oscillator control circuit (to the left of points *1* and *2*) and receiver oscillator circuit which it controls (to the right of points *1* and *2*).

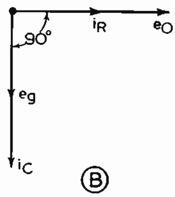


FIG. 19B. Vector diagram for oscillator control circuit.

ance of R_1 is so much greater than the reactance of condenser C_1 that we can consider this phase-shifting network as essentially a resistance. This means that the oscillator coil voltage e_O will send through R_1 and C_1 an R.F. current i_R which is essentially in phase with e_O.

Let us again resort to vector diagrams, to avoid the need for keeping phase relationships in mind while studying the circuit. We will use e_O as our reference vector, and it is therefore drawn as shown in Fig. *19B*. Vector i_R can now be placed, also along the reference line since it is in phase with e_O.

The flow of R.F. current i_R through C_1 develops across this condenser an R.F. voltage e_g which lags i_R by 90° (see diagram *L* in Chart *1*). We therefore draw vector e_g lagging behind i_R by 90°. This R.F. voltage e_g is applied to the control grid of the oscillator control tube through D.C. blocking condenser C_K, causing A.C. plate current i_C to flow through the oscillator control tube. This plate current will be in phase with the A.C. grid voltage, for this is a conventional amplifier circuit action in which a positive increase in the grid input voltage results in an increase in the plate current. We therefore draw vector i_C in phase with vector e_g, as in Fig. *19B*. Our vector diagram now shows clearly that R.F. current i_C lags oscillator coil voltage e_O by 90°. If we consider that part of the circuit to the left of points *1* and *2* in Fig. *19A* as a device having two terminals, we can readily see that the current i_C which is drawn by this device will lag by 90° the voltage e_O which is applied to the device. We have thus shown that the oscillator control circuit acts as an inductance shunting the oscillator coil L_O.

Now let us see how the D.C. control voltage produced by the discriminator will affect the value of this inductance shunting L_O. If the D.C. control voltage which is applied to the grid of the oscillator control tube through R_2 is positive with respect to ground, the net bias on this grid will become less negative, increasing the D.C. plate current of the oscillator control tube. Since this 6J7 tube is operated on the curved portion of its E_g-I_p characteristic curve, the increase in D.C. plate current produced by a positive D.C. control voltage moves the operating point for the tube to a steeper portion of the E_g-I_p characteristic. This means that a given A.C. voltage e_O on the grid of the tube will produce a larger A.C. plate current i_C, making this stage act as a smaller inductance. If the D.C. control voltage is negative, the net C bias voltage on the 6J7 tube becomes more negative. This shifts the operating point nearer to plate current cut-off, and e_O produces a low A.C. plate current, making this stage act as a larger inductance. Clearly, *the D.C. control voltage produced by the discriminator* serves to change the effective inductance of the oscillator control circuit.

Now, for the first time, we can consider the action of the entire A.F.C. system. When the receiver is properly tuned, so that the I.F. signal frequency corresponds to the resonant frequency of the discriminator resonant circuit, no D.C. control voltage is produced by the discriminator and the only C bias acting upon the oscillator control tube is that produced by C_C and R_C. This bias sets the operating point for the tube at a point which allows a medium value of A.C. plate current i_C to flow. The inductance corresponding to this A.C. plate current, acting in shunt with the oscillator inductance L_O, has been allowed for in the design of the oscillator, and consequently the A.F.C. system can be considered inactive when the receiver is properly tuned.

When tuning is such that the I.F. signal frequency is below the I.F. value of the receiver, the discriminator produces a positive D.C. control voltage which increases the A.C. plate current and decreases the inductance effect of the oscillator control tube, thereby decreasing the shunt inductance across the oscillator tank coil and increasing the oscillator frequency.

When the I.F. signal frequency is higher than the correct value for the I.F. amplifier, the discriminator will produce a negative D.C. control voltage which makes the net negative C bias on the oscillator control tube more negative. The result is a decrease in A.C. plate current i_C; this corresponds to an increase in the effective inductance shunting oscillator inductance L_O, and this action of course lowers the oscillator frequency just enough to compensate for incorrect tuning.

The A.F.C. system cannot correct completely for errors in tuning, for then there would be no D.C. control voltage for correction purposes. The response of the I.F. amplier is always broad enough to allow for small errors in tuning, however, and consequently the A.F. action is satisfactory for all practical purposes.

Typical A.F.C. Circuits

Although the circuits in Figs. *15* and *19* have given the basic principles of A.F.C. systems, you will find a great many variations of these circuits. Before analyzing a number of typical circuits to familiarize you with these variations, let us consider briefly those components of each section which are to be found in all A.F.C. systems.

The discriminator section can be identified on the circuit diagram of a receiver having A.F.C. by the fact that it will have *a double-diode vacuum tube, with the two diode plates connected into a tuned circuit having a split or center-tapped coil which is fed with the I.F. amplifier output voltage both inductively and by a direct connection to the center tap.* Each diode section thus gets two distinct I.F. voltages: *1*, half of the I.F. output voltage of this resonant circuit; *2*, the I.F. amplifier output voltage. The phase relationship between the voltages determines what the resultant I.F. voltage acting on each diode section will be.

In general, the oscillator control tube will have C bias voltages produced by two different sources: *1*, by a cathode circuit resistor; *2*, by the discriminator, feeding through a resistance-capacitance filter which keeps out R.F. components. Furthermore, the oscillator control circuit will have a phase-shifting network, usually made up of a resistor in series with a condenser, the combination being in shunt with the coil of the oscillator resonant circuit. The condenser in this phase-shifting network will have a very low capacity, ordinarily from about 2 mmfd. to 20 mmfd. Occasionally the grid-to-cathode inter-electrode capacity of the oscillator control tube will be used in place of a separate phase-shifting condenser.

With these general ideas in mind, we are ready to consider a few of the unique variations of the basic A.F.C. circuit just studied.

General Electric A.F.C. System. In Fig. *20* is shown the circuit diagram of the A.F.C. system and associated circuits used in General Electric Models E-101, E-105 and E-106 all-wave superheterodyne receivers. The A.F.C. system follows very closely the fundamental circuit presented in Figs. *15* and *19*, except that the discriminator in this General Electric circuit also serves as second detector and A.V.C. tube.

The output of the I.F. amplifier feeds into the discriminator circuit, through a conventional split-secondary I.F. transformer with which you are already familiar (Fig. *15*). Notice, however, that the resistor between the cathodes of the double-diode tube is divided into three sections rather than two. Point *2* is the midpoint of this resistor network. Between this point and the upper cathode (point *4*) is a 470,000-ohm load resistor, while between point *2* and point *1*, the lower cathode, is a 220,000-ohm resistor in series with a 270,000-ohm unit, these together being approximately equal to the 470,000-ohm resistor. The tap at point *3* serves to provide a lower A.V.C. voltage for one or more of the A.V.C.-controlled stages in the receiver.

Ordinarily we would expect the circuit to be grounded to the chassis at point *1;* instead, however, it is grounded through a 10 mfd. condenser of low voltage rating, which provides an entirely satisfactory ground for I.F. and A.F. signals. The use of this condenser permits connecting point *1* through a 100,000-ohm resistor to a —3 volt terminal in the power pack voltage divider. In this way all A.V.C.-controlled tubes in the receiver get an initial C bias of —3 volts, eliminating the need for automatic C bias resistors in some of the cathode circuits. The 100,000-ohm resistor and 10 mfd. condenser also serve to keep power pack hum out of the discriminator circuit.

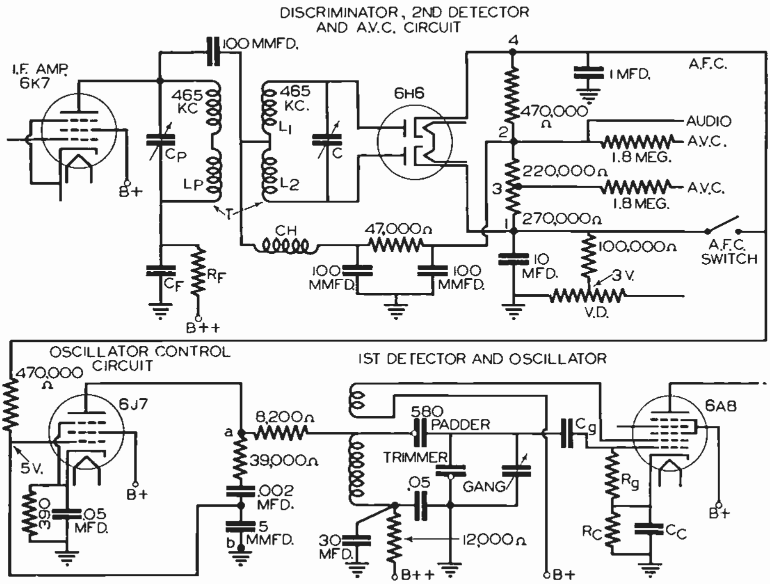


FIG. 20. Circuit diagram of the A.F.C. system used in General Electric Models E101, E105 and E106 receivers.

The cathode of the upper diode section is grounded through a 1 mfd. condenser, and the cathodes of both diode sections are therefore at ground R.F. potential. It is not essential that condensers of equal capacity be across each diode load resistor. The A.V.C. sources feed through 1.8-megohm A.V.C. filter resistors.

A resistance filter made up of two 100 mmfd. condensers and a 47,000-ohm resistor is placed between point

2 and choke coil *CH* in order to place point *2* at ground potential for I.F. currents. These two condensers are not large enough to by-pass any audio currents to ground, but they do serve to keep I.F. currents out of the audio circuit.

Now locate the A.F.C. switch in the discriminator circuit. When this switch is closed, the A.F.C. voltage developed between point *4* and point *1* is shorted out, and no D.C. control voltage is applied to the oscillator control tube. The receiver now behaves like any ordinary superheterodyne receiver not having A.F.C. At first glance, one might believe that the A.F.C. switch also shorts out the A.F. and A.V.C. voltages; actually, however, the discriminator circuit becomes a full-wave detector, as shown in Fig. *21*, when the switch is closed. With this connection, one diode will rectify one-half of each cycle of the I.F. signal, and the other diode will rectify the other half of each cycle. Both half-wave rectified currents are fed through the same parallel resistors, thus providing full-wave rectified voltages across these resistors.

The 1-mfd. condenser between point *4* and ground acts with the diode load resistors as a time delay which prevents immediate building up of the D.C. control voltage produced by the discriminator. The duration of this time delay is purposely made longer than the A.V.C. time delay, in order that the I.F. signal delivered to the input of the discriminator will reach its final value before A.F.C. circuit action begins. This is necessary because the D.C. control voltage produced by the discriminator is dependent upon the intensity of the I.F. signal as well as upon the amount by which it is off resonance (the greater the intensity of the I.F. signal, the greater will be the D.C. control voltage available for correcting mistakes in tuning, and consequently the A.F.C. system will be able to pull in strong stations even though the tuning dial setting may be considerably off from its correct value for that station).

The D.C. control voltage produced by the discriminator in Fig. *20* is fed to the control grid of the oscillator

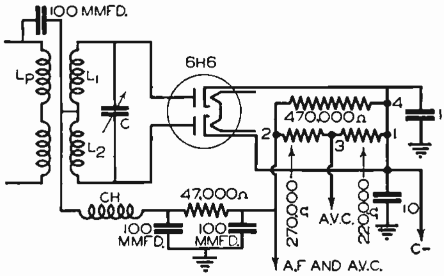


FIG. 21. When the A.F.C. switch in the circuit of Fig. *20* is closed, the discriminator circuit is transformed into the conventional full-wave detector circuit shown here.

control tube through a 470,000-ohm circuit-isolating resistor. The parts between points *a* and *b* in the oscillator control circuit form the phase-shifting network. A .002-mfd. condenser is inserted between the customary resistor and phase-shifting condenser to prevent the D.C. plate supply source from acting upon the control grid of the oscillator control tube. This extra condenser has negligible reactance at R.F. signal frequencies, and therefore serves merely as a D.C. blocking condenser.

The oscillator control circuit to the left of points *a* and *b* acts as an inductance whose value depends upon the polarity and magnitude of the D.C. control voltage provided by the discriminator; thus effective inductance is shunted across the coil in the oscillator resonant circuit, the circuit being through a 30 mfd. condenser which serves as a D.C. blocking condenser, and through an 8,200-ohm resistor which has the effect of equalizing over the entire tuning range of the receiver the amount of shunt inductance applied to the oscillator resonant circuit.

With these facts in mind, you should have no difficulty in completing an analysis of this General Electric A.F.C. system. It reacts in exactly the same way as the circuits in Figs. *15* and *19* to I.F. signals which are above or below the I.F. value of the receiver.

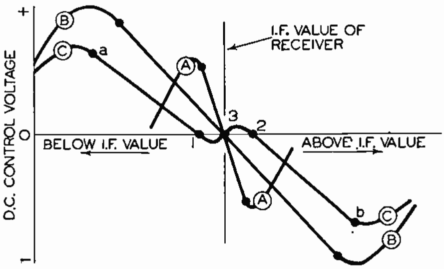


FIG. 22. Types of S-curves obtained with discriminator transformers having various degrees of coupling.

Discriminator Transformer Design Problems. The conventional discriminator transformer used in the circuits of Figs. *15* and *20* require careful design. Weak coupling between the primary winding and the split secondary winding makes these two tuned circuits highly selective, giving the S-curve marked *A* in Fig. *22*. The steepness of the linear region of this curve indicates that stations will be pulled in very close to the I.F. value (to point *3*); the small frequency difference between the ends of the linear region means that manual tuning must be quite accurate before A.F.C. will take hold, and the relatively low magnitudes of D.C. control voltages provided by curve *A* may not be sufficient for full correction.

Approximately critical coupling gives S-curve *B*, indicating greater D.C. control voltages and a greater frequency range over which A.F.C. will pull in a station; in fact, the linear range may be too wide, allowing an undesired station to be dragged over an adjacent desired station. The linear section of the curve is less steep, indicating that A.F.C. will not correct as completely as with curve *A*, but a deviation of a few hundred cycles from resonance is ordinarily quite permissible.

When coupling is greater than the critical value, the two tuned circuits interact, giving a double-peak response curve which results in the undesirable S-curve at *C* in Fig. *22*. This curve tells us that I.F. signals which are outside of the region between points *1* and *2* will be pulled in to a frequency corresponding to these points rather than to the correct I.F. value at point 3.

The curves in Fig. *22* show clearly that the design of a discriminator transformer must be a compromise between the various desired performance characteristics. In addition, the receiver must have a good A.V.C. system, in order that signals which are received at different signal levels will produce almost identical voltages in the discriminator circuit. If this were not true the amount of correction provided for mistuning would vary with the strength of the signal picked up.

Silvertone (Sears Roebuck) A.F.C. System. The manufacturers of Silvertone receivers, as well as a number of other manufacturers, have overcome these discriminator transformer design problems by using a triple-tuned circuit ahead of the discriminator, as shown in Fig. *23*. The three resonant circuits, L_1-C_1, L_2-L_M-C_2, and L_3-L_4-C_3 are all peak-tuned to the I.F. value of the receiver. Circuit L_3-L_4-C_3 is designed with the correct Q factor to give the desired S characteristic, and the coupling between L_M and L_3-L_4 is made close enough to give the required voltages across L_3 and L_4 for the diode sections.

Another unique feature of this Silvertone A.F.C. system is the absence of the choke coil ordinarily found between points *1* and *2*. In this particular circuit the choke coil is unnecessary because the required voltage is developed by the middle resonant circuit (L_2-C_2-L_M) which is directly connected between points *1* and *2*. Point *2*, being negative with respect to ground and having a potential which is proportional to the rectified current flowing through the lower diode load resistor, serves as the A.V.C. terminal. The 1-megohm resistor and .05 mfd. condenser make up the A.V.C. filter which removes A.F. and I.F. components from the A.V.C. voltage and at the same time determines the time constant of the A.V.C. system. Point *2* also serves as the A.F. voltage supply terminal, with the .05 megohm resistor and the two .00025 mfd. condensers keeping I.F. signals out of the audio amplifier. Terminal *3* on the diode load resistor network is, of course, the point from which the D.C. control voltage for A.F.C. purposes is fed into the oscillator control circuit. The connection is through a 1-megohm resistor and .1 mfd. condenser which serve as the A.F.C. filter. The time constant of this filter is greater than that of the A.V.C. filter, as is required.

The oscillator control circuit in Fig. *23* is of conventional design, with R_N and C_N serving as the phase-shifting network. The receiver oscillator is of the tuned plate type, with the phase-shifting network shunting the oscillator tuning coil.

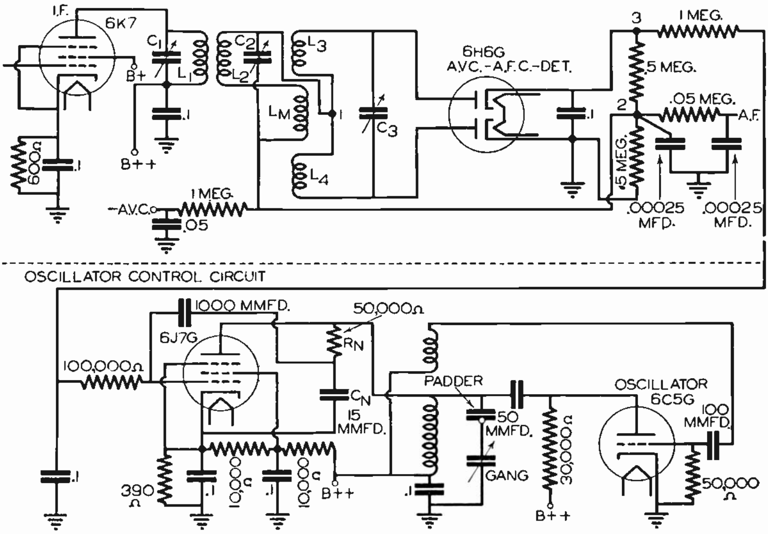


FIG. 23. Circuit diagram of the A.F.C. system used in the Silvertone model 4587 receiver.

A somewhat similar discriminator circuit is also used in one RCA A.F.C. system; the essential difference between the RCA and Silvertone circuits is shown in Fig. *24*. The first two tuned circuits in the discriminator transformer are the same in both cases, the difference being in the third tuned circuit. Note that in Fig. *24* coil L_M induces a voltage in the split-coil arrangement L_3-L_4, rather than in two separate coils as was the case in Fig. *23*. Across L_3-L_4 is fixed condenser C_3 and variable inductance L, having an iron dust core whose position can be varied in order to change the inductance of L and tune the discriminator circuit. Coil section L_3 also has an adjustable iron dust core which can be adjusted during alignment of the receiver to make the inductance of L_3 exactly equal to the inductance of L_4 and thus make both coils develop the same I.F. voltage for the diode section.

Effect of Preselector Upon A.F.C. Action. Up to this point we have neglected the effects of the preselector upon the action of the A.F.C. system. Actually, however, the selectivity of the preselector is quite important with relation to that characteristic of an A.F.C. system which is known as "dragging." Consider, for example, a receiver having an S curve which indicates the ability to correct for signals as much as 5 kc. off tune. When a station is properly tuned in, then gradually tuned off resonance, the A.F.C. circuit will correct the oscillator frequency satisfactorily for about 5 kc. off resonance. Tuning farther off than this does not remove the discriminator control voltage entirely, as you can see by referring to the S curve in Fig. *18;* actually the D.C. control voltage may be produced for a considerably greater deviation from resonance, but it will be insufficient to correct completely for the off-tune condition. This action of an A.F.C. system in making a partial correction outside of the efficient operating range of the system is referred to by engineers as "dragging."

When two stations are close together in frequency, and one of the stations is tuned in, it is perfectly possible that a receiver having A.F.C. and a broad preselector might not be able to pick up the other station. The station originally tuned in is held by the A.F.C. system because of excessive dragging action. With this broad preselector, the only way to hear the adjacent station would be to cut off temporarily the A.F.C. action of the receiver in order to allow the adjacent station signal to take hold of the A.F.C. system; a highly selective preselector, however, *would not allow* an A.F.C. system to hang onto a powerful local station when the receiver is tuned to a weaker adjacent station.

Here is another interesting result of dragging action; when a receiver having A.F.C. is tuned carelessly to a desired weak station, so that the desired signal is being dragged in from a position considerably off tune, any fading of this desired signal may allow an adjacent station to take hold.

The remedy for excessive dragging involves improving the selectivity of the preselector enough so that when the tuning condensers are outside the desired range of A.F.C. action, the reduction in R.F. gain will reduce the I.F. signal enough to make the discriminator release its control over the oscillator control tube. Strictly speaking, the preselector should be band-passed so it will tune broadly in the frequency range over which A.F.C. is to act, but will have a sudden reduction in gain (high selectivity) immediately outside of this band-pass region.

Band-pass preselectors are rarely used in receivers, but sufficient selectivity should be incorporated in the preselector to prevent annoying dragging action. Because it is not easy to get high preselector selectivity in the high frequency bands of an all-wave receiver, A.F.C. action is often omitted in these bands. Any A.F.C. circuit is most effective for strong stations in the broadcast band.

Philco Push-Pull A.F.C. System. The automatic frequency control system used in some Philco receivers is unique in that when the receiver is properly tuned or the A.F.C. system is shorted out, the receiver oscillator circuit is entirely independent of the

A.F.C. system. It is therefore possible to align the oscillator and preselector independently of the A.F.C. system, whereas in the systems previously described the shunt inductance of the oscillator control tube always had to be considered when aligning the oscillator trimmer condensers.

A typical example of this unique Philco push-pull A.F.C. system, that used in the Philco model 37-9 all-wave superheterodyne receiver, is shown in Fig. *25;* it is also known as a *magnetic tuning system.* As you can see, the type 6K7G tube in the final I.F. amplifier stage feeds into two entirely separate circuits, a 6Q7G second detector-A.V.C.-first A.F. tube circuit (not shown) and the conventional 6H6G double-diode discriminator circuit.

The two diode sections of the discriminator tube each receive two I.F. voltages in the usual manner; the I.F. voltage existing across the tuned plate circuit of the 6K7G tube is applied between the center tap of the split secondary winding and the cathodes of the 6H6G tube, and the I.F. currents flowing in the split secondary (due to the voltage induced by current in the tuned plate circuit) produce across the coil sections the other I.F. voltage acting on each diode section. The resulting rectified current flow develops the required D.C. discriminator control voltage across the two 2-megohm resistors connected between the cathodes. The polarity of this voltage depends, of course, upon whether the I.F. signal frequency is above or below the correct value, and the magnitude of this D.C. voltage depends upon the amount of error in tuning. This D.C. control voltage is applied across two 1-megohm resistors having their midpoint grounded, and hence points x and y will *always* be equal to each other in potential and of opposite polarity *with respect to ground.* In this manner the discriminator output voltage is divided into two equal voltages of opposite polarity.

During off-tune conditions these equal and opposite voltages at x and y are fed to points a and b, at the input of the oscillator control tube. Note that there is a 490,000-ohm re-

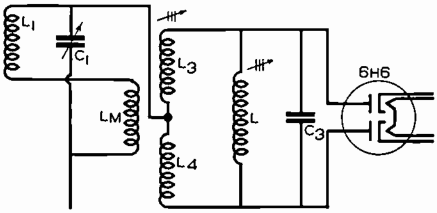


FIG. 24. Discriminator transformer connections used in RCA model 812K receiver.

sistor in each lead, with a .3 mfd. condenser shunted across the leads; these filters serve to remove all I.F. and A.F. signal components and at the same time delay the discriminator action enough to make it slower than A.V.C. action. The two .15 mfd. condensers with common terminals grounded serve to maintain a balance between the filtered A.C. currents. Switch SW_1 is the A.F.C. ON-OFF switch; when in the OFF position it grounds points a and b. Switch SW_2 closes only when the dial tuning mechanism is operated, and shorts points a and b to prevent A.F.C. from dragging one station beyond the dial setting for another station.

Observe now that a type 6A8G pentagrid converter tube serves as the first detector-mixer-oscillator tube for the receiver, with the first grid serving as the oscillator control grid and the second grid acting as the oscillator plate. The oscillator tuned circuit, made up of L_1, C_1, C_3 and the 85-ohm resistor, is connected between the first grid and the chassis. The necessary feed-back is obtained by connecting the oscillator plate electrode through a 250-mfd. condenser to the lower end of coil L_1; current flow through this section of L_1 induces the feed-back voltage in the main section of L_1. C_3 serves as the oscillator low frequency padder and C_2 as the high frequency trimmer. Rectified grid current flowing through L_1 and a 32,000-ohm resistor in the oscillator tuned circuit produces across this re-

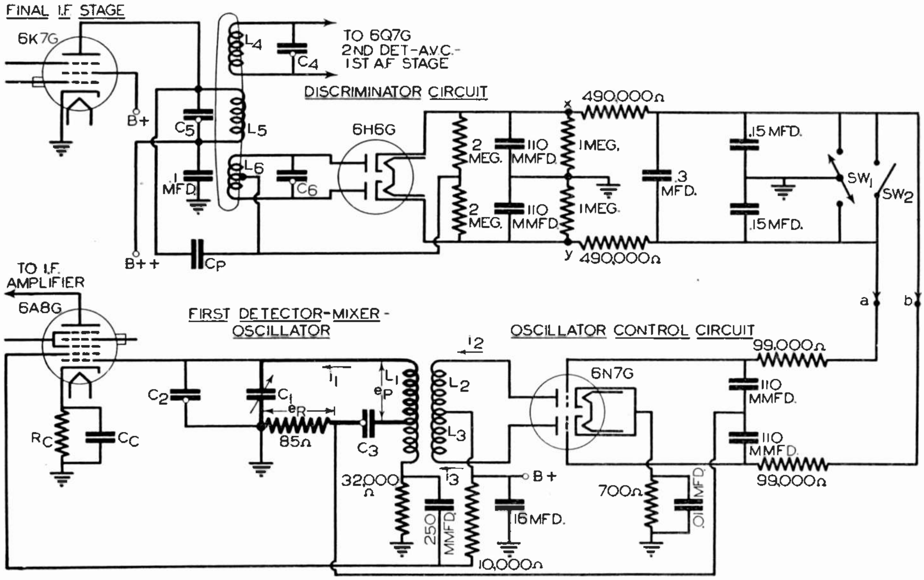


FIG. 25. Circuit diagram of the push-pull A.F.C. system (also known as magnetic tuning) used for the broadcast band on the Philco model 37-9 all-wave receiver. There is no A.F.C. action on short-wave bands in this set.

sistor a self-adjusting negative C bias which acts in series with the fixed C bias produced by the oscillator cathode resistor.

Locate the oscillator tuned circuit, shown in heavy lines in Fig. *25* and made up essentially of L_1, C_1, C_3 and an 85-ohm resistor. The same R.F. current i_1 flows through all of these parts, developing across the 85-ohm resistor an R.F. voltage e_R which is in phase with the current.

R.F. voltage e_R is applied to the two control grids of the 6N7G oscillator control tube through 110 mmfd. condensers. Note that 99,000-ohm resistors connected to these grid leads prevent the R.F. voltage from feeding into the discriminator circuit. This R.F. voltage e_R produces R.F. plate currents i_2 and i_3 which are *in phase* with e_R, are equal in value when both tube sections have the same C bias voltage, and flow in opposite directions through the two halves (L_2 and L_3) of the secondary winding of the oscillator control transformer.

From your study of coils you will recall that increasing the amount of flux through a coil increases its inductance, and decreasing the flux lowers the inductance. If current i_2 flowing through L_2 produces a flux which *increases* (aids) the flux produced by i_1 through L_1, then i_3 flowing in the opposite direction through L_3 will produce a flux which *decreases* (opposes) the flux produced by i_1 through L_1. (This holds true only when all three flux-producing currents are *in phase,* as they are in this circuit.) Current i_2 thus has the effect of increasing the inductance of L_1 in the oscillator tuned circuit, while i_3 decreases the inductance of L_1.

When i_2 and i_3 are equal, their effects upon the inductance of L_1 will be equal and will cancel each other. This proves clearly that when the A.F.C. system is inoperative, or when the receiver is properly tuned, *the oscillator control tube has no effect whatsoever upon the oscillator tuned circuit.*

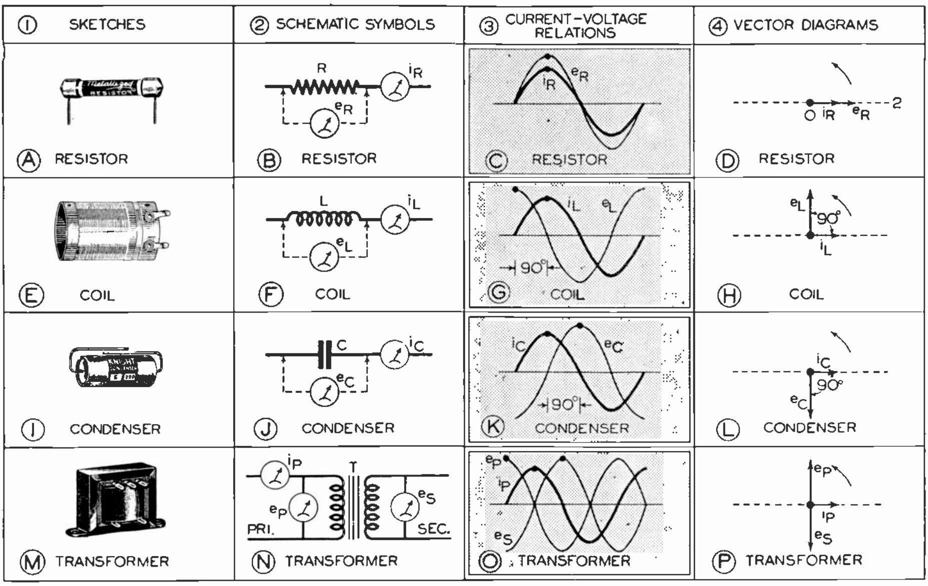


CHART 1. **This chart gives you important facts about the phase relationships of voltages and currents for resistors, coils, condensers, and transformers in A.C. circuits.**

As you already know, improper tuning of a receiver causes D.C. voltages of equal value but opposite polarity with respect to ground to be developed by the discriminator; these are applied to the grids of the 6N7G oscillator control tube through 99,000-ohm resistors, making one grid less negative and the other more negative than the bias value determined by the 700-ohm cathode resistor. Making the net C bias of one triode section less negative moves the operating point on the E_g-I_p characteristic to a steeper region, increasing the *A.C.* plate current for that section; at the same time the net C bias on the other triode section becomes more negative, moving the operating point to a less steep region and reducing the A.C. plate current for that section. The D.C. control voltage thus makes i_1 different from i_2. The effects of the larger current upon the inductance of L_1 are not altogether cancelled out by the effects of the smaller current; the result is a net change in the inductance of L_1, and this changes the frequency of the oscillator. In other words, one current *pushes* up and the other *pulls* down the inductance of L_1. The manner in which leads *a* and *b* are connected to the control grids of the 6N7G tube determines whether this control will be in the proper direction; if the control is such as to exaggerate errors in tuning, reversing the leads will correct the trouble.

Adjusting A.F.C. Systems

Fortunately for Radiotricians, the adjustment of an A.F.C. system is quite simple. The only instruments needed are an ordinary signal generator capable of producing the I.F.

value of the receiver, and a sensitive low-range (0-10 volts) voltmeter. At least a 5,000 ohms-per-volt meter should be used; if this is not available, use an ordinary vacuum tube voltmeter or one which you assemble yourself from a type 31 tube and batteries, using a milliammeter as the indicator.

The signal generator is set at the I.F. value of the receiver and is connected to the input of the I.F. amplifier. The sensitive voltmeter is connected across the D.C. output terminals of the discriminator (points *1* and *4* in Fig. *20;* between the chassis and point *3* in Fig. *23;* between points *a* and *b* in Fig. *25*). The I.F. amplifier stages are now aligned in the usual manner for a maximum reading of the voltmeter. (Do not touch the trimmer across the split secondary of the discriminator stage at this time unless the voltmeter deflection is too small for an accurate adjustment; in this case, adjust the trimmer in either direction just enough to get a suitable deflection.) When adjusting the tuned circuit ahead of this split secondary winding, it is a good plan to move the signal generator to the input of the previous tube; adjust this discriminator input circuit carefully for maximum output.

Now, without changing the voltmeter or signal generator connections, adjust the trimmer condenser in the split coil circuit for *zero meter reading.* This adjustment is quite critical, so be sure that the minimum reading is secured when the adjusting tool is removed. This is all there is to the adjustment of a conventional A.F.C. circuit.

You might think that with so simple an adjusting procedure, the information given in the first part of this lesson is unnecessary for the practical man. This is decidedly not true, however, for an understanding of how A.F.C. systems work is quite necessary when trouble develops due to failure of various parts in the system. If your work will involve the servicing of receivers having automatic frequency control, you will at some time or other find use for every bit of the information given in this lesson.

TEST QUESTIONS

Be sure to number your Answer Sheet 31FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Where are meter-type tuning indicators ordinarily connected in a receiver having A.V.C.?
2. Why is an A.F.C. system essential in a receiver having an electro-mechanical (motor-driven) automatic tuning system?
3. What voltage in a receiver is used to control a cathode ray tuning indicator?
4. How does core saturation affect the reactance of the secondary winding of the General Electric Colorama tuning reactor?
5. Name the two essential sections of an A.F.C. system.
6. In a receiver having A.F.C., what voltage serves to change the effective inductance of the oscillator control circuit?
7. How can you identify the discriminator section on the circuit diagram of a receiver having A.F.C.?
8. Will a highly selective preselector allow an A.F.C. system to hang on to a powerful local station when the receiver is tuned to a weaker adjacent station?
9. When the Philco push-pull A.F.C. system is inoperative or when the receiver is properly tuned, what effect does the oscillator control tube have upon the oscillator tuned circuit?
10. When adjusting an A.F.C. system a signal generator set at the I.F. value of the receiver is fed into the I.F. amplifier and a sensitive D.C. voltmeter is connected across the D.C. output terminal of the discriminator. How is the trimmer condenser in the split-coil discriminator circuit adjusted as regards the meter reading?

HOW TO USE CIRCUIT DIAGRAMS AND LOCATE CHASSIS PARTS

32FR-2

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

PRACTICE BRINGS PERFECTION

This lesson suggests a number of different ways in which you can actually practice the material studied. First of all, you can take one receiver chassis after another and identify each tube and stage from the top of the chassis, with and without a circuit diagram or service manual, just as was done for the model receiver in this lesson. Choose superheterodynes if possible, since they will be encountered most often in actual work.

Second, you can verify for yourself the general rules for checking continuity from tube electrodes to various other points in the receiver; any ohmmeter or multimeter can be used for this. The more you practice this now, the faster you will be able to make continuity tests when doing actual service work.

Practice locating parts first on the circuit diagram and then on the actual chassis; make a game of this, if you like, by dropping a pencil on the circuit diagram with eyes shut, and then locating the part which is closest to the pencil dot.

Get the habit of analyzing one or two interesting sections of each circuit diagram which comes your way, following the same general procedure outlined in this lesson.

Most important of all, practice actual radio servicing technique whenever you can, for you can learn much simply by trying. You'll remember any failures when you do study the particular troubles encountered, and will really be able to appreciate the simplicity and effectiveness of the modern N. R. I. service techniques.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

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A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
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How To Use Circuit Diagrams and Locate Chassis Parts

What a Circuit Diagram Tells

As YOU know, a schematic circuit diagram is a symbolic means for showing the electrical connections in a radio set. A schematic diagram tells very little about the construction of each part, how the parts should be adjusted, where the parts are located on the actual chassis, or how the connections are actually made between various points; nevertheless, to a man possessing the fundamental training in radio theory and practice which you are now acquiring, this diagram can yield information of great value in connection with the servicing and maintenance of radio equipment.

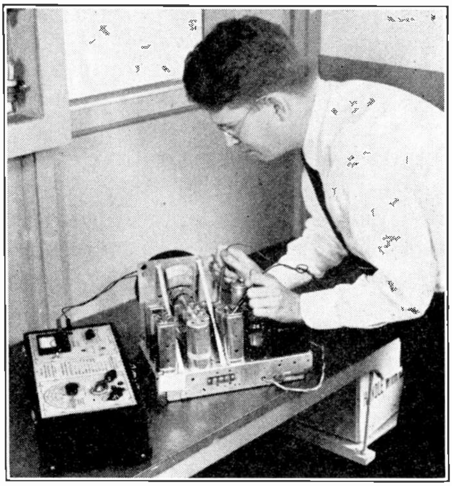
There is no more need for a Radiotrician to analyze a complete receiver circuit diagram when repairing a defect, than there is need for a carpenter to study the complete building plans for a new home when repairing the front porch railing. Once you become familiar with the general principles of radio servicing, you will agree that a circuit diagram is a "reference text" rather than a "study text."

Principles of Radio Servicing

When you tackle a defective receiver, you know that it must belong to one of the two general trouble groups in which all defective radio receivers can be placed: *1, the receiver is dead*—it does not play at all; *2, the receiver plays improperly*—it may howl, squeal, distort, lack selectivity, lack sensitivity, be noisy, have a faulty automatic tuning or A.F.C. system, or have any one of a host of other defects which are considered elsewhere in the Course.

Surface Defects. Occasionally the trouble which results in a dead or improperly operating receiver is not in the chassis at all, but on the outside or on the *surface,* where it can be readily seen and corrected. Obviously you will want to check for surface defects before removing the chassis.

The practical radio serviceman generally starts in by checking the antenna system and the power line cord, making sure that all tube caps are in position and not touching the shields, making sure that all extension wires and cable plugs are in place, and noting whether any tubes are obviously defective. He may even remove each tube and check it in a tube tester, to see if a simple replacement of a defective tube will clear up the trouble.



Making a continuity test between the top caps of two tubes on the Philco model 38-7 receiver, using the multimeter section of a combination signal generator and multimeter.

When a check for surface defects in this manner proves unsuccessful, one trouble-locating procedure is followed for the case of a dead receiver, and an entirely different procedure is chosen for an improperly operating receiver. In both of these procedures the schematic circuit diagram is brought into use.

Dead Receiver. When anything goes wrong, the natural first step is to ask yourself what the trouble could be. This applies to any machine, to any human being, and to any action, as well as to the radio receivers under discussion. We therefore ask: "Why does a receiver become dead?" There are a number of answers—one or more tubes may be defective, some part in the power pack or in the voltage supply system for the receiver may have opened up or become shorted, a signal circuit part may have opened or shorted, or a connection may have opened somewhere.

With a dead receiver, then, our first task is the locating of the defective tube, part or connection. Do we have to check all parts and connections until we find the one which is defective? Not if we reason out this problem a bit first. You know that a carrier signal modulated with an intelligence signal enters the antenna circuit of a receiver, with this intelligence signal working its way through a chain of stages to the loudspeaker. The receiver is dead because one or more links in this chain have failed. Radio men say that one or more stages have become defective; once they locate this defective stage, they have limited the task of locating the defective part to a smaller portion of the receiver.

As you will learn elsewhere in your Course, there are two ways of locating the defective stage in a dead receiver; we will present them here only briefly. In the *dynamic stage-by-stage elimination test,* a modulated signal generator is connected to the input of the second detector; if the modulation signal is heard in the loudspeaker, you know immediately that the detector and the audio amplifier are free of trouble. If no signal is heard, headphones are connected in turn to the output of the detector and to the output of each following audio stage. Failure to hear the output signal in the headphones at any stage identifies that stage as being defective, assuming that the power supply has been checked and found to be performing properly.

If the detector and the stages following it are found to be operating properly, the signal generator is advanced toward the antenna one stage at a time; the signal should become louder as this is done. Failure to hear the signal identifies the defective stage.

The simplest and speediest test for isolating the defective stage in a dead receiver is the *circuit disturbance test.* This depends upon the fact that when a tube is pulled out of its socket and quickly returned, or when the grid of a tube is touched or shorted to the chassis, or when the grid cap connection to a tube is removed and returned, a sharp change in the plate current for the tube takes place. This sudden change or shock is relayed through the receiver and is heard in the loudspeaker as a click, a thud or a squeal provided that all stages in the path of this disturbance are operating properly. Starting at the last audio stage and working toward the antenna stage, one of these methods for producing a disturbance is employed on each tube in turn. When you reach a tube which produces no indication in the loudspeaker while being shocked, you have isolated the trouble to that stage.

Once the defective stage is isolated, it is given a thorough check either with an ohmmeter or a voltmeter in a manner explained elsewhere in the Course, after making sure that the tube is good. Supply voltages for the tube are usually checked first.

Obviously you must know something about the circuit of a receiver in order to be able to isolate the defective stage and then isolate the defective part in that stage. You must be able to identify the second detector tube, which is the usual starting point for a stage isolation procedure. You must be able to locate the first, second and power audio tubes so you can follow the chain of stages in the proper order from the second detector to the loudspeaker; likewise you must be able to locate the I.F. and R.F. amplifier tubes in their proper order from the second detector to the antenna. You should know where to connect a voltmeter in order to check the main power supply. Once the defective stage is located, you must be able to locate and identify the various parts in the grid, plate, screen grid and suppressor grid circuits of the tube. You may be able to determine all these things by a study of the chassis itself, but this will take time; a schematic circuit diagram gives this information far more readily. If the service manual of the receiver also contains a tube layout diagram, showing the positions of the various tubes on the chassis and identifying their functions, your task is further simplified.

Improperly Operating Receiver. Expert Radiotricians will tell you that a dead receiver is generally easier to service than an improperly operating receiver. The true value of theoretical training, modern technique and practical experience becomes evident when it is necessary to service a receiver which squeals (oscillates), blocks, distorts, hums, is noisy, cuts off intermittently, lacks selectivity, lacks sensitivity, or lacks output volume. The value of circuit diagrams becomes increasingly more evident as servicing problems become more complicated.

A customer may bring in a receiver for repair, complaining that he can't understand the announcements or speeches as reproduced by the loudspeaker. After making sure that surface defects are not the cause of this distortion, a Radiotrician will automatically ask himself these questions:

1. Under what conditions of receiver operation does distortion ordinarily occur? Does the receiver distort only when the volume level is high, only when the volume level is low, or at all volume levels and all settings of the receiver controls?

2. What are the general reasons for distortion which occurs under the conditions noted?

3. What are possible causes, in this particular receiver, for the type of distortion observed? (Reference text "Radio Receiver Troubles—Their Cause and Remedy," which was sent you some time ago, covers many of the common causes for various types of distortion. This reference text will help you develop an ability to reason from observed effects like distortion to the logical causes.)

When a serviceman cannot answer these questions, he is compelled to test all stages and parts, using some systematic method of defect isolation. The checking of operating voltages for all tubes is an important part of this procedure; the correct voltages are usually given in the service manual.

Distortion at High Volume Levels. Let us assume that the receiver in question distorts only when the volume level is high. If it is an inexpensive midget table model receiver, this distortion may be natural and unavoidable, especially if it is most serious when powerful local stations are tuned in. Experience is a great help in determining whether or not an actual defect exists. Reference to the circuit diagram of the receiver will often tell whether or not the receiver is capable of handling high volume levels. If you decide that the receiver is operating as well as can be expected for that particular type of circuit, you will have to explain the situation to the customer and point out that the volume level should be kept below the point at which distortion begins.

If the receiver is of normal design and you decide that it should handle the maximum volume level without distortion, the next question to answer is: What can cause distortion when the volume level is high? The Radiotrician knows that possible causes for this effect are overloading of the detector, overloading of the audio output tube, overloading of the loudspeaker, weak tubes (low emission), low supply voltages, or a defective loudspeaker. With these probable causes in mind, you should now proceed to eliminate them one by one until you reach the true cause of the trouble. Test the tubes first of all, then check the main supply voltage and the individual supply voltages for each suspected tube. You may have to refer to a circuit diagram in order to determine where the voltmeter connections should be made for each test.

Plate and screen grid supply voltages are usually measured between these electrodes and the cathode of the tube, while a C bias voltage is measured between the cathode and the chassis, as a rule. Quite often, manufacturers will specify, in service manuals, all electrode voltages with respect to the chassis. Reference to the schematic circuit diagram will tell you exactly where connections can best be made to measure a particular voltage.

Can you quickly locate the plate, screen grid and cathode terminals on an actual tube? Few people can, for there are hundreds of different types of tubes in use today, each with different connections between the electrodes and the terminal prongs. Receiver manufacturers sometimes show tube sockets in pictorial form in the service manual, either on the schematic circuit diagram itself or on a separate chassis diagram. Tube manufacturers likewise supply socket connection diagrams for all tubes, so there should be no trouble in securing a tube diagram to serve as a guide.

When there are two or more stages in a receiver employing the same type of tube, how can you locate one of these tubes on the circuit diagram? The answer is quite simple; examine a few of the parts in the chassis which are connected to the tube in question, then determine which tube in the schematic diagram has these same parts connected to it.

Now you can check the values of each part in the defective stage against the values specified on the circuit diagram; check for changes in the resistance of a part and for shorted or leaky condensers, as any of these defects will alter the supply voltage enough to cause distortion when the volume level is high.

If you have followed the servicing procedure up to this point without locating the defect, refer to the schematic circuit diagram and determine whether the receiver has A.V.C. If the volume control is connected into the input of the audio system, you can be pretty sure that some of the preceding I.F. and R.F. amplifier stages are A.V.C controlled. Assuming this to be the case, you can be fairly certain that R.F., I.F., and second detector signal and supply circuits are all in order since there is no distortion at low volume levels on the particular receiver being analyzed.

You think a bit—could there be

overloading of an audio amplifier stage? As soon as you think of a reasonable cause of trouble, check up on it. An easy way to locate the overloaded stage is to turn up the volume control while tuned to a strong local station, so that distortion is clearly evident, and then connect headphones across the output of each audio stage in turn, starting with the second detector and ending at the loudspeaker terminals. Reference to the schematic circuit diagram and perhaps to the pictorial layout diagram will tell you where to make the headphone connections. The stage at which distortion is first noticed in the headphones will very likely be the overloaded stage. If no distortion is first noticed in the headphones up to the loudspeaker, then you can be pretty certain that there is a defect in the loudspeaker or its input circuit.

Hum. Now let us consider a receiver which has excessive hum. Naturally you turn on the set and make the usual inspection for surface defects. Let us assume that while doing this you note one tube with a blue glow between the cathode and plate. By noting the number of this tube, by referring to the parts layout diagram in the service manual, or by noting that there are no grid electrodes between the cathode and plate in the tube, you identify it as a rectifier. Obviously you have located a surface defect, for these tubes (with the exception of mercury vapor rectifier tubes) should not glow when operating properly; there is no sense in looking farther for other causes of hum until this trouble is cleared up.

A blue glow inside a vacuum type rectifier tube indicates the presence of gas; we say that the tube is *gassy.* The question is: Why did the tube become gassy? A logical answer is normal aging of the tube with constant use, for rectifier tubes are often operated very nearly at their maximum capacity in receivers. On the other hand, there may be a short in the power pack which is making this rectifier tube deliver higher than normal current. It would not be safe to insert a new tube until the power pack has been examined for possible defects. Again you would refer to the circuit diagram, noting what parts are in the power pack circuit and noting what their values should be. From your study of condensers, you know that paper condensers should have very large resistances, above 20 megohms, and electrolytic condensers should have resistance above at least 250,000 ohms when properly tested. Since filter condenser failure is a very common cause of hum, and excess rectifier tube current, you check these first, then check the electrical values of other parts in the power pack or in the power supply system.

But suppose that the inspection for surface defects gave no sign of the trouble. In this case the Radiotrician would turn to the schematic circuit diagram with one thought in mind: What part of circuit in this particular receiver could become defective and cause hum? As he glances over the power section of the circuit diagram, he may notice a tuned filter; knowing that even small changes in the values of the condenser and choke coil can result in hum, he checks these parts carefully with his multimeter. Or he may notice a hum bucking coil indicated in the schematic symbol for the loudspeaker; this could well be the cause of the hum, so a careful check of this part is made. There are electrolytic condensers in the power pack, and they have an unfortunate tendency to become leaky with age, so he checks them next. There are resistance-capacitance filters in grid circuits for application of a C bias voltage, so he checks these for leaky condensers and shorted resistors.

But this is not intended to be a lesson telling how to service a radio receiver; we have briefly considered these actual examples of servicing problems primarily to illustrate correct service technique and to show how the schematic circuit diagram and the other information contained in service manuals can be of help in servicing. You are becoming acquainted with the process of figuring or reasoning out probable causes of trouble when certain effects are observed—a process which we call "effect-to-cause reasoning."

A knowledge of how radio circuits work is one essential requirement for successfully applying effect-to-cause reasoning; this knowledge you are now acquiring in your Fundamental Course. Experience with actual radio apparatus and continued reference to schematic circuit diagrams will eventually make effect-to-cause reasoning become second nature to you.

Alignment Procedures. We have by no means exhausted the Radiotrician's uses for circuit diagrams. One highly important use, in connection with the alignment of tuned circuits in a receiver, deserves particular attention, for it is often desirable to realign a repaired receiver to secure maximum selectivity and sensitivity.

In a conventional superheterodyne receiver having peak-tuned circuits, the I.F. stages are aligned first and then the oscillator is made to track the preselector. In an all-wave receiver the preselector-oscillator tracking adjustment must be made for each band. Before any of these adjustments can be made, however, you will first want to know how many trimmers there are to be adjusted, where each one is located, and what it does. A study of the schematic circuit diagram will give you this information. Furthermore, this analysis of the diagram will reveal if there are any image rejection circuits, harmonic or code interference traps, A.F.C. circuit trimmers, or fidelity-equalizing trimmers. Once you spot these on the circuit diagram and note their functions, you can mentally omit them from your alignment procedure and concentrate upon the true circuit-aligning trimmers. You may note that certain oscillator coils have adjustable iron cores; this establishes the fact that they are the low-frequency oscillator adjustments.

The circuit diagram may reveal the presence of variable-selectivity I.F. transformers and band-pass circuits which can be adjusted either for peak response or for broad (band-pass) response. It would be difficult to determine the presence of a band-pass circuit from mere study of the receiver chassis, yet the schematic circuit diagram and your knowledge of circuit operation immediately suggests the correct aligning procedure. If you know radio theory and the usual design practices, there will be no need for you to follow detailed alignment instructions as given in service manuals.

Once you have determined what the correct alignment procedure should be, you must locate the trimmer condenser adjusting screws or nuts on the actual chassis; again the schematic circuit diagram can be of great help in identifying each trimmer. If a pictorial layout is available, do not overlook it during an alignment procedure; this diagram often reveals the exact locations of the various trimmers.

Subjects for Further Study. The preceding brief outline of the technique of radio servicing has shown you many uses for circuit diagrams and the associated information prepared by receiver manufacturers in the form of service manuals. We will now consider in some detail how these service manuals can be used to best advantage in radio servicing, and how the information needed for servicing can be obtained directly from the receiver chassis when no service manual is available. The important subjects for further study are therefore:

1. How to identify the various stages on a schematic circuit diagram.
2. How to analyze each stage of a schematic circuit diagram.
3. How to identify the various stages on the actual receiver chassis.
4. How to locate various parts on the chassis with a pictorial layout diagram.
5. How to locate parts when no pictorial layout is available.
6. How to trace each tube electrode circuit with and without the help of a schematic circuit diagram.
7. How to locate the alignment trimmer condensers.
8. How to appraise the performance of a receiver.
9. Important differences between schematic diagrams and actual chassis wiring connections.

For the purpose of illustrating the various points covered in this lesson, we have selected a popular model of a well known receiver (Philco Model 38-7) and have reproduced, in the center pages of this lesson, the following material pertaining to this receiver: Fig. *1*—the schematic circuit diagram as it appears in the service manual of the receiver; Fig. *2*—the pictorial layout diagram for parts underneath the chassis, as given in the service manual; Fig. *3*—pictorial layout of parts on the top of the chassis, as given in the service manual; Fig. *4*—tube socket connections as seen when looking at the bottom of the chassis, and electrode operating voltages; Fig. *5*—reproduction of an actual photograph of the top of the chassis, corresponding to the diagram in Fig *3*; Fig. *6*—reproduction of an actual photograph of the bottom of the chassis, corresponding to the diagram in Fig. *2*.

For convenience in referring to these diagrams while studying this lesson, it is suggested that you pry up the staples holding this lesson together, carefully remove the inside four pages (13, 14, 15 and 16), and bend back the staples again. When you have completed your study of this text-book, you can replace these diagrams in the same manner.

Identifying Stages on a Schematic Diagram

When a Radiotrician first takes up a schematic circuit diagram, he makes a general survey before attempting to locate any individual circuits or parts, in order to determine the general line-up of stages in the receiver. When looking at Fig. *1*, for example, he would immediately identify the circuit as that of a two-band superheterodyne receiver which is A.C. operated and has a simple tuned input circuit feeding directly into a pentagrid converter tube which acts as oscillator-mixer-first detector. He notices that this is followed by a single I.F. amplifier stage which feeds into a double-diode detector in which one section acts as the actual demodulator and the other serves as the A.V.C. tube. The diode demodulator feeds into a single audio amplifier stage which in turn feeds a pentode power output amplifier stage. He notes also that the power pack employs a full-wave rectifier tube. An experienced man could make this identification of stages almost at a glance, for familiarity with the tubes and circuits employed enables him to omit a great many of the steps in the reasoning process now to be described.

Circuit diagrams are invariably arranged so they can be read from left to right when tracing the path taken by intelligence signals from the antenna to the loudspeaker. We therefore start at the upper left of the diagram in Fig. *1*, where we find a terminal strip having provisions for two antenna connections and one ground connection. Observe that the signals pass through R.F. transformer *1*, the secondary winding of which is tuned by one section of a ganged variable condenser. This tuned circuit feeds into a type 6A8G tube having five grids. Although on this particular diagram the designation *DET.-OSC.* identifies this stage as the detector-oscillator, you will find many circuit diagrams in which only the tube type numbers are given. We know, however, that the first stage must be either an R.F. amplifier stage or the first detector; we trace from the plate of this tube into I.F. transformer *13*, and we know that tubes having five grids (pentagrid conveters) are almost invariably used as combination oscillator-mixer-first detector tubes, so we feel safe in identifying this stage as the mixer-first detector of a superheterodyne circuit.

Another glance at input R.F. transformer *1* reveals that each of its windings is in series with the winding of another R.F. transformer marked *2*, and that there are switches for shorting out one secondary winding. Clearly, then, we have a two-band receiver. Verification of this can be secured by tracing from the first grid of the 6A8G tube, which we know must be serving as the grid of the local oscillator; this goes to two tuning coils, *5* and *6*, and one of these can be shorted out with a switch.

The second tube in our receiver line-up, a 6K7G, is fed by the secondary of the first I.F. transformer and feeds into the primary of the second I.F. transformer; it must therefore be an I.F. amplifier stage. We know that this second I.F. transformer (*19*) must feed either into a second detector or into another I.F. amplifier stage. The tube in question is a 6J5G triode, and triodes are seldom if ever used as I.F. amplifiers. We must examine this circuit more carefully to determine its true function (assuming that the *2ND DET-A.V.C.* designation is not present). Note that the secondary voltage of second I.F. transformer *19* is applied between the grid of this triode and ground, with the cathode of the tube directly grounded. This looks much like an ordinary diode detector circuit, with the control grid of the triode serving as the diode plate. Resistors *20* and *21* are in the circuit, and now we note a volume control potentiometer connected across resistor *21*, with condenser *24* in series to block direct currents. The plate and cathode of this triode tube must therefore be serving as the A.V.C. diode, since the plate is also fed by the second I.F. transformer through D.C. blocking condenser *23*.

From the movable contact of the volume control we trace our signal path to the grid of a 6K5G triode, which can only be a first audio amplifier stage since it follows a diode second detector. This tube in turn feeds into a pentode type 6F6G tube having a loudspeaker as its plate load, and consequently this is the power output stage.

One glance at the *power transformer symbol* in the power pack circuit in Fig. *1* is sufficiently to identify our circuit as that of an A.C. receiver, for power transformers are never used in universal or D.C. sets.

There are a great many other clues which will prove useful in identifying each stage when you first go over a circuit diagram to get the general line-up, and consequently you will seldom if ever have any difficulty in identifying a stage even though its function is not indicated on the diagram.

Analyzing Each Stage on a Schematic Diagram

When the servicing procedure has advanced to the point where the defective stage is isolated, it is often necessary to refer to the circuit diagram and analyze in detail that particular stage. Since all of the stages in a receiver are subject to failure, you should know how to analyze any one of the stages when necessary. To show how simple this can be when the analysis is made in the proper manner, we will go through the process for each stage in turn in the circuit of Fig. *1*.

Oscillator - Mixer - First Detector. Below the sketch of band-changing switch *48* is a note indicating that this switch is shown in the broadcast band position. Comparison of this diagram with the individual switches in the R.F. input and oscillator coil circuits shows that these separate switch symbols are also in the broadcast band position. For the broadcast band setting, then, the short across the primary of antenna coil *1* makes this coil inactive. Signals picked up by the antenna (the RED terminal) thus pass through the primary of antenna coil *2* and through switch contacts *A1-A2* to ground, inducing in the secondary winding an R.F. voltage which is applied through the inactive secondary of antenna coil *1* to the fourth grid of the 6A8G tube. The fact that the secondary of antenna coil 2, has a higher D.C. resistance than the secondary of antenna coil *1* verifies the fact that coil *2* serves for the broadcast band (a higher resistance usually indicates more turns of wire, giving the higher inductance required for the lower-frequency bands).

The only switch in the oscillator circuit, that for contacts *A3-A4*, is open during broadcast band operation, and consequently oscillator coil *6* acts in series with oscillator grid coil *5* in the oscillator tuned circuit. The feedback voltage required for oscillation enters this circuit through oscillator plate coil *5*, which is in the second grid (oscillator plate) circuit of the 6A8G tube. The oscillator section of the gang tuning condenser connects between the first grid and ground, and consequently is shunted across both coils in the tuned circuit.

For the short-wave setting of the band-change switch, contacts *A1-A2* are open, making antenna coil *1* effective, and contacts *A6-A7* are closed, shorting the secondary of antenna coil *2* and thereby making this transformer ineffective. Switch contacts *A3-A4* in the oscillator circuit are connected together, shorting oscillator coil *6* and thus reducing the inductance in the oscillator tuned circuit to the value required for the higher - frequency band.

Condensers *7* and *8* acting with resistor *9* furnish the automatic C bias for the local oscillator. Condenser *7B* is simply an oscillator coupling condenser, which serves to feed A.C. plate current into the tuned grid circuit during broadcast band operation. Condenser *7* also serves as the low-frequency padder in the oscillator circuit for broadcast band operation. Trimmer condenser *7A* is the oscillator high-frequency trimmer for the broadcast band, and trimmer condenser *4B* is the oscillator high-frequency trimmer for the short-wave band. There is no oscillator low-frequency padder on the short-wave range. High-frequency trimmer *4A* is the only input circuit alignment adjustment; consequently we can assume that the input circuit or preselector is quite broad in frequency response on the short-wave band, and is adjusted only for the broadcast band.

The pictorial diagrams of the antenna and oscillator coils, at the lower left in Fig. *1*, give coil connection information which is often helpful in tracing continuity through the coil circuits. The small numbers on these coil sketches correspond to the numbers on the schematic symbols for the corresponding coils.

I.F. Amplifier. We recognize the 6K7G I.F. amplifier tube as a pentode, and learn from a tube chart that it is a super-control amplifier tube which can be A.V.C.-controlled. Tracing from the control grid or first grid of this tube through the secondary of the first I.F. transformer, we find the circuit to be through one-megohm resistors *15* and *27* to a tap on the voltage divider in the power pack, and then to ground. This means that the tube receives an initial negative C bias from the power pack. From the common connection of resistors *15* and *27* we note a lead which can be traced to ground through one diode section of the 6J5G tube (that formed by the plate and cathode), which means that the tube also receives an A.V.C. voltage.

There is a third winding on the first I.F. transformer, which places the suppressor grid at D.C. ground potential. The secondary of this I.F. transformer induces in this coil a signal voltage which can produce either regeneration or degeneration, depending upon the manner and upon the phase relationship of the secondary coil current with respect to the coil voltage. This third coil is connected in such a way that whenever the circuit tends to oscillate (regenerate), a degenerating voltage is applied the suppressor; likewise, when the circuit tends to degenerate during off-tune conditions, a regenerating voltage is applied to the suppressor. The third winding thus serves to stabilize the circuit during off-tune conditions.

Following the 6K7G tube is the second I.F. transformer, of conventional design. Trimmer condensers *13A*, *13B*, *19A* and *19B* permit peak adjustments of the two I.F. transformers.

Second Detector. The output voltage of the I.F. amplifier is applied to the grid and cathode of the 6J5G triode, with resistors *20* and *21* serving as the load for this diode detector circuit. Resistor *20* also acts in combination with condensers *19C* and *19D* as an I.F. filter. Rectified diode current flowing through resistor *21* develops across it an A.F. voltage which is transferred through D.C. blocking condenser *24* to potentiometer *26*. Resistor *32* and condenser *38*, connected between a tap on this potentiometer and ground, provide automatic bass compensation. Switch *39* has one contact for shorting out condenser *38* when automatic bass compensation is not desired, and other contacts for tone control circuits. The movable contact on volume control potentiometer *26* feeds A.F. signals through condenser *28* to the grid of the 6K5G first audio amplifier tube.

A.V.C. Tube. The output voltage of the I.F. amplifier also acts upon the plate of the 6J5G triode tube through condenser *23*. The grid and cathode of this tube thus serve as one diode, while the plate and cathode form another diode section which acts as the A.V.C. tube. Resistor *27* (trace down from the plate of the 6J5G tube) serves as the load for this second diode; the D.C. voltage required for A.V.C. purposes is developed across this resistor. The circuit from resistor *27* to ground is through the 8-ohm and 35-ohm sections of voltage divider *43*, and consequently the D.C. voltage drop across these sections is applied to the A.V.C. controlled tubes in the form of a constant negative C bias, as well as a delay voltage for the diode A.V.C. tube. The A.V.C. voltage is applied to the two A.V.C.-controlled tubes (6A8G and 6K7G) through an A.V.C. filter made up of resistor *15* and condenser *3*.

First A.F. Amplifier Stage. A tube chart tells us that the 6K5G tube is a high mu triode designed especially for use in resistance - capacitance coupled audio amplifiers. Resistor *36*, coupling condenser *34* and grid resistor *35* make up the resistance-capacitance coupling network through which this tube feeds into the output stage. A negative C bias for the first audio tube is obtained from tap *2* on voltage divider *43*, with resistor *33* and condenser *30* serving as a filter.

Output Stage. According to a tube chart, the 6F6G tube in the output stage is a power amplifier pentode. The entire voltage drop across voltage divider *43* serves as the negative C bias for this tube, and likewise the entire output voltage of the power pack is applied to the plate of the tube through the primary winding of output transformer *41*. Note that condensers *37* and *40* are connected in series between the plate of the output tube and ground, with the common connection of these condensers going to one contact on tone control switch *39*. When the switch is set at this contact (at its extreme right-hand position), condenser *40* is shorted out and condenser *37* then by-passes the higher frequency components of the intelligence signal to ground, giving the effect of a boost in bass notes. When switch *39* is at some other setting, the extremely low capacity of condenser *40* (.008 mfd.) makes the reactance of this shunt path to ground so high that there is very little attenuation of any signal frequencies.

The voice coil of the dynamic loudspeaker, marked *42*, is connected across the secondary of output transformer *41*. The single-loop coil symbol drawn in series with the voice coil but in the opposite direction represents a hum bucking coil.

Power Pack. Obviously we have a full-wave rectifier circuit here, since the two plates of the 5Y4G rectifier tube are connected to the outer ends, *5* and *7*, of the high voltage secondary winding on power transformer *46*. Center tap *6* on this secondary winding is therefore the negative or B— terminal of the power pack; it traces through resistor *43* to the chassis and ground, making terminals *2*, *3* and *4* on this resistor increasingly more negative with respect to point *1*, the chassis.

Point *3* on the rectifier tube filament winding is the high-voltage terminal of the rectifier system, so we will find the power pack filter network connected between this point and either the B— terminal or ground. The main filter employs condenser input (*45*) with loudspeaker field coil *44* serving as a choke and condenser *11A* serving as the output filter condenser. The symbols indicate that condensers *45* and *11A* are of the electrolytic type. The common terminal of field coil *44* and filter condenser *11A* is the B+ or high-voltage output terminal of the power pack, and feeds directly to the plate of 6K7G I.F. tube, the 6K5G audio amplifier tube and the 6F6G output tube through the plate load of each tube.

A separate filter system is employed for the 6A8G pentagrid converter, however; this is made up of filter resistor *12* and electrolytic condenser *11*. A voltage divider network (resistors *16* and *22*) is connected between the output of this filter and ground, with the higher output voltage being fed through resistor *10* and the oscillator feed-back coil to the second grid (oscillator plate) of the 6A8G tube. The plate of the 6A8G tube receives this same high output voltage through the primary of the first I.F. transformer. A lower voltage is applied from the common junction of resistors *16* and *22* to the screen grids of the 6A8G and 6K7G tubes, with condenser *14* serving as the screen grid by-pass condenser.

Filament connections are indicated but not completed on this diagram. Observe that terminal *8* of the filament winding on power transformer *46* is grounded and that one filament terminal of each tube except the rectifier is likewise grounded. The other filament terminal for each tube is terminated in an arrow, as also is the other filament winding terminal; this of course, indicates that all these terminals are connected together. All tube filaments except the rectifier are thus connected together in parallel across the filament winding having terminals *8* and *9*.

Observe that two condensers, marked *47*, are connected in series across the 110 volt A.C. power line, with their midpoints grounded. These condensers shunt to ground any noise interference signals which might otherwise enter the receiver.

The extreme left position of switch *39* is the off or open position for the receiver on-off switch which is in series with the primary of the power transformer. This power switch is closed for all other positions of switch *39*. Moving this switch one contact to the right shorts out automatic bass compensation condenser *38*, providing normal receiver operation. Moving the switch one more contact to the right places this condenser in the circuit, and the final position of the switch to the right shorts out condenser *40*, giving a bass-boosting effect together with automatic bass compensation.

A note at the bottom of the schematic circuit diagram indicates that on some receiver models employing this circuit, a shadowgraph indicator is inserted in series with the plate supply lead to the I.F. amplifier tube, with a .05 mfd. condenser connected between the plate side of this meter and the chassis to keep R.F. current out of the meter. The small diagram at the lower right of the circuit diagram indicates that pilot lamp *49* is connected in parallel with the tube filaments across the filament winding on the power transformer. A note indicates that an extra pilot lamp (*49X*) is used on one model to operate a shadowgraph tuning indicator.

Remember that it will seldom if ever be necessary for you to analyze a complete receiver circuit as we have just done. Modern servicing techniques isolate the trouble to a particular stage or section, making it necessary to analyze that one small part of the receiver circuit. Furthermore, do not expect to be able to analyze a diagram or even a part of a diagram completely right from the start. As you acquire additional knowledge and experience, you will find it easier and easier to secure the information which schematic diagrams can give you.

Identifying Stages on the Chassis

By including top-of-the-chassis layout diagrams along with the schematic diagrams in some service manuals, receiver manufacturers have made it quite easy to identify each tube and its function. A typical diagram of this type, in which the position of each tube is clearly indicated with respect to easily recognizable parts such as the power transformer and the tuning condenser, is shown in Fig. *3*. With this layout at hand, it is a simple matter to perform either a dynamic stage-by-stage elimination test or a circuit disturbance test when hunting for the defective stage.

A tube layout diagram has other uses in radio servicing. Since octal-base tubes are used in practically all modern receivers, any tube will fit into any socket. The sockets on the chassis are ordinarily not marked for the proper tubes, and consequently the tube layout diagram serves as a valuable guide for replacing tubes when all are removed for testing, or in order to clean the chassis. The wise Radiotrician usually does not depend upon a tube layout diagram, however; he removes only one tube at a time, returning it or replacing it with a new tube before testing the next tube.

But how do we go about identifying the stages on the chassis when no schematic diagram and no tube layout diagram are available? All we

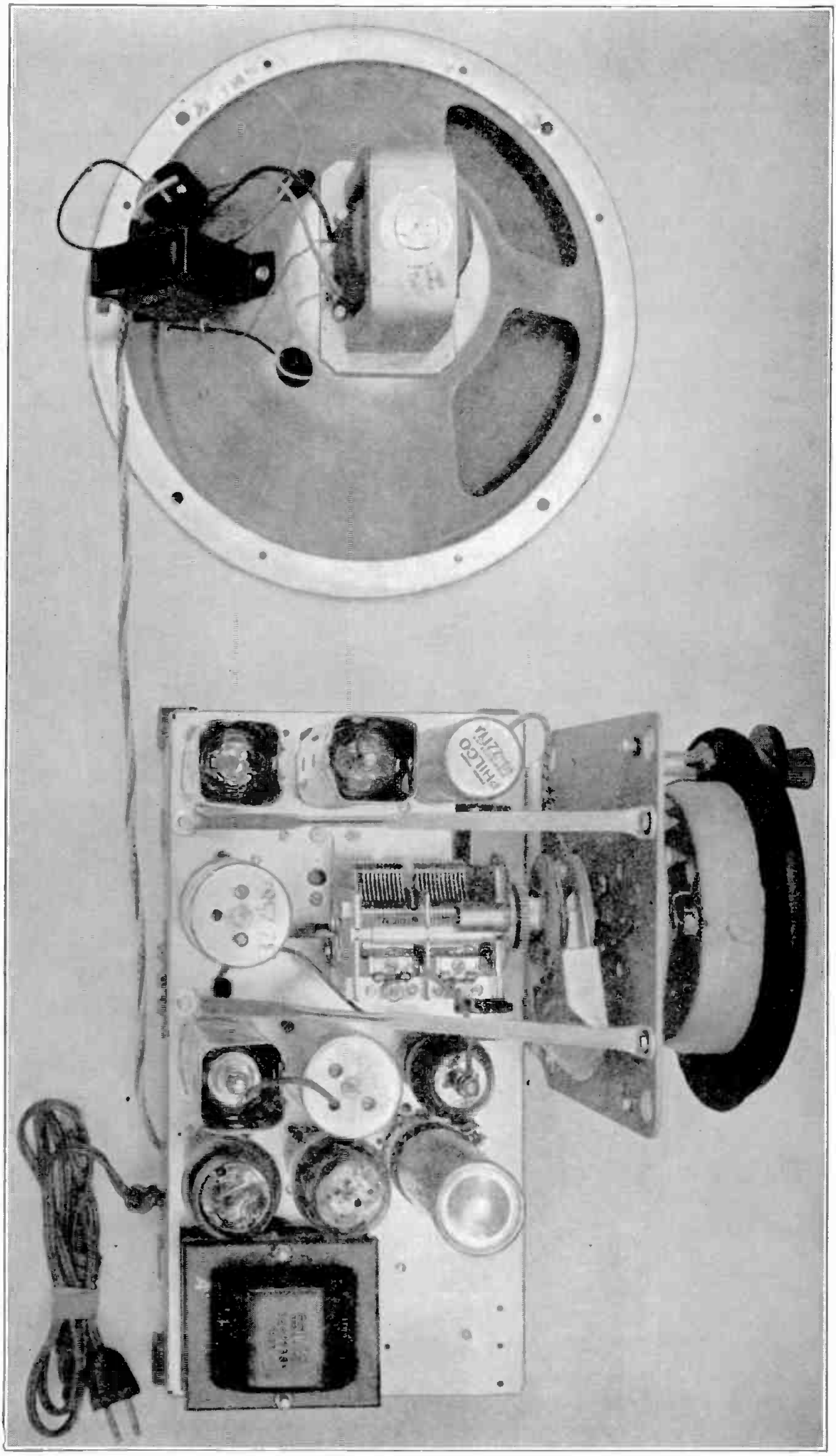
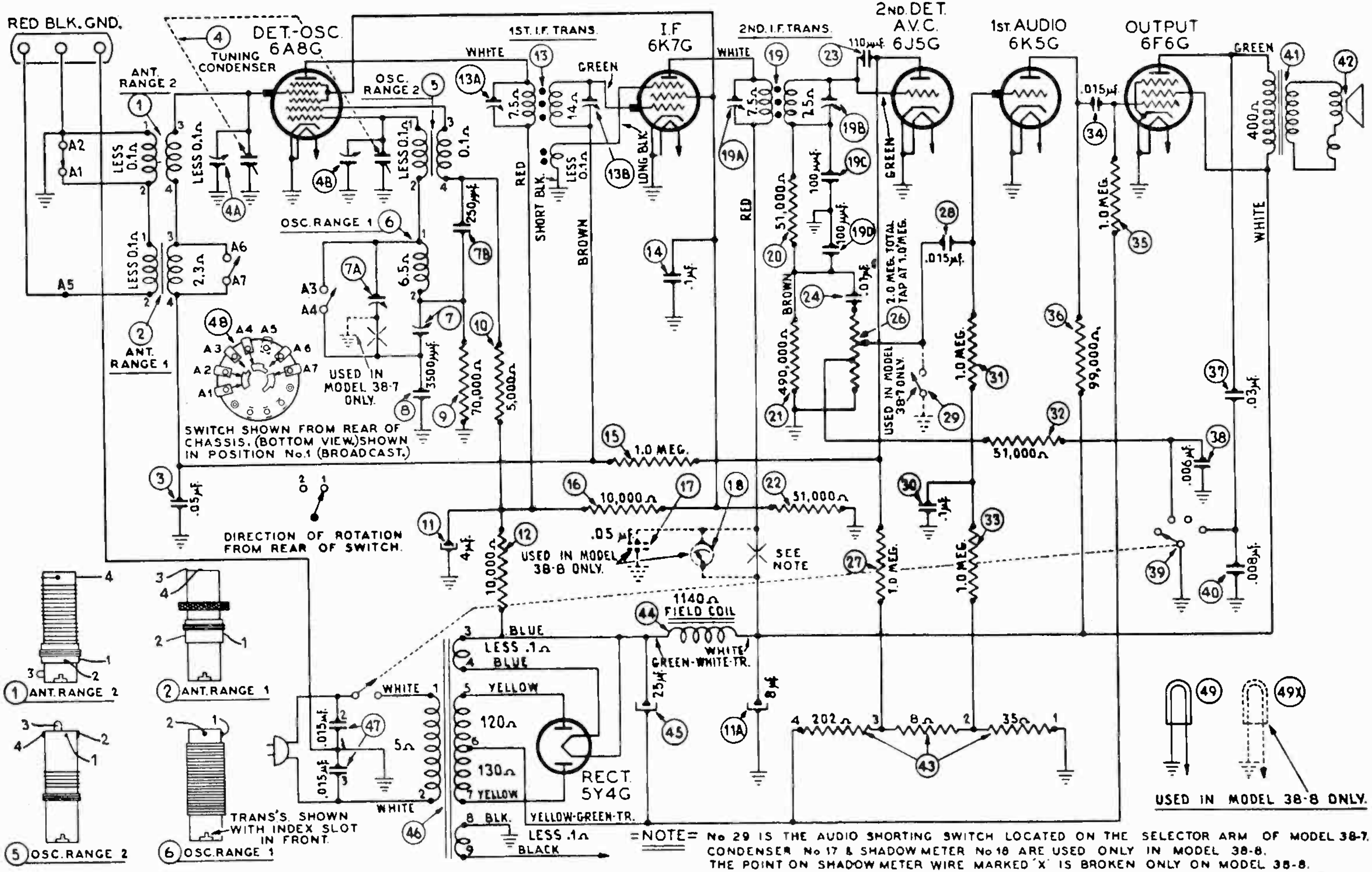


FIG. 5. Top of chassis of Philco model 38-7 receiver



Courtesy Philco Radio and Television Corp.

FIG. 1. Schematic circuit diagram of Philco model 38-7 two-band superheterodyne receiver. A dot at the intersection of circuit lines indicates a connection; when two circuit lines cross and there is no dot at the intersection, there is no connection between them. NOTE: For convenience, lift up the staples and remove these four center pages of illustrations temporarily while studying this book.

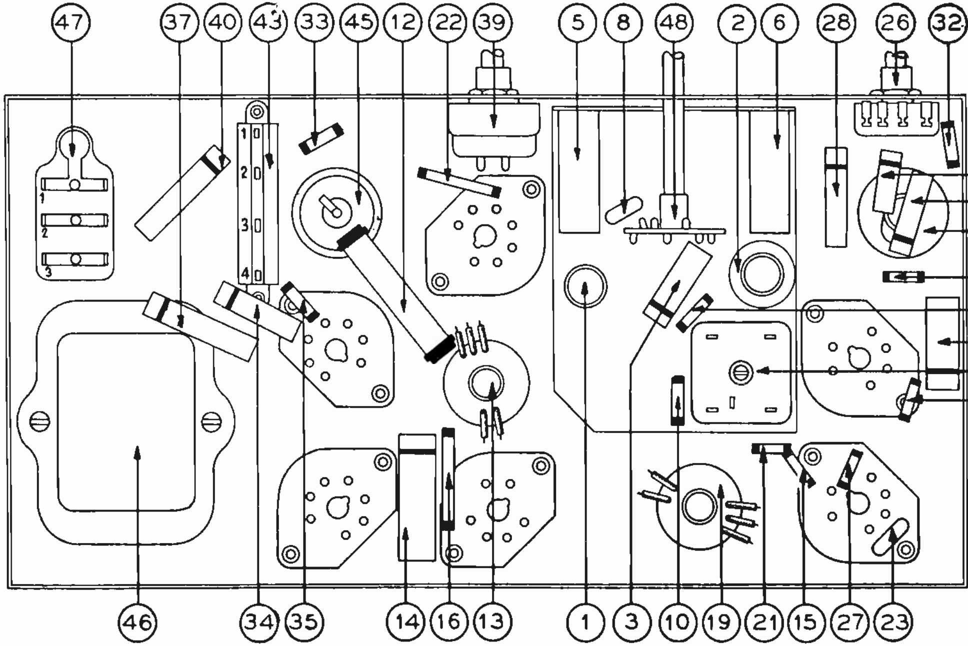


FIG. 2. Pictorial layout diagram for parts under chassis of Philco model 38-7 receiver. The parts list on this page serves as a guide when ordering replacement parts for this receiver.

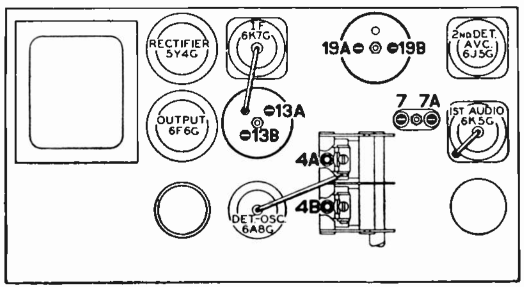


FIG. 3. Pictorial layout diagram for parts above chassis of Philco model 38-7 receiver.

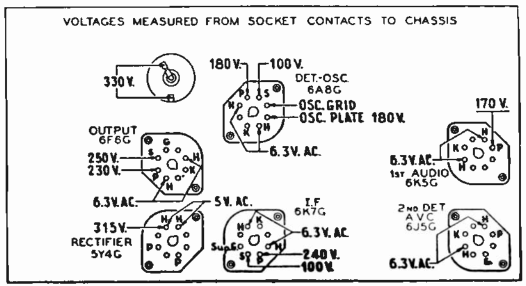


FIG. 4. Tube socket connection diagram and electrode voltages for Philco model 38-7 receiver.

Schem. No.	Description	Part No.
1	Antenna Transformer—Short Wave	32-2558
2	Antenna Transformer—Broadcast	32-2557
3	Condenser .05 mf.	30-4519
4	Tuning Condenser, Models 8 and 9	31-2026
	Tuning Condenser, Model 7	31-2040
5	Osc. Transformer—Short Wave	32-2560
6	Osc. Transformer—Broadcast	32-2559
7	Compensator Dual Models 8 and 9	31-6188
	Compensator, 580 KC. (Model 7)	31-6195
7A	Compensator Model 7 (1500 KC.)	31-6196
8	Condenser 3500 mmf. mica	30-1094
9	Resistor 70,000 ohms (½ watt)	33-370339
10	Resistor 5000 ohms (½ watt)	33-250339
11	Condenser, Electrolytic Dual (4 and 8 mfd.)	30-2217
12	Resistor 10,000 ohms (3 watt)	33-310639
13	1st I. F. Transformer	32-2580
14	Condenser .1 mf.	30-4455
15	Resistor 1.0 meg. (½ watt)	33-510339
16	Resistor 10,000 (1 watt)	33-310439
17	Condenser .05 mf. (38-8 only)	30-4454
18	Shadowmeter (38-8 only)	45-2307
19	2nd I. F. Transformer	32-2582
20	Resistor 51,000 (mounted in 19)	33-351339
21	Resistor 490,000 ohms (½ watt)	33-449339
22	Resistor 51,000 ohms (1 watt)	33-351439
23	Condenser, mica, 110 mmf.	30-1031
24	Condenser .01 mf.	30-4479
25	Removed Prior to Production	
26	Volume Control	33-5216
27	Resistor 1 meg. (½ watt)	33-510339
28	Condenser .015 mf.	30-4358
29	Audio Shorting Switch (38-7 only) Part of Selector Crank	
30	Condenser .1 mf.	30-4499
31	Resistor 1.0 meg. (½ watt)	33-510339
32	Resistor 51,000 (½ watt)	33-351339
33	Resistor 1.0 meg. (½ watt)	33-510339
34	Condenser .015 mf.	30-4515
35	Resistor 1.0 meg. (½ watt)	33-510339
36	Resistor 99,000 (½ watt)	33-399339
37	Condenser .03 mf.	30-4447
38	Condenser .06 mf.	30-4467
39	Tone Control	42-1327
40	Condenser .008 mf.	30-4112
41	Output Transformer (Model 7)	32-7862
	Output Transformer (Models 8 and 9)	32-7019
42	Cone and Voice Coil Assembly (H31)	36-3801
	Cone and Voice Coil Assembly (K41)	36-3174
	Cone and Voice Coil Assembly (HS)	36-3796
	Cone and Voice Coil Assembly (S7)	36-3157
43	Bias Resistor	33-3316
44	Field Coil Assembly (H31)	36-3665
	Field Coil Assembly (K41)	36-3931
	Field Coil Assembly (HS)	36-3690
	Field Coil Assembly (S7)	36-3039
45	Electrolytic Condenser	30-2219
46	Power Transformer, 115V, 50/60 cycle	32-7833
	Power Transformer, 110V, 25 to 40 cycle	32-7627
	Power Transformer, 115/230V, 50/60 cycle	32-7835
47	Condenser .015—.015 mf., 25 mf.	3793DG
48	Wave Switch	42-1325
49	Pilot Lamp, Models 8 and 9	34-2064

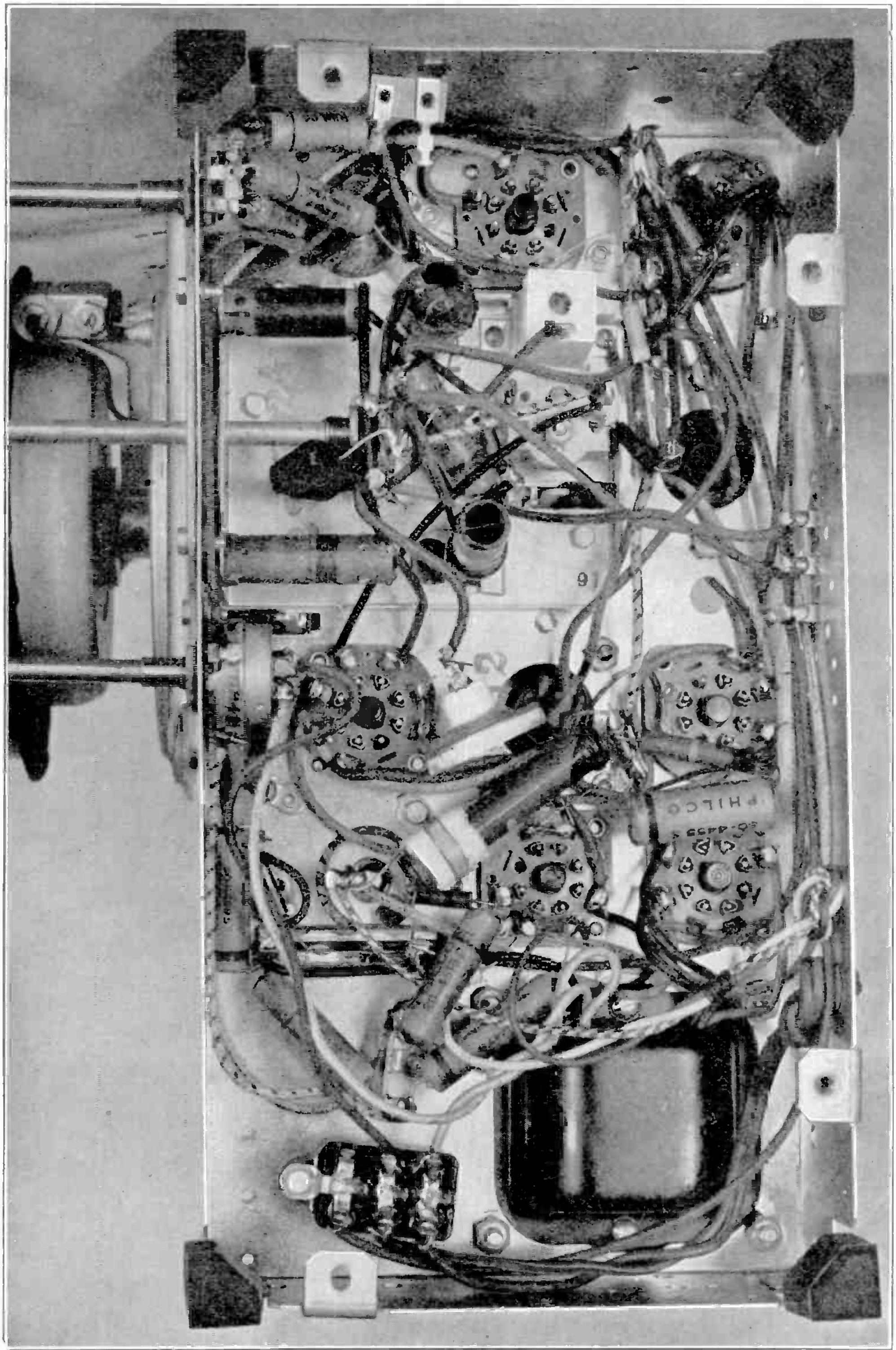


FIG. 6. Bottom of chassis of Philco model 38-7 receiver.

have is the chassis itself, which can be represented in this discussion by the photographs in Figs. *5* and *6*. We will concentrate upon Fig. *5*, which shows a top view of the chassis, since you will often want to identify the tubes and stages without removing the chassis from its cabinet.

The power transformer and the two-gang tuning condenser are, of course, easily identified. Likewise you can be pretty sure that the two cylindrical metal cans adjacent to the tuning condenser, each having two adjusting screws, are I.F. transformers. Their presence identifies the receiver as a superheterodyne. The fact that there is a lead coming out of one I.F. transformer to the top cap of a tube is further proof that we are dealing with a superheterodyne, for in tuned radio frequency receivers the top caps of tubes usually go to the stator sections of the gang tuning condenser.

The shapes of the completely enclosed metal cans, one to the right and below the power transformer, and the other at the lower right on the chassis, identify these parts as electrolytic filter condensers; with experience you will be able to spot these at a glance.

Once you have determined the type of circuit, you can proceed to identify the tubes. First of all, look for the rectifier tube, which will have two rectangular electrodes with a heavy filament wire inside each, but no other electrodes. We notice a tube like this, marked 5Y4G, at the upper right of the power transformer (see Fig. *5*); reference to a tube chart verifies that this is a rectifier tube.

Below the rectifier tube and next to the power transformer in Fig. *5* is a tube which is larger than all other tubes except the rectifier. This has a rather large plate, with a cathode and several other elements inside. By counting the elements or by determining its number and referring to a tube chart, we identify this as a pentode; since there is no top cap connection for the control grid, we know definitely that it is not an R.F. pentode. It is logical to assume, then, that we have a power output pentode, a tube widely used in the output stages of receivers. A tube chart would verify this assumption.

To the left of the tuning condenser in Fig. *5* is a tube marked 6A8G; a tube chart identifies this as a pentagrid converter, the fourth grid of which connects to the top cap. We say, therefore, that this tube is for the oscillator - mixer - first detector stage. A lead from the top cap of this tube goes to the upper stator section of the tuning condenser, identifying it as the preselector tuning condenser. The other section of the tuning condenser must therefore tune the oscillator circuit.

At the right of the rectifier tube in Fig. *5* is a tube marked 6K7G; according to our tube chart, this is an R.F. pentode. Since there are only two sections in the gang tuning condenser, one for the first detector input and one for the oscillator, we know that there is no R.F. amplifier stage. This means that the 6K7G R.F. pentode must be used as an I.F. amplifier; the fact that there is a lead coming from the I.F. transformer to the top cap of this tube verifies our assumption. The tube chart also reveals that this is a super-control tube, and since a receiver designer ordinarily does not employ such a tube unless it is to be A.V.C.-controlled, we know that this receiver has A.V.C.

The two tubes at the upper right on the chassis in Fig. *5* still remain to be identified. The upper is marked 6J5G, and reference to a tube chart reveals it to be a triode which can have a number of different uses. The lower tube is marked 6K5G but here the tube chart tells us definitely that it is a high-gain audio amplifier tube. Since we have not yet located the second detector-A.V.C. tube, with only these two tubes left to identify, we can say that the 6K5G is the first audio amplifier tube and the 6J5G is the second detector-A.V.C. tube. We could verify this by measuring the voltage between the plate and cathode of each tube; we would find that the tube selected as the audio amplifier had a reasonably high D.C. supply voltage, whereas the plate of the 6J5G tube was slightly negative with respect to the cathode. These measurements would tell us that a delay voltage was present in the A.V.C. system.

We have just seen how each tube in this receiver can be identified as to its function without removing the chassis from its cabinet. Naturally a person would not go through this procedure if a tube diagram were at hand, or if a schematic circuit diagram were available, for it is not always possible to determine the function of each tube on a chassis without tracing connections underneath the chassis. On the other hand, with experience you will be able to identify the various tube stages on most receivers almost at a glance, and will not have to refer to diagrams.

General Suggestions. The ability to recognize radio parts by their appearance alone is obviously quite desirable when it is necessary to identify stages on the chassis. For this reason it is important that you keep in touch with new developments as announced in radio magazines and in the latest catalogs of mail order radio supply houses or of your local radio parts distributor.

You can generally secure the latest tube charts from your local parts distributor, or from the manufacturer of the tubes which you handle. These charts will familiarize you with the appearances and characteristics of new and old tubes alike.

The first thing you want to know, when working on a chassis without a service manual, is whether you have a T.R.F. or superheterodyne receiver. Look for I.F. transformers, as they are clues identifying a superheterodyne; if these I.F. transformers are under the chassis, as they often are, look for the screws of their adjusting trimmers on the top of the chassis. If one of the sections of the gang tuning condenser has rotor plates which are shaped differently from those in other sections, you have another clue toward a superheterodyne. A receiver having only two sections in the gang tuning condenser but with six or more tubes can reasonably be assumed to be a superheterodyne. Older radio receivers with three, four and five sections in the condenser gang will generally be T.R.F. sets, but make sure that there are no I. F. transformers before deciding this.

Next you will want to know how the receiver is powered. If there is a multi-lead cable in place of the line cord, it is a battery receiver; if there is a two-wire cord having at its end the familiar two-prong wall outlet plug, you can be sure that it is a socket-powered receiver. But do we have an A. C., D. C., or universal socket-powered receiver? If a power transformer is visible on the chassis, you can be sure it is an A. C. receiver. If there is a rectifier tube but no power transformer, it is a universal A.C.-D.C. receiver. If there is no power transformer and no rectifier tube, it is a D.C. receiver. These rules will enable you to identify practically all receivers, but be on the lookout for exceptions. A few transformerless A. C. receivers have been made; these will have the conventional full-wave rectifier tube, so you will have to check the rectifier connections to make a positive identification. *

Now let us concentrate our attention upon the stages ahead of the I.F. amplifier in a superheterodyne receiver. A two-section ganged variable condenser means that there is no R.F. amplifier stage ahead of the first detector, for one section serves for tuning the oscillator and the other for tuning the input to the first detector. Three sections ordinarily indicate that there is one stage of R.F. amplification ahead of the mixer-first detector, but occasionally you may find a band-pass preselector instead. You may find a pentagrid converter tube or a pentode tube being used as a combination mixer-first detector-oscillator, or there may be a pentode serving as mixer-first detector and a separate triode (or even a screen grid or pentode tube) serving as the oscillator tube.

Most superheterodynes use screen grid or pentode tubes in the R.F. first detector and I.F. stages; this means that the control grid connection for each of these tubes will be to a top cap. In the case of a pentagrid converter, the top cap will be connected to the fourth grid inside the tube, and there will be an external connection from this cap to the stator section of the detector input tuning condenser; with a three-gang condenser the oscillator stator will be at one end, and will not have a connection to a tube cap if a pentagrid converter is used.

Because I.F. transformers require complete shielding, they will be found in metal shields or cans and will usually be mounted on the top of the chassis. The secondary of the first I.F. transformer will always be connected to the control grid of the I. F. amplifier tube; since this will be a screen grid or pentode tube, you can expect to find a flexible lead coming out of the top or side of the I.F. transformer and going to the top cap of the tube.

When there are two I.F. transformers, the second will feed into the second detector, usually by means of an under-chassis connection (only when the second detector is a screen grid or pentode tube will there be a connection from the second I.F. transformer to its top cap).

Since diodes or triodes are ordinarily used as second detectors, you can usually assume that any tube having a top cap connection into an I.F. transformer is an I.F. amplifier tube. If there are three I. F. transformers, look for two I.F. amplifier tubes; in all probability you will find them in line with the mixer-first detector and the second detector.

The second detector has a few peculiarities which permit easy identification. Look for a double diode, a double diode-triode, a double diode-pentode, or a triode following the last I.F. transformer. Occasionally you may run into a screen grid or pentode second detector which will have a lead from its top cap to the last I.F. transformer. When the R.F. and I.F. stages use pentode tubes and there is a pentagrid converter in the line-up, look for tubes such as the 56, 6C5, 6C6, 55, 85, 75, 6B8 and 6H6 serving as the second detector, the second de-

* There is seldom need to make a positive identification unless you isolate a defect to the power pack. In this case you will naturally remove the chassis, and an inspection of rectifier connections will reveal the type of circuit used. If it is an A.C. set with a voltage-doubling power pack circuit, you will usually find that the plate of one diode section is directly connected to the cathode of the other diode section. There will be two electrolytic condensers connected in series, with the negative lead going to the remaining diode plate and the positive lead to the remaining cathode. The common connection of these two condensers goes to one side of the power line, and the other side of the power line goes to the common plate-cathode connection. The circuit for this is given in an earlier lesson in your Course.

tector-A.V.C. tube, or as the second detector-A.V.C.-first A.F. amplifier.

Rectifier tubes in an A.C. receiver are easy to locate, for they are almost always *right next to the power transformer.* Obviously it would not be good design practice to run high voltage A.C. leads any distance through the chassis from the power transformer to the rectifier tube. Look for such tubes as the 80, 25Z5, 82, 83 5Z3, 5Z4 and 6X5, for these are all rectifier tubes. Most of these have glass envelopes, through which you can usually see two long black rectangular or cylindrical anodes, with a thick V-shaped filament inside each.

Output tubes can be recognized by their numbers and by their relatively large size in comparison to all other tubes except the rectifier. Double-triode power amplifier tubes such as the 19, 6N7, 6A6, 79 and 53 are instantly identified as output tubes connected for push-pull or push-push operation. Such tubes as the 45, 47, 2A3, 6L6, 2A5, 59, 43 and 42 are power output tubes which you will find used singly or in pairs for push-pull or push-push operation.

An additional tube, usually a triode, located between the second detector and the power tubes or near them is very likely an audio voltage amplifier tube.

Cathode ray tuning indicator tubes can, of course, be identified on sight. Automatic frequency control tubes, noise-limiting and noise-suppression tubes, A.V.C. tubes and A.V.C. amplifier tubes are not so easy to identify from the top of the chassis. When the circuit contains extra tubes which are not readily identified, it is wiser to secure the circuit diagram and identify these extra tubes by a process of elimination or by comparing tube numbers. With some receivers it is practically impossible to identify all tubes merely by studying the top of the chassis; in these cases it is either necessary to refer to a service manual or remove the chassis and trace tube connections. When metal tubes are used, the tube numbers stamped on the sides of the tubes must serve as your guide.

Locating Parts with a Pictorial Layout Diagram

Let us suppose that the receiver being used as our example in this lesson has developed an annoying squeal. We might logically suspect that a screen grid by-pass condenser is open somewhere; referring to the schematic circuit diagram in Fig. *1,* we see that screen grid by-pass condenser *14* for the 6K7G I.F. amplifier tube is a likely offender. We can make a quick check by shunting this condenser with a good unit of the correct value (.1 mfd.), provided that we can locate condenser *14.* An examination of the underside of the chassis reveals at least nine tubular paper condensers which could be *14;* by referring to the parts layout diagram in Fig. *2,* however, we learn that the condenser under suspicion is near the back edge of the chassis and is between two tube sockets. With this information, it is easily located on the chassis; turn to Fig. *6* and see how quickly you can locate it on the photo. If the squeal stops when we temporarily shunt this condenser with a good condenser, we know that condenser *14* requires replacement.

Now let us consider the case where the receiver has an annoying hum, and an inspection for surface defects reveals that the rectifier tube is gassy (a blue glow can be seen between its electrodes). Before inserting a new tube, we naturally want to check the electrolytic condensers with an ohmmeter to determine if excessive leakage through them was the cause of rectifier tube failure. To locate these condensers, we first refer to the circuit diagram and determine what numbers are assigned to them. At the right of the rectifier tube in Fig. 1 are two electrolytic condensers, *45* and *11A*, while above the power transformer is another, marked *11*. This numbering indicates that *11* and *11A* are in the same housing, and the fact that only two electrolytic condensers were found on top of the chassis is further proof of this assumption.

We locate condenser *11* on the pictorial layout diagram in Fig. *2*, finding it in the upper right corner of the diagram, near the volume control. An inspection of the connections underneath this chassis would show three leads, colored black, green and red respectively. This means that the two condenser sections must have a common connection; an inspection of the schematic circuit diagram verifies this and shows that the common negative terminal is grounded. The black lead on the condenser itself is grounded, so this must be negative; the red and green leads are therefore the positive leads for these electrolytic condensers. A leakage test is now readily made with an ohmmeter, connecting the plus terminal of the ohmmeter (that terminal which goes to the plus terminal of the ohmmeter battery) to the plus terminal of the condenser. The practical man seldom bothers to figure out condenser polarity, however; he connects both ways and uses the highest-resistance reading, for he knows he will then have the correct polarity. One of the condenser leads is disconnected for this test, as there are usually other parts shunting the condenser.

Let us consider one more case, that where the receiver is dead and the defect is localized to the pentagrid converter by means of a stage-by-stage elimination test. Measurements of electrode voltages on this tube show that there are no D.C. supply voltages; other measurements reveal that there is no screen grid voltage on the I.F. amplifier tube. A study of the schematic circuit diagram reveals that an open circuit through resistor *12* could be a cause of the trouble. The parts layout diagram in Fig. *2* shows that resistor *12* is located under the chassis, between electrolytic condenser *45* and I.F. transformer *13*. Since it is a 10,000 ohm resistor, we have the additional clue that it will have a brown body, black end and orange dot in accordance with the RMA color code for resistors. You should now be able to locate this resistor in Fig. *6;* it is a large carbon resistor, supported at one end by a metal clamp under which is white insulating paper. Naturally you would look for a defect in this resistor or for a break in its connection.

These two examples show the value of the parts layout diagram in bridging the gap between the schematic circuit diagram and the actual receiver chassis.

Locating Parts without a Pictorial Layout Diagram

The procedure for locating on the chassis a part which is indicated on the schematic circuit diagram becomes considerably more involved when no pictorial layout diagram is available. Familiarity with the appearance of various radio parts will speed your search, as also will experience in tracing actual wiring on a chassis. A few examples will illustrate the procedure to be followed.

On the schematic circuit diagram, condenser *14* is shown connected between the screen grid of the 6K7G I.F. amplifier tube and ground; let us see how we would go about locating this condenser on the chassis. First of all we locate the 6K7G tube on the top of the chassis and determine the position of its socket underneath the chassis. We would find this socket to be at the rear edge of the chassis; almost exactly midway between the sides of the chassis (you can locate it for youself on Fig. *6* by referring to the socket connection diagram in Fig. *4*).

The next step is the location of the screen grid terminal on this socket; a tube chart will give this information if a socket connection diagram like that in Fig. *4* is not available. We look for terminal *S*, for this letter (as well as the notations G_s or G_2) are used to designate the screen grid terminal. We know that condenser *14* is connected between this terminal and ground, and a careful study of the schematic diagram shows that there is no other condenser connected to this screen grid terminal. We trace each lead in turn from this terminal of the socket until we locate one going to a tubular paper condenser marked .1 mfd.; we note that the other lead of this condenser goes to a soldering lug which is riveted to the chassis, and thus have definite proof that this is condenser *14*.

Here is another example: suppose that the trouble has been isolated to the R.F. input circuit. We suspect an open circuit in one of the windings of R.F. transformers *1* and *2*. A study of the schematic circuit diagram shows that if we connect an ohmmeter between the two antenna terminals marked *RED* and *BLK*, we can check continuity of the primary winding. If the ohmmeter indicates a resistance of about .1 ohms when the band change switch is in the broadcast position (shorting contacts *A1* and *A2*), we know that the primary of R.F. transformer *2* is good. A changeover to the short-wave setting of the switch removes the short across the primary of R.F. transformer *1*, and if the ohmmeter reads about .2 ohm, we know that this primary winding also is good.

Now we study the circuit diagram again to see how we can check the continuity of the secondary coils. Observe that there is a complete conductive path from the fourth grid of the 6A8G tube to the secondary of the first I.F. transformer and control grid (top cap) of the 6K7G I.F. amplifier tube. The diagram further indicates that if we place an ohmmeter between the top caps of these two tubes, we should measure a D.C. resistance of .1+2.3+14, or a total of approximately 16.4 ohms. We do not even have to remove the chassis from the cabinet in order to make this test.

If, when measuring the resistance between the top caps of the first two tubes, we secured an infinite resistance reading, we would know that an open circuit existed somewhere along the path being checked. To make sure that the trouble is an R.F. coil, we could make an ohmmeter test between the top cap of the 6K7G tube and the chassis. The schematic circuit diagram indicates a resistance of a little over 2 megohms (the combined resistance of parts *15*, *27* and a section of *43*) between these two points. Any resistance reading differing greatly from this value, or an open circuit reading, would indicate trouble in the I.F. transformer. If the ohmmeter reads the correct value of 2 megohms, we make the same test between the top cap of the 6A8G tube and the chassis; let us assume that we get an open circuit reading.

To determine which of the R.F. coils is defective, we must locate them underneath the chassis and test each one individually. The sketches at the lower left in Fig. *1*, with each coil connection numbered and the relative lengths of the windings shown, makes identification of these coils on the chassis quite simple.

Oftentimes, however, these coil pictures are not provided on the circuit diagram. In this event we would trace from the top cap of the 6A8G tube to the input tuning condenser stator, and from there to point *3* on the secondary of R.F. transformer *1*. (Each stator section has two terminals, one above and one below; the R.F. transformers are underneath the chassis, so we look underneath the chassis for a lead coming through it directly under the stator section in question.) We trace through the heavy wire forming the secondary winding to the other terminal, marked *4*, and then in turn trace to point *A6* on the band change switch, to point *3* of the secondary of R.F. transformer *2*, and through this winding to terminal *4*. We can then make a continuity test across this entire circuit or any part of it.

Tracing Tube Electrode Circuits

Once the various tube stages have been identified, the defective stage isolated and the tube in that stage checked, the next logical step is a check-up of the circuits in the defective stage. These tests are simple and easy to make if you recognize that electrode circuits in any receiver can always be traced to certain definite points. It is then a simple matter to make continuity tests of the paths between the tube electrodes and these points. Let us trace the conductive paths from the electrodes in Fig. *1* before considering the general continuity-checking rules which apply to all circuits.

Plate Circuits. Suppose we start at the plate of the 6K7G I.F. amplifier tube and trace a conductive path as far as we can. From the plate we go through the primary of second I.F. transformer *19* in Fig. *1*, down a lead marked *RED* to loudspeaker field coil *44*, and through this coil to the filament of the 5Y4G rectifier tube. Clearly the rectifier filament is one terminal in this path.

Now trace from the plate of the 6A8G pentagrid converter tube through the primary of first I.F. transformer *13* and down another lead marked *RED* through resistor *12* to the rectifier filament. The plate of the 6K5G first audio amplifier tube traces through resistor *36* and loudspeaker field coil *44* to the rectifier filament, and likewise the plate of the 6F6G output tube traces through the primary of the output transformer and through field coil winding *44* to the rectifier filament.

There is a very good reason why the plates of all these tubes should trace to the rectifier filament or to a rectifier cathode. In any rectifier type of power pack the filament is the highest positive voltage terminal, and consequently all electrodes which are supplied with a positive voltage must eventually trace to the rectifier filament.

Screen Grid Circuits. Since the screen grid of a tube is likewise supplied with a positive D.C. potential, you should also expect to trace a conductive path from it to the rectifier filament. We can check this very easily in Fig. *1*. From the screen grid of the 6K7G tube (the middle grid, which is also connected directly to the screen grid of the 6A8G detector-oscillator tube), we trace through resistors *16* and *12* to the rectifier filament. In a similar manner we can trace from the screen grid of the 6F6G output tube through loudspeaker field coil *44* to the rectifier filament.

The only other electrode in this particular circuit which requires a positive D.C. potential is the second grid of the 6A8G pentagrid converter tube, which serves as the anode of the oscillator. Observe that this traces through *oscillator plate coil 5* and then *through resistors 10* and *12* to the rectifier filament.

Control Grid Circuits. Since the control grid of an amplifier tube must be negatively biased with respect to its cathode, we know that there must be a conductive path between the control grid and the cathode of an amplifier tube. Let us verify this on the circuit in Fig. *1*. The fourth grid of the 6A8G tube is serving as a control grid, so we trace from it through the secondary winding of R.F. transformer *1* and *2* and then through resistors *15, 27* and *43* to the chassis and the grounded cathode. Clearly there is a continuous path here for direct current. The first grid of this tube, serving as the oscillator control grid, likewise traces to the cathode through oscillator grid coil *5,* through coil *6* and then through resistor *9* and the chassis. The control grid of the 6F6G output tube traces through resistors *35* and *43* to the chassis and cathode. A circuit can likewise be traced from the other control grids to their respective cathodes through the chassis.

As you know, the center tap of the high voltage secondary winding on the power transformer (feeding the two plates of the rectifier tube) is the lowest negative D.C. terminal in the power supply. A further study of Fig. *1* will show that the control grids can also be traced to this most negative point in the power pack. This means that in an A.C. receiver you can, after turning the set off, make a continuity test of each control grid circuit by connecting one ohmmeter lead to the control grid and the other to the cathode of the tube, to one of the plates of the rectifier tube or to the most negative point in the power pack. In a universal receiver, where there is no power transformer, the most negative D.C. point will be the receiver side of the main power switch; be sure this switch is open when you make your test.

Suppressor Grid Circuits. When an external prong connection is provided for the suppressor grid of a tube, this will either trace to the cathode of the tube or to some negative supply terminal. For continuity checking purposes, then, you may treat the suppressor grid just as if it were a control grid.

Diode Detector Circuits. Since a diode detector is a rectifier and consequently passes direct current, we know that there must be a conductive path from the plate through the external circuit to the cathode. An ohmmeter connected between the cathode and plate of a diode detector should therefore indicate continuity. (There may be an exception to this rule in the case of a power pack rectifier tube used as a diode rectifier, for the load on this diode may be tubes in the receiver which are conductive only when their cathodes are heated.)

The second detector-A.V.C. tube in Fig. *1* employs two diodes, one for detection and one for A.V.C. purposes, but the plate of each can be traced to the cathode. For example, the actual plate of the tube traces through resistors *27* and *43* to the chassis and then to the cathode, while the grid (which serves as the other diode plate) traces through the secondary of I.F. transformer *19* and through resistors *20* and *21* to the chassis and cathode.

General Rules for Checking Continuity of Electrode Circuits in A.C. Receivers

1. **There should be a conductive path *from the rectifier tube filament or* cathode (the highest positive D.C.**

terminal) *to all tube electrodes which are supplied with a positive D.C. potential,* such as plates and screen grids.

2. There should be a conductive path *from the most negative D.C. terminal in the power pack to all control grids and suppressor grids which require zero or negative bias voltages.* Likewise there should be a conductive path *between the control grid and the cathode of a tube,* and *between the suppressor grid and cathode of a tube.*
3. In diode detectors or diode A.V.C. tubes, there should be a conductive path between the plate and the cathode.

Failure to secure a conductive path in any of the cases mentioned, as evidenced by an infinite-resistance reading of the ohmmeter, indicates a break in the electrode circuit in question. It should then be a simple matter to check the circuit piece by piece to locate the break.

When the schematic circuit diagram and the parts layout diagram are available, all parts suspected of being open can be located first on these diagrams and then on the chassis. Each part is then checked for continuity, making sure that the test includes the connecting leads.

When neither the circuit diagram nor the pictorial layout diagram is available, the circuit must be traced on the chassis for the most likely path between the points in question before making ohmmeter measurements. For example, if you found that there was no continuity between the plate of the 6K5G first audio amplifier tube and the rectifier filament, you would first locate the plate terminal of the audio tube socket, There would be a wire from this terminal running around the front edge of the chassis to a terminal to which a resistor and a .015 mfd. condenser are soldered. Of course, no continuity should be expected through the condenser, so you trace through the resistor to the screen grid of the power output tube and then to the field coil of the loudspeaker. You know that your circuit should trace through this field coil rather than through leads going to the electrodes of other tubes and so you arrive at the rectifier filament. Having traced the circuit, you can then proceed to test continuity of each part and section of it.

How to Locate Trimmer Condensers

As you know, the location and identification of each trimmer condenser in a receiver is essential for alignment purposes. If the manufacturer supplies a circuit diagram like that in Fig. *1* and a trimmer layout diagram like that in Fig. *3,* this task is simple. When no trimmer layout diagram is available, however, the problem becomes more complicated. Let us see how this would be done on the receiver being used as an example if the only service manual data available is the circuit diagram in Fig. *1.*

First of all, we note that there are two holes in the top of each I.F. transformer through which can be seen adjusting screws. Those in the first I.F. transformer we can identify as I.F. trimmers *13A* and *13B,* while those in the second I.F. transformer must logically be I.F. trimmers *19A* and *19B.* We next note that there is a trimmer condenser mounted on each stator section of the gang tuning condenser. That one which is on the R.F. input stator section we identify as high-frequency trimmer *4A;* the trimmer on the oscillator stator section must therefore be oscillator-high frequency trimmer *4B.*

A glance over the circuit diagram in Fig. *1* shows that there are only two more trimmer condensers, *7* and *7A.* Since manufacturers will make all trimmer condenser adjustments available from the top of the chassis wherever posible, we look for these on the chassis and finally locate the two adjusting screws to the right and a little above the gang tuning condenser unit, near the last I.F. transformer. We must turn the chassis over and trace connections, however, in order to tell which is *7* and which is *7A*. Figure *1* shows that these trimmers have one common connection through condenser *8* to ground, with the other connections going to opposite ends of oscillator coil *6*. Trimmer *7A* also connects to one terminal on oscillator coil *5*, so we can positively identify as trimmer *7A* on the chassis that trimmer which connects to two oscillator coils. The remaining trimmer, which connects to only one oscillator coil, will therefore be *7*.

General Trimmer-Locating Suggestions. For each band in an all-wave superheterodyne receiver there will usually be the following separate trimmers: *1*, one high-frequency trimmer for each preselector stage which is tuned to the incoming R. F. carrier frequency; *2*, a high-frequency oscillator trimmer; *3*, a low-frequency oscillator padder. (The receiver used as an example in this lesson is an exception to this rule, for there is one high-frequency oscillator trimmer for each band but only a low-frequency oscillator padder for the broadcast band. In the preselector, one high-frequency trimmer serves both bands.) In the case of a three-band receiver having one R.F. amplifier stage, there would be four trimmers in the preselector and oscillator sections for each band, making a total of twelve trimmers ahead of the I.F. amplifier. Usually there will be two trimmers for each I.F. transformer, but in the less expensive receivers which have no R.F. amplification and only one stage of I.F. amplification, a high gain I.F. transformer using only one tuned circuit and consequently only one trimmer may be found.

Look for I.F. trimmer adjustment screws either at the top or on the side of the I.F. transformer shield; occasionally, however, you may find them at the bottom of the transformer, visible only from the bottom of the chassis. Some manufacturers mount these trimmers directly on the chassis rather than in the shield, but they will always be located close to the I.F. transformers they tune.

In a conventional broadcast band superheterodyne receiver, all of the high frequency trimmer condensers will be mounted on the stator plates of the condensers which they adjust. The low-frequency padder will be a separate unit, mounted somewhere near the oscillator coil or the oscillator tuning condenser section. If two or more trimmers are found on the chassis of a broadcast band receiver, trace the circuit to each in order to make sure that the one selected as the padder is not a wave trap adjustment or some other special circuit arrangement. The oscillator low-frequency padder will generally be in series with the oscillator coil; sometimes this padder will be shunted by a fixed condenser.

Ordinarily there will be no high-frequency trimmers mounted on the gang tuning condenser of an *all-wave receiver;* these will be located near the coils which they adjust, instead. (The Philco two-band receiver used as our example in the lesson is not considered an all-wave receiver.) Sometimes all of the oscillator circuit coils will be found in a separate aluminum shield can, along with the oscillator high-frequency trimmers, while another shield can will be used for the preselector coils feeding into the mixer-first detector, and one more shield for the antenna coils if an R.F.

amplifier stage is used. There will be one adjusting screw on each of these shields for each band in the receiver; for example, in the case of a three-band receiver there will be three high-frequency trimmer adjusting screws on the side or on top of each preselector and oscillator coil shield.

Sometimes the preselector and oscillator coils are placed below the chassis, completely shielded from each other and from other parts by metal partitions and a metal cover plate. The adjusting screws for the high-frequency trimmers will be accessible through holes in the cover plate.

Low-frequency padder condensers are ordinarily mounted on the chassis, and are usually ganged or grouped together on a common insulating strip. Identification of these in the case of an all-wave receiver can sometimes be made by noting the number of plates in each unit; that padder having the largest number of plates will be for the broadcast band, while the other with the fewest plates will be for the high-frequency band. It is best, however, to identify trimmers by referring to a circuit diagram and to a chassis layout when available. Experienced Radiotricians can often identify the bands controlled by preselector and oscillator trimmers simply by adjusting each in turn and noting the effects; if you attempt to do this, however, be sure to note the original setting of the trimmer so you can restore this setting in case the wrong trimmer is chosen.

Appraising Receiver Performance

When servicing a receiver, it is obviously a waste of time to attempt to secure better performance than was originally intended by the manufacturer. Each receiver is designed to sell for a definite price, and consequently, lower-priced receivers will lack many of the features which are incorporated in the more expensive sets.

Actual experience with the various types of receivers is, of course, the best guide for determining when a receiver is performing in a satisfactory manner, but there are a number of recognizable clues indicating how much can be expected from a particular receiver in the way of selectivity, sensitivity and fidelity.

First of all, the number of tuned stages in a receiver is an excellent guide as to its selectivity and sensitivity, for increasing the number of tuned stages improves both of these performance characteristics.

The presence of more than two tuned circuits between adjacent R.F. or I.F. amplifier tubes indicates improved selectivity, possibly with some sacrifice in gain (sensitivity). Plate and grid connections to taps on tuning coils are signs of improved selectivity; the use of these taps also indicates that the stages in the receiver provide more gain than is considered essential, for the introduction of a selectivity-improving scheme tends to cut down the gain.

The number of tubes in the entire R.F. and I.F. amplifier systems, not including the oscillator and oscillator control tubes, is another rough guide to the amount of selectivity and sensitivity in a receiver. A superheterodyne will give better selectivity and better gain than a T.R.F. receiver having an equal number of tubes, simply because the I.F. amplifier in a super utilizes higher Q factor circuits and more tuned circuits per stage than does a T.R.F. receiver. Furthermore the gain and selectivity will be more uniform over the entire band in a super than in a T.R.F. receiver.

The presence of a stage of R. F. amplification ahead of the mixer-first detector in a super indicates a highly sensitive receiver with a high ratio of signal level to converter noise level. In other words, with an amplifier stage in the preselector, weak stations should be heard with clarity and freedom from converter noise interference.

Do not expect the selectivity and gain of an all-wave receiver to be as good on the higher-frequency bands as on the broadcast band, for the Q factors of the tuning coils are considerably reduced at the higher frequencies.

When checking the selectivity of a receiver, pay no attention to the space on the tuning dial which is covered by a station, but rather, note whether stations which are received at your location with approximately equal intensity can be heard separately even though only 10 kc. apart.

To determine what you can expect from a particular receiver in the way of fidelity, study the loudspeaker and the compartment in back of it carefully. If the design of these indicates a wide range of frequency response, means for suppressing cavity resonance and means for utilizing bass reflection, you can be quite sure that high fidelity performance was intended.

The presence of band-pass circuits in the R.F. and I.F. amplifiers, especially in the preselector circuits, are equally important clues pointing to a high fidelity receiver. The mere fact that I.F. transformers have a tuned primary and tuned secondary is no indication that they are band-passed, but if these transformers are critically coupled or over-coupled (as indicated by your inability to secure a sharp peak response curve with a cathode ray oscilloscope), they are very likely designed for band-pass use. If a receiver employs three or more I.F. transformers, and the design of the preselector appears to indicate a broad response, then band-passing is probably present.

An I.F. amplifier circuit employing variable coupling between the windings of the I.F. transformer is a fidelity control, permitting the customer to choose between high fidelity and high selectivity.

In receivers having automatic frequency control, the regular I.F. amplifier circuits are very likely intended to be band-passed for high fidelity if the discriminator is fed through one or more independent and highly selective tuned circuits.

Schematic and Chassis Wiring

The fact that the actual wiring on a chassis may be considerably different from the connections indicated on the schematic circuit diagram cannot be emphasized too strongly even though the differences between schematic and actual chassis wiring have already been taken up in this Course. Remember that the lines on a schematic diagram merely indicate which terminals of the various parts are connected together *electrically;* these lines are not intended to show how wires actually run from point to point on the chassis, nor do they indicate the relative lengths of the connecting wires.

For example, referring to the first audio amplifier stage in Fig. *1*, notice that parts *34* and *36* are both connected to the plate of this first audio tube. It might be possible to solder the condenser and resistor leads directly to the plate terminal of this tube socket. Actually, however, the resistor is soldered directly to this tube terminal and a long lead run from this terminal to condenser *34*, which is soldered directly to the grid terminal of the tube socket in the following stage. Experience with actual receivers will show you that other electrical connections indicated on a schematic circuit diagram can be made in many different ways on the actual chassis.

TEST QUESTIONS

Be sure to number your Answer Sheet 32FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Is it necessary for a Radiotrician to analyze the complete circuit diagram of a receiver when repairing a defect?

2. Into what two general trouble groups can all defective radio receivers be placed?

3. What is the simplest and speediest test for isolating the defective stage in a dead receiver?

4. Referring to the schematic circuit diagram in Fig. 1, what symbol identifies the circuit as that of an A.C. receiver.

5. Give the numbers of the trimmer condensers in Fig. 1 which permit peak adjustments of the two I.F. transformers.

6. Near what easily identified part would you expect to find the power pack rectifier tube in an A.C. receiver?

7. Through what parts does the second grid (oscillator plate) of the 6A8G tube in Fig. 1 trace to the rectifier filament?

8. What is the general rule for checking continuity in the circuits of all electrodes (in an A.C. receiver) which are supplied with a positive D.C. potential?

9. Should there be a conductive path (continuity) between the plate and cathode of a diode detector?

10. Are high frequency trimmer condensers ordinarily mounted on the gang tuning condenser of an all-wave receiver?

BEHAVIOR OF RADIO WAVES AND RECEIVING ANTENNAS

33FR-2

PIONEER HOME STUDY RADIO SCHOOL

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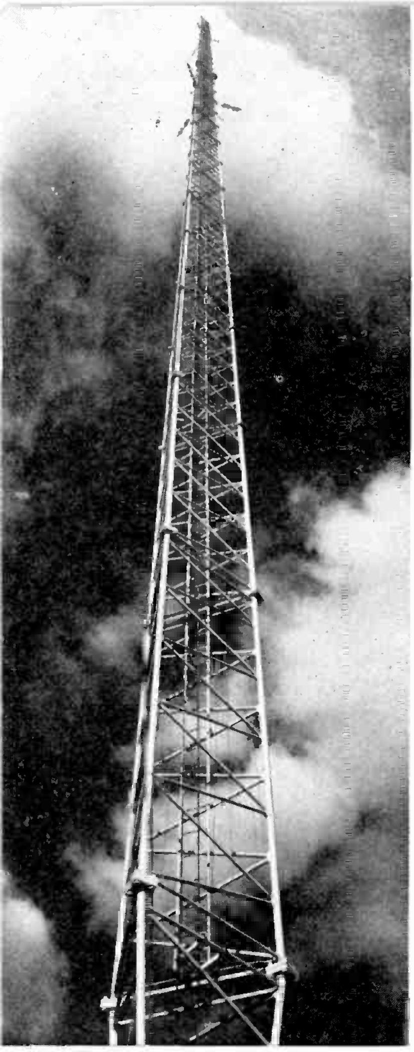

TOWERS IN THE SKY

Above the dust and clamor here below
These sentinels of mind and spirit rise;
Deftly their fingers touch the vibrant skies
Where winged words are passing to and fro.
They dwell on high, where rarer currents
flow—
Perhaps behold, in pity and surprise,
The low estate of recompense we prize,
The narrow round of things we seek to know.

O stalwart towers, unshakeable, serene,
Make us more worthy of your office here!
Refine our message, whatsoe'er it be;
Attune our thoughts to listeners unseen.
On far horizons may our words ring clear,
Proclaiming there the truth which makes
men free!

—GEORGE P. CONGER

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

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A LESSON TEXT OF THE N. R. I. COURSE
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Behavior of Radio Waves and Receiving Antennas

Introduction

THE extremely high sensitivity of modern radio receivers has made many servicemen somewhat careless with the installation of receiving antennas. In addition to feeding strong signals from desired stations into a receiver, a good receiving antenna must also have a *high signal-to-noise ratio,* if station programs are to be heard with a minimum of interfering noises. The introduction and rapid acceptance of all-wave receivers brought added responsibilities to the serviceman, along with puzzling questions concerning the peculiarities of radio waves at various frequencies.

In order to answer these highly practical questions and solve the receiving antenna problems which occur in service work, you must first understand what radio waves are, how they behave, how a receiving antenna can be made to intercept a maximum of radiated energy, and how intercepted signals can be fed to a receiver with highest possible efficiency. All this information will be given you in this lesson.

Radio Waves

Components of a Radio Wave. Whenever electrons flow through a conductor, *both an electric field and a magnetic field will always be produced.* (Of course, either field can exist by itself if no electron motion is involved; an electric field exists alone between two electrically charged bodies, while a magnetic field exists around a permanent magnet.) Furthermore, whenever electrons *change* their speed of travel through a conductor or oscillate back and forth, the result is a *moving* electric field and a *moving* magnetic field which together are known as an *electromagnetic field.* If the electrons are oscillating back and forth at a high enough rate (at a high frequency), the electromagnetic field will travel off into space at the speed of light (186,000 miles per second), giving what is known as an *electromagnetic wave* or a *radio wave.* A radio wave, therefore, has two components: *1. The electric field component; 2. The magnetic field component.*

How Radio Waves Are Produced. A study of the fields in the vicinity of a typical transmitting antenna such as that shown in Fig. *1A* will give you a good idea of how radio waves are radiated into space. This is a *doublet antenna,* for it is broken at its center and the two sections are fed with an oscillating electron flow produced by a radio transmitter; it is also known as a *di-pole antenna.** Suppose that the transmitter polarity at one instant of time is as indicated in Fig. *1A;* electron flow will then be in the directions indicated by arrows *i*, making the upper end of the doublet negative and the lower end positive. We can consider the circuit between the two halves of the antenna to be completed through space, for

*Although you will find the terms "doublet antenna" and "di-pole antenna" used interchangeably in many cases, the following definitions are accepted by most radio engineers: *A doublet antenna* is fed at its center, and its two sections are essentially equal in length and are in the same straight line; a doublet antenna may or may not be at resonance for the frequency of the signal fed to it. *A di-pole antenna* is to the radio physicist a theoretically perfect antenna having uniform current throughout its length and with ends having opposite polarity; to the practical radio man a di-pole antenna has *essentially* uniform current throughout its length, is *not* at resonance with the signal frequency fed to it, has ends with opposite polarity, and may be fed anywhere along its length.

these halves form a condenser having the surrounding air as a dielectric. A *displacement current* (the equivalent of an electron movement) flows from the negative half of the antenna through space to the positive half.

To simplify our study, we can neglect the transmitter connection and consider this antenna as a single length of wire in space, having the polarity shown in Fig. *1B* when electron flow i is upward as indicated; this antenna wire can be thought of as a source which is feeding power into space. The polarity will reverse from instant to instant of time in step with reversals in electron flow through the wire.

When electron flow through a doublet antenna is in the direction shown in Fig. *1B*, a *magnetic* field will encircle the wire and will act in the direction shown in Fig. *1C;* this magnetic field is usually designated by the letter H. At the same time an electric field having the direction shown in Fig. *1D* will be set up in space by the oppositely charged halves of the antenna; this electric field is usually designated by the letter E. At any point in space, the electric and magnetic fields (E and H) produced by an energized antenna *will always be at right angles to each other.*

A continuously oscillating (alternating) electron flow in a doublet antenna produces in the vicinity of the antenna an electromagnetic field; the relative intensities of the electric and magnetic components of this field at various distances away from the antenna at one instant of time are shown in Fig. *1E*. At point *1*, for example, there is an electric field component E_1 which is acting upward parallel to the antenna (in the plane of this page), and a magnetic field component H_1 which is at right angles to the electric field (towards you, at right angles to this page). The arrow lines E_1 and H_1 are intended to show the relative strengths of the electric and magnetic fields at point *1*, and the directions in which these fields act; these arrow lines *do not* represent the paths of electric and magnetic fields, for these paths are shown in Figs. *1C* and *1D*. Each other point in Fig. *1E*, such as *2, 3, 4, 5, 6, 7* and *8*, will likewise have its electromagnetic field with an electric component E and a magnetic component H; note that between points *4* and *8* there is a reversal in the directions of the components, with E now acting downward in the plane of the paper and H acting away from you perpendicular to the paper. The electromagnetic field is traveling away from the transmitting antenna in all directions, at the speed of light; both the electric and the magnetic components of this field are always acting *at right angles to this direction of travel.*

A portion of the electromagnetic field produced by a transmitting antenna acts as if it were permanently associated with the antenna and were staying in its immediate vicinity; this portion is known as the *induction field.* The other part of the electromagnetic field, known as the *radiation field,* the *electromagnetic wave* or the *radio wave,* breaks away from the antenna and travels outward through space. Insofar as energy is concerned, the E and H components of the radiation field or radio wave are always equal to each other at a distance from a transmitting antenna (in the region of the radiation field); close to the antenna, in the region of the induction field, the E component may be considerably greater than the H component. We will consider only the radiation field (radio wave) for the remainder of this lesson unless otherwise indicated, since the induction field ordinarily exists only for a few hundred feet away from the antenna.

Wavelength. During the time required for one complete cycle of the alternating current flowing through the antenna in Fig. *1E*, the electromagnetic wave will travel from point *0* to point *8*, and both the electric field *E* and the magnetic field *H* at any point will also go through one complete sine wave cycle. The distance between point *0* and *8* is known as *one wavelength.*

When engineers study radio waves in space, they ordinarily consider only one component (usually the electric field component *E*), and consequently they think of a radio wave as having the simple sine wave form shown in Fig. *1F*. The distance between the extremities of one complete cycle of this wave is therefore one wavelength. Fractions of a cycle are called fractions of a wavelength; half a cycle is thus half a wavelength or simply a half-wave, and 1½ cycles are 1½ wavelengths or 3/2 waves.

The next important fact for you to recognize is that *a wavelength is a different value* (in feet or in meters) *at each frequency.* Doubling the frequency means that we get twice as many alternations or cycles of the radio wave into a given distance, and each cycle or wave will therefore be only one-half as long; Fig. *1G* illustrates this clearly. The higher the frequency of a radio wave, the shorter will be the length of one complete wave or cycle.

Wavelength of an Antenna. The characteristics of a receiving antenna depend to a great extent upon its length with respect to the wavelength of the signal being picked up. For this reason, it is common practice to describe an antenna as being "so many" wavelengths long for a particular signal frequency. When a radio signal produces a half-sine-wave distribution of current along a receiving antenna, we know that the antenna is half as long as one wavelength of that particular signal, and we say that the antenna is *one-half wavelength long.*

We could easily determine the wavelength of an antenna at a particular frequency by drawing the radio wave and the antenna on the same line at the same scale, and simply counting the number of cycles covered by the antenna. Figure *1G* illustrates this; line *CD*, which represents an antenna drawn to scale, covers 1½ cycles and consequently we have a 3/2-wave antenna at this particular signal frequency. It is generally more convenient to figure out this information than to secure it graphically, however; simply divide the length of the antenna by the wavelength of the signal (using the same units of length), and the result will be the wavelength of the antenna. Example: Antenna length is 100 feet;

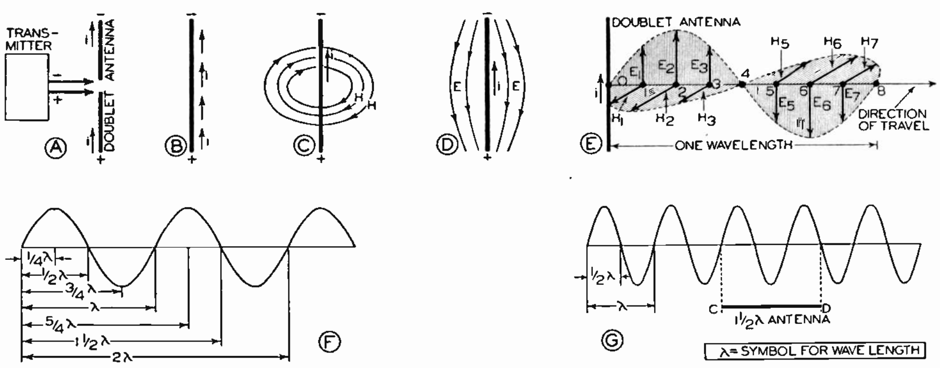


FIG. 1. These diagrams show the first steps in the formation of a radio wave by a simple doublet antenna which is fed by a transmitter. Electron flow *i* through the antenna wire in the direction shown produces a magnetic field *H* and an electric field *E*, both of which travel away from the antenna at the speed of light.

signal wavelength is 200 feet; 100 ÷ 200 = ½, and consequently we have a half-wave antenna in this example.

Frequency - Wavelength Relationship. Oftentimes the frequency of a radio wave rather than the wavelength is known. The preceding section indicates that there is a definite relationship between frequency and wavelength; this relationship is based upon the fact that an electromagnetic wave *in space* always travels at the same speed, approximately 300,000,000 meters per second or 186,000 miles per second (this is also the speed at which light travels through space). The following formula gives the relationship between the speed, frequency and wavelength of a radio wave in space:

Wavelength in meters multiplied by frequency in cycles per second always equals 300,000,000.*

Figure *1E* shows only one of the many possible paths for radio waves away from the antenna. There will be many other paths in all directions. When a radio wave travels along the ground directly to the receiving antenna, it is known as a *ground wave.* When a radio wave travels up into the sky and is then bent back to the receiving antenna, it is known as a *sky wave.* Both the ground wave and the sky wave must be considered when studying problems involving the transmission and reception of radio signals.

*When dealing with antennas it is usually more convenient to speak in terms of wavelength than frequency. If either the frequency or the wavelength of a radio wave is known, you can easily determine the missing value. It is common practice to let f represent frequency *in cycles per second* and λ (Greek letter lambda) represent wavelength *in meters;* the above formula then becomes $\lambda \times f = 300{,}000{,}000$.

To find frequency when wavelength is known, use this variation: $f = 300{,}000{,}000 \div \lambda$. Example: If wavelength is 5 meters, what is the frequency? Answer: $f = 300{,}000{,}000 \div 5 = 60{,}000{,}000$ cycles or 60 megacycles.

To find wavelength when frequency is known, use this variation: $\lambda = 300{,}000{,}000 \div f$. Example: If frequency is 1,500 kc., what is the wavelength? Answer $\lambda = 300{,}000{,}000 \div 1{,}500{,}000$, or 200 meters.

To get wavelength in feet, multiply the wavelength in meters by 3.28 (roughly 3¼).

Radiation Patterns of Transmitting Antennas

It is a well-known fact that radio stations which are intended to serve a local area, such as broadcast band stations in this country, use antennas which radiate signals having maximum intensity *along the ground.* Stations which must send messages or programs to far-distant receiving points use antennas which direct radio waves skyward, for it is now known that there is a layer in the upper atmosphere which will bend the sky wave back to earth again at a point considerably distant from the station. Commercial short-wave stations in transoceanic use, amateur radio stations, and short-wave stations which transmit entertainment programs to far-distant countries all use antennas which are carefully designed to produce the strongest possible sky wave.

Field Intensity Surveys. Careful measurements must be made of the amount of energy radiated in each direction (north, south, east and west) from a transmitting station in order to determine whether an antenna is giving adequate coverage of the desired local service area or is radiating satisfactory signals to desired distant points, as the case may be. It is customary to measure the energy in the electrical component E of the radio wave; the results are expressed in terms of microvolts per meter, millivolts per meter or volts per meter, with these units expressing the voltage existing between two points which are exactly one meter apart in space at the location where the signal intensity is measured. These field intensity units also correspond to the voltage which would be measured between the ends of a true di-pole antenna exactly one meter long, erected at the receiving location being checked. Measurements are usually made with a loop receiving antenna, and the readings are converted by means of higher mathematics to equivalent values for a true di-pole antenna. The final values are plotted on a graph to give what is known as the *radiation pattern* of a transmitting antenna.

How Radiation Patterns Are Secured. If an engineer wants to know how well the ground wave is getting out in various directions from a broadcast station antenna, he might take suitable field intensity measuring equipment first to a position P_1, which is two miles due east of the antenna, place his pick-up antenna at the angle and direction which give maximum signal, and make the first measurement; he could then travel in a two-mile-radius circle around the antenna and make measurements at positions P_2, P_3, P_4, etc., in Fig. *2A*, which are NE, N, NW, W, etc., from the antenna along this circle (any other convenient radius could just as well be used).

An alternative procedure involves selecting convenient positions each two miles away, regardless of their direction from the transmitting antenna, and measuring the angle θ (see Fig. *2A*) between a line to the antenna and a line running due east from the antenna. After measurements have been made for a sufficient number of points, the engineer draws a diagram similar to that in Fig. *2A*, with radial lines running from the antenna location to each point at which a measurement was made. Along line A-P_1, starting from A, he plots the signal intensity measured at point P_1, using any convenient scale (he might let one inch represent 10 millivolts per meter). The length of line AE_1 then represents the field intensity measured at point P_1, two miles due east of the antenna. The same procedure is repeated for each other radial line, and a smooth curve is drawn through the various points. This curve is the *horizontal radiation pattern;* it indicates the approximate signal intensity in millivolts per meter which can be expected at a point two miles from the transmitting antenna at any angle with the due east line, eliminating the need for making measurements at all angles. The particular pattern shown in Fig. *2A* indicates that practically no energy is being radiated along the ground in the NW, W and SW directions, and that almost uniform energy is being radiated in the N, NE, E, SE, and S directions.

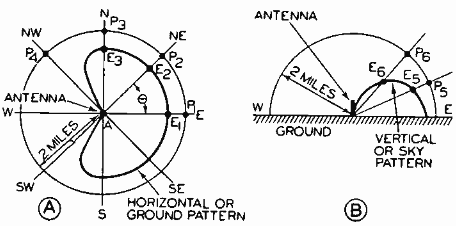


Fig. 2. Horizontal and vertical radiation patterns for a directional transmitting antenna.

Similar information concerning sky wave radiation can be obtained by making measurements from an airplane or blimp. An example of a pattern secured for a flight due east and west over an antenna is shown in Fig. *2B*. This radiation pattern indicates that signal intensity is a maximum along the ground, but that considerable energy is being radiated into the sky in the form of a sky wave.

Vertical and Horizontal Polarization

Action of a Receiving Antenna. A short straight antenna will pick up a maximum signal when it is *parallel* to the electric lines of force associated with a radio wave, as indicated in Fig. *3A*. Free electrons in the antenna wire move back and forth along the wire in step with changes in the direction and intensity of the electric lines of force, with the result that an alternating current is sent down to the receiver. When the antenna is at right angles to the electric lines of force, the electrons will oscillate from side to side across the wire, and no current will flow to the receiver.

You can also visualize the action of a receiving antenna by considering the magnetic lines of force, which are at right angles to the antenna. These magnetic lines, moving through space at the speed of light, cut across the receiving antenna and induce in it a radio frequency voltage which is proportional to the number of lines which cut the antenna per unit of time. This voltage in turn forces a current down the antenna lead-in wire to the receiver.

Polarization of Radio Waves. When the electric lines of force associated with a radio wave are perpendicular to the ground, as indicated in Fig. *3B*, they are said to be *vertically polarized.* When the electric lines of force associated with a radio wave are parallel to the ground, as indicated in Fig. *3C*, they are said to be *horizontally polarized.* The magnetic lines of force associated with a radio wave are also polarized, but we can neglect them when considering the effectiveness of various receiving antennas.

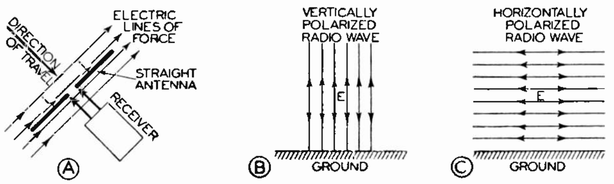


FIG. 3. The electric field E associated with a radio wave may have any angle whatsoever with respect to ground when it arrives at a receiving antenna, and this angle will have an important effect upon signal pick-up by a given antenna. When E is perpendicular to the ground, we say that the radio wave is vertically polarized; when E is parallel to the ground, the radio wave is horizontally polarized.

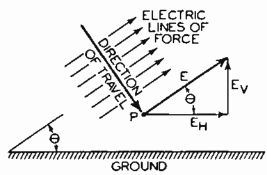


FIG. 4. An electric field arriving at the angle θ to ground may be considered equal to a vertically polarized component E_V acting with a horizontally polarized component E_H.

The electric lines of force associated with a sky wave seldom have perfect vertical or horizontal polarization; they are usually at an angle with the ground, somewhat as shown in Fig. *4*. Here the radio wave is traveling toward the ground after reflection from the sky. The intensity and direction of the electric field at point P (above the ground on this path of travel) can be represented by the arrow line E. This arrow line can be considered to have two components; a vertical component E_V and a horizontal component E_H, as shown in Fig. *4*. To secure a maximum signal at location P, you would have to place a straight doublet antenna in the direction indicated by E. A vertical antenna would only pick up a signal corresponding to the length of E_V, and a horizontal antenna would in this case give but slightly more signal pick-up, corresponding to the length of E_H.

The Ground Wave

The transmitting antennas used by broadcast stations for local coverage are generally of the vertical type, for these can be designed to radiate considerable energy along the ground and at the same time keep the sky wave at a low enough intensity to avoid interference betwen ground and sky waves within the service area of the station. The electric lines of force produced by an energized vertical antenna are essentially parallel to the antenna when near the surface of the earth, and hence are very nearly vertically polarized. We might conclude that for maximum signal pick-up at the receiving location, the receiving antenna should be of the vertical type, but we know that the majority of receiving antennas are actually horizontal.

There are several reasons why a

horizontal antenna is more satisfactory for receiving purposes. First of all, high vertical antennas are expensive and difficult to erect, making them unsuited for the average home. Secondly, electric lines of force bend forward as they move away from the antenna, as indicated in Fig. *5B*, due to the presence of the ground; one engineer describes this phenomenon by saying "the radio waves are pushed forward with their feet dragging on the ground." Another reason is this: Radio waves which tra''el over hilly or mountainous country or near tall steel buildings are reflected enough to change their angle of polarization and their direction of travel. At a reasonably distant receiving location such as that shown in Fig. *5A*, there is invariably a large enough horizontal component E_H (Fig. *5B*) to excite a horizontal antenna.

There is still another good reason for making receiving antennas horizontal. Electrical devices which cause man-made interference produce far more vertically polarized electric lines of force than horizontally polarized lines, and since these interference-producing devices are close to the receiver location, they would induce strong signals in a vertical receiving antenna. A horizontal antenna picks up a minimum of noise signals and still intercepts enough of the signal from a local transmitting antenna to give a satisfactorily high signal-to-noise ratio. In most cases, a horizontal antenna gives better reception of sky waves than does a vertical antenna.

Ground waves radiated by either a broadcast or short-wave station will follow the earth until they are totally absorbed or are too weak to affect receiving antennas. Only by increasing the amount of power radiated by the transmitting antenna can stronger ground waves and more distant reception of ground waves be secured. All reception at points outside the range of ground waves will be due to sky waves reflected back to earth by a layer in the upper atmosphere. These sky waves are absorbed very little by the atmosphere, and consequently will often be reflected back to points thousands of miles away from the station with surprisingly high signal strength.

Television Receiving Antenna Problems

At the carrier frequencies used in modern television systems, automobile ignition systems and electrical devices having sparking contacts can cause considerable interference. It is highly desirable to use a horizontal receiving

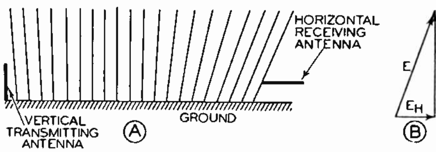


Fig. 5. Vertically polarized electric lines of force produced by a vertical transmitting antenna gradually change their angle with the ground as they travel away from the antenna.

antenna in order to keep out these vertically polarized interference signals. Television transmitting antennas are usually designed to radiate horizontally polarized radio waves, for these will be picked up with maximum efficiency by a horizontal receiving antenna and will therefore give a maximum signal-to-noise ratio.

Television signals may reach a receiving antenna in a city location over two or more different paths. This multiple transmission effect is due to reflection of waves from buildings, bridges and other steel structures, and may give two or more images superimposed on each other due to slight differences in the times of arrival of the signals over the various paths. This secondary or ghost image effect can be minimized by erecting the horizontal doublet receiving antenna as high as possible and in a direction which gives maximum reception of either the direct wave or the reflected wave, but not both. When there are two television stations in a locality, a doublet antenna must necessarily be in a position which gives a satisfactory compromise between signals arriving from the two directions. An alternative procedure involves the use of two doublets at right angles to each other and crossed at their centers, with the system oriented to give best possible pick-up from both stations.

Beam Characteristics of Ultra-High-Frequency Waves. Ultra - high - frequency (u.h.f.) radio waves such as are used in modern television systems are above 40 megacycles. These u.h.f. waves behave like beams of light, in that they travel in essentially straight

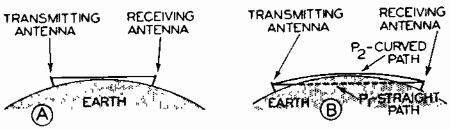


FIG. 6. Radio waves at ultra-high frequencies travel in essentially straight lines, limiting the reliable range of reception of television programs to line-of-sight distances.

lines from the transmitting antenna. This means that if the transmitting antenna is not visible from the top of the receiving antenna on a clear day, signals will in all probability not be received. With antennas at ordinary heights on level ground, the curvature of the earth definitely restricts the coverage of a given station. This is illustrated in exaggerated form in Fig. *6A;* increasing the distance between the two antennas would make the radio waves pass over the top of the receiving antenna without affecting it, for these u.h.f. waves cannot bend around the earth. Television broadcasts from the tower of the highest building in the world, the Empire State Building in New York City, can normally be picked up only within a radius of about sixty miles of the transmitting station. Occasionally, reception at greater distances is possible because of a peculiar distribution of moisture in the air which bends ultra-high-frequency sky waves back to the earth at more distant locations. In Fig. *6B*, for example, reception of signals over the direct path marked P_1 would be blocked by the earth, but under certain conditions the sky waves might be bent back to the lower atmosphere, taking path P_2 to the receiving antenna. In general, however, sky wave reception at ultra-high frequencies is unreliable.

Sky Waves; The Kennelly-Heaviside Layer

Before Marconi in 1901 succeeded in transmitting a radio message from England to the North American Continent, scientists generally believed that all radio reception was by means of ground waves, and that long-distance transmission was impossible because of the absorption of energy by the ground. The success of Marconi proved this theory false, and many new theories were advanced to explain the amazing long-distance transmission of signals. Kennelly in America and Heaviside in England simultaneously presented the explanation that there are electron layers in the sky which act like any conductive layer in reflecting and bending electromagnetic waves. These theories have been proved correct, and today we speak of this wave-bending layer in the atmosphere as the Kennelly-Heaviside layer. The reason for the existence of this layer is usually explained in the following manner: The surface of the earth is surrounded by air, which thins out (becomes rarefied) away from the earth. Under the action of ultra-violet rays of light from the sun, this rarefied air becomes ionized, with the result that a layer made up of free electrons, positive ions and negative ions is formed high above the earth.

A radio wave passing into the Kennelly-Heaviside layer will impart some of its energy to the free electrons in the layer, setting them into vibration. The velocity of vibration will be the least at the highest frequencies, for even an electron has a certain amount of mass which prevents large amplitudes of vibration at high frequencies. The mass of the electron makes it act as a reactance, so its velocity is 90° out of phase with the velocity of the radio wave. The oscillating electrons in the layer produce a new radio wave which acts with the original wave. This combining of velocities which are 90° out of phase results in an apparent speeding up of the radio wave when it hits the electron layer.

Radio waves at low radio frequencies cause the electrons in the layer to vibrate with great amplitude. These electrons collide with air particles, giving up their energy and liberating ions and more electrons. In this way a portion of the energy in the original radio wave is lost in the Kennelly-Heaviside layer; the loss may amount to as much as 30% and occurs chiefly at the lower levels, where there are more ions of air to absorb energy.

Refraction of Radio Waves. Let us assume that the Kennelly-Heaviside layer has a uniform distribution of electrons and that the electric lines of force associated with a radio wave are moving toward it at the angle shown in Fig. *7A*. As the radio wave enters the layer, portion *y* encounters electrons first and speeds up. The result is a bending of the electric lines of force and of the radio wave path itself; this bending of the path of travel is always down toward the earth. Scientists refer to this phenomenon as *refraction* rather than as bending.

Progressive Refraction. The electron density (number of electrons per unit volume) in the Kennelly - Heaviside layer is greater in the upper regions than in the lower regions. We would naturally expect this, since the upper portion of the layer is closer to the sun and is consequently subject to greater ionization. A radio wave entering the Kennelly-Heaviside layer at an angle encounters regions of increasingly greater electron density, and consequently undergoes increasingly greater refraction or bending; this phenomenon is known as *progressive refraction.* It is quite possible for the bending to progress to the point where the radio wave travels horizontally with respect to the earth, then actually bends back toward the earth in the manner shown in Fig. *7B*.

E, F_1 and F_2 Layers. Actually, the Kennelly-Heaviside layer is not as simple as is shown in Fig. *7B*. The action of the sun upon the upper atmosphere is such as to produce three separate layers, one above the other. If we were able to measure electron densities, starting from the earth and going vertically upward, we would find that for the first thirty to forty-five miles there would be a negligible number of electrons. Continuing upward, the electron density would increase to the first maximum value at a height of about sixty miles, then gradually decrease. Higher up still, electron density would increase again and reach another maximum at about 125 miles. Farther up we would pass through another region

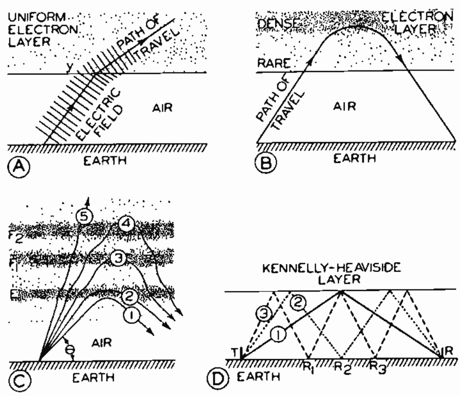


FIG. 7. These diagrams show how sky waves can be refracted (bent) back toward the earth by the Kennelly-Heaviside layer in the upper atmosphere.

of gradually decreasing and then increasing electron density until we reached the third and final maximum-density level at about two hundred miles up. Above this level the electron density decreases to a negligible value, for at this height in the stratosphere there is almost a total vacuum, and little ionization can occur. These three maximum-density layers are known as the E, F_1 and F_2 layers respectively.

The E layer is nearest the earth and is fairly constant in height; the F_2 layer is highest and may vary in height from 150 miles to 225 miles. This highest layer is most affected by the sun and hence it varies greatly in height and electron density from day to night, from summer to winter, and with con-

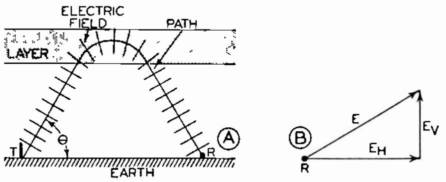


FIG. 8. Effect of the Kennelly-Heaviside layer upon the polarization of a sky wave.

ditions on the sun such as sun spots (solar eruptions). The F_2 layer also varies with latitude, and may be higher or lower around the equator than it is in the north temperate zone or at either pole. Oftentimes the F_1 (middle layer) and F_2 layers will merge to form what is called an F layer. Less often, the E layer will separate into two layers, with one being known as the normal E layer and the other as the *sporadic* E layer.

A sky wave may be refracted back to earth by the lower portion of the E layer, as shown by path *1* in Fig. *7C;* on the other hand, it may be refracted by the upper part of the E layer as in path *2,* may pass completely through the E layer and be refracted by the F_1 and F_2 layers as shown by paths *3* and *4,* or may pass completely through all three layers as in path *5* and be lost in interplanetary space. As a rule, the longer wavelengths (broadcast band and longer wavelengths) are refracted by the E and F_1 layers, and shorter wavelengths are refracted by the F_1 and F_2 layers. The extremely short waves (ultra-high frequencies) pass through all three layers, and hence are not ordinarily received.

The angle θ in Fig. *7C* (the angle between the sky wave and the earth) has a vital effect upon the path taken by the sky wave; the greater this angle, the more chance there is for the wave to get through the E layer and be refracted by the higher layers. A sky wave radiated at a high angle will be bent back to earth closer to the transmitting station than a wave radiated at a low angle and refracted by a lower layer. This statement is illustrated in Fig. *7D;* radiation of the sky wave at the largest angle, along path *3,* results in reception at point R_1, which is near to station T. Radiation at a low angle, along path *1,* gives reception at point R, which is a considerable distance from the station. Of course, the ground wave will be received in the immediate vicinity of the station in all cases.

Long-Distance Reception. The Kennelly-Heaviside layer makes possible long-distance reception of signals from low-power radio stations, for this layer bends radio waves back to the earth at points far beyond the range of reliable ground wave reception. These sky waves will be reflected skyward again by the earth, and will oftentimes be refracted by the Kennelly-Heaviside layer and reflected by the earth one or more additional times. Each path from earth to sky and back again is called a *hop.* Signals from station T in Fig. *7D* may reach receiving point R in 1, 2 or 3 hops, as illustrated by paths *1, 2* and *3* respectively in Fig. *7D.* As a rule, signals on the longer wavelengths are sent with fewer hops than those on the shorter wavelengths. The best wavelength to use for communication between two given points depends considerably upon the conditions in the electron layers. The number of hops is controlled by the angle at which the sky wave leaves the station; the ideal number of hops at any time depends upon conditions in the upper layers. Where reliable transmission is essential, the same message is oftentimes broadcast simultaneously on several different wavelengths, each reflecting from a different layer and giving a different number of hops.

Peculiarities of Sky Wave Reception

Polarization of Sky Waves. If we analyze the electric field produced at receiving point R by the sky wave from station T in Fig. *8A,* we find that it has doublet antenna at R in Fig. *8A,* the antenna wire should of course coincide with the electric lines of force nearest point R in this diagram; amateur and commercial antenna systems are sometimes tilted to take advantage of this fact, but for home entertainment purposes it is impractical and unnecessary to provide means for tilting the antenna to a new angle each time a new distant station is tuned in.

Fading. For signals below 3 megacycles in frequency, the sky wave is refracted and bent back to the ground almost immediately after its entrance into the lowest electron layer (the E layer). If there is an appreciable amount of high-angle radiation (sky waves) from the station, receiving an-

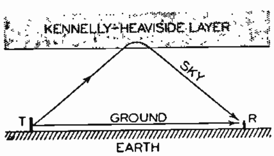


FIG. 9. This diagram shows why fading sometimes occurs within 50 miles of a broadcast station.

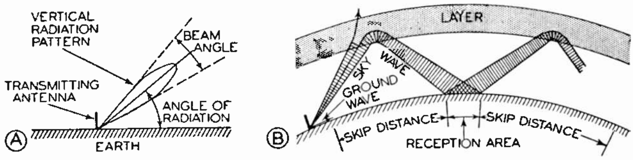


FIG. 10. Long-distance communication via short-wave radio depends entirely upon sky waves. The transmitter engineer chooses operating conditions which will make the sky wave come back to earth at the desired reception area.

a vertical component E_V and a horizontal component E_H, as shown in Fig. *8B*. When θ (the angle of radiation) is more than 45°, the E_H component will be the stronger, and a horizontal receiving antenna will give better signal pick-up than a vertical antenna. When a radio wave travels a long distance with a single refraction from the Kennelly-Heaviside layer, θ may be less than 45°; the vertical component of the electric field will then predominate, and a vertical antenna will give better signal pick-up provided there is no man-made interference near the receiver. When interference is present, a horizontal antenna is invariably more satisfactory, for the horizontal component E_H of a sky wave is usually strong enough to give a high signal-to-noise ratio.

For maximum signal pick-up with a tennas about fifty miles away from the station will pick up the ground wave directly and the sky wave after refraction, as indicated in Fig. *9*. The sky wave, traveling a considerably longer distance, may arrive *in phase with* the ground wave, in which case there is reinforcement and maximum signal pick-up; more likely, the two waves will be partially or completely *out of phase,* giving partial or complete cancellation of the signal. The phase relationship may vary from instant to instant, causing fading, for the Kennelly-Heaviside layer sometimes shifts up and down slightly. Briefly, then, sky waves cause fading at receiving locations near the limits of reliable ground wave reception from a given station because the phase relationship between the sky and ground waves changes continually due to refraction of the sky wave by the rapidly - shifting Kennelly - Heaviside layer, giving partial or complete cancellation of the ground wave.

If the shifts which cause fading occur in less than one-tenth of a second, the a.v.c. system in the average receiver will not be able to compensate for them and the variations in signal strength will be annoyingly noticeable at the receiver loudspeaker. Even when fading takes place at a slow rate, the automatic changes in receiver gain may result in noticeable alternate periods of clear and noisy reception.

Fading is generally less severe during the daytime. The Kennelly-Heaviside layer is then so dense that radio waves at broadcast band frequencies are almost completely absorbed as they enter the lower regions of the layer. Fading at distances of from 40 to 60 miles away from a broadcast station can be kept at a minimum by designing the transmitting antenna to radiate most of its energy along the ground; vertical antennas which are about 5/8 wavelength high are best suited for this purpose.

Skip Distance. At frequencies of from 3 to 30 megacycles, the sky wave is used almost exclusively for communication purposes. The transmitting antenna is in this case designed to radiate most of its signal into the sky, and may have a vertical radiation pattern like that in Fig. *10A*. Notice that maximum signal intensity occurs at a definite *angle of radiation* with the ground, and that radiation is concentrated over a definite angular distance which is known as the *beam angle*. There may be enough radiation along the ground in a case like this to provide adequate reception for distances of perhaps ten miles away from the station, but most of the energy is radiated into the sky, where it is either bent back to the earth or lost through absorption. This type of radiation pattern for a transmitting antenna provides reception over a more or less restricted area at a great distance away from the station; the distance and the area both depend upon the width of the beam, the angle of radiation, the frequency of transmission and upon conditions in the Kennelly-Heaviside layer. The distance between the maximum limit of ground wave reception and the closest point at which the sky wave returns to earth is commonly known as the *skip distance* (see Fig. *10B*). Different frequencies must be used for each distance covered, and frequency must be changed at night to compensate for the shift in the height of the electron layers and the resulting change in the skip distance, as each frequency is acted upon differently by the layers. As a general rule, high transmitting frequencies are best for daylight and lower frequencies are better for night transmission. Furthermore, radio transmission is better in winter than in summer, for in winter there is less absorption of signals by the electron layers.

Selective Attenuation. We must not overlook the fact that the transmission of voice and music is accomplished by sending a number of side-band frequencies along with an r.f. carrier. Each side frequency is acted upon by the Kennelly-Heaviside layer in a slightly different manner, and consequently the various frequencies may take various paths back to the earth or may be attenuated differing amounts. The result is that side frequencies in the received signal may have a different strength relationship to the carrier frequency than they had at the transmitting station, causing amplitude distortion in the demodulated audio signal; this cannot be corrected in the receiver. Since conditions in the Kennelly-Heaviside layer fluctuate quite rapidly, reception may be distorted severely at one moment and may become clear in the next instant, particularly when the receiver is located near the boundary between a skip area and a reception area.

Receiving Antenna Problems

Even though a transmitting station is designed to "lay down" a strong signal in a definite receiving area, part or all of this energy will be wasted unless the receiving antenna is properly designed. Three important factors are involved in the selection and installation of a receiving antenna:

1. That portion of the antenna which intercepts the electric and magnetic components of the radio wave must have *maximum possible signal pick-up.* This involves consideration of the directional properties of the antenna, the polarization of radio waves from favorite stations, and the frequency range over which signals are to be picked up.
2. The signal energy picked up by the antenna must be transferred to the receiver with a minimum of loss over the desired range of carrier frequencies. This involves matching the transmission line impedance to the impedance of the antenna and to the impedance of the receiver input, *to secure maximum transfer of energy from the antenna to the receiver.*
3. There should be a *maximum signal-to-noise ratio* at the receiver input. This is usually secured by designing the antenna system so it will accept a minimum of noise signals.

Directivity of Receiving Antennas

The directional characteristics of a receiving antenna system depend upon a number of important factors: 1. The current and voltage distribution along the antenna; 2. The position of the antenna with respect to ground; 3. The position of the pick-up section with respect to other elements of the antenna, if the system is made up of more than one wire; 4. The electrical characteristics of the ground near the antenna.*

*Items *3* and *4* are not covered in this lesson since they are ordinarily neglected when designing and installing antennas for home radio receivers. These factors are extremely important in connection with amateur and commercial receiving antennas and with television receiving antennas, and are taken up in advanced lessons dealing with these subjects.

Current and Voltage Distribution of Half-Wave Doublet Antennas. A single straight half-wave doublet antenna like that in Fig. *11A,* located in free space (away from the influence of the earth and other objects) and fed with energy either by a direct connection to a transmitter or by radiation of power through space from a distant transmitter, acts like a number of small elements of inductance and capacity connected together in the manner shown in Fig. *11B.* If a.c. power is fed into the center in the case of a half-wave doublet transmitting antenna, the current encounters small elements of inductance which serve to choke it and reduce its value, and for each inductance there is an elemental capacitive path which draws off a portion of the antenna current and brings it to a corresponding point on the other half-section of the antenna. The result is that the r.f. signal current is the greatest *at the center* of a half-wave receiving antenna, and gradually drops to zero as it approaches the extreme ends. Across each elemental inductance there will be a voltage drop due to current flow through it, and those elements nearest the center will naturally have the highest voltage drops. The result is that the r.f. voltage *with respect to the center of the antenna* increases rapidly as we move outward from the center, then increases more gradually to a maximum value at the ends; furthermore,

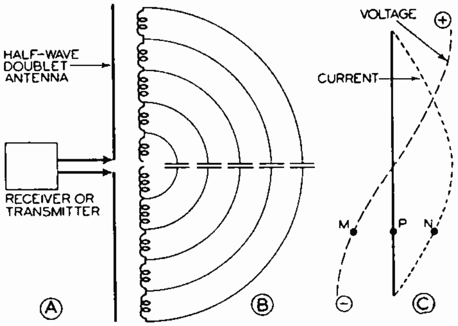


FIG. 11. Characteristics of a simple half-wave transmitting or receiving antenna in free space.

the ends will be opposite in polarity at any instant and will reverse in polarity *once for each cycle.* The curves in Fig. *11C* show this current and voltage distribution; they tell, for example, that the effective (r.m.s.) value of the r.f. current at point P is proportional to the distance NP, and the r.m.s. value of voltage at point P is proportional to the distance MP. Notice that both curves are sinusoidal (having a sine wave shape), with maximum current at the center and maximum voltage at the ends. (Since the center of the antenna has zero voltage, it may be considered at ground potential and all voltages measured with respect to the center rather than to ground.)

This half-sine-wave distribution of current and voltage will be obtained for any doublet transmitting or receiving antenna in free space whenever the length of the antenna wire is equal to one-half the wavelength of the signal. This condition can occur at only one signal frequency; at that frequency the antenna radiates or picks up a maximum signal, and is said to be *at resonance.*

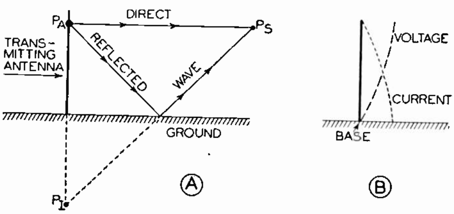


Fig. 12. Characteristics of a grounded vertical quarter-wave antenna. A perfectly conductive ground is assumed.

The essential requirement of a resonant receiving antenna is that it act as a pure resistive source. This requirement can be met by making the antenna one-half wavelength long or some multiple of a half wavelength (2, 3, 4, 5, etc., times as long). An antenna which is not a multiple of one-half wavelength for a particular radio wave will have either an inductive reactance or a capacitive reactance which raises its impedance and reduces the amount of current which can be delivered to the receiver. It is possible to introduce either capacity or inductance in the antenna circuit in order to cancel out the existing reactance; this *tunes* the antenna to resonance, making it purely resistive and giving at its ends the zero-current, maximum-voltage condition which results in maximum signal pick-up.

Current and Voltage Distribution of Grounded Vertical Antennas. If a vertical antenna is grounded at one end, it will be at resonance when only ¼ wavelength long, for the earth serves to duplicate the effect of the other ¼ wavelength. A quarter-wave grounded vertical antenna is shown in Fig. *12A;* a receiving antenna at point P_S in space will receive a radio wave directly from point P_A on the transmitting antenna, and will receive another radio wave directly from point P_A by reflection from the ground. This reflected wave appears to come from a point P_I which is located the same distance below the surface of the earth as P_A is above the earth. In the language of radio engineers, we have an *image antenna* in the ground; although it is a purely imaginary structure, the observed effects are exactly the same as if it were present.

The current and voltage distribution curves for a grounded quarter-wave vertical antenna are shown in Fig. *12B;* note that current is zero and voltage a maximum at the upper end of the antenna, just as with a half-wave antenna. (Remember that these curves indicate r.m.s. values; the current and voltage at each point along the antenna are varying in a sine wave manner at the signal frequency.) A grounded vertical antenna is at resonance whenever its height is some odd multiple of ¼ wavelength; it can therefore be $\lambda/4$ (λ is the symbol for one wavelength), $3/4\lambda$, $5/4\lambda$, etc. An untuned vertical antenna (an antenna whose height at a particular signal frequency is not a multiple of $\lambda/4$) can be tuned to resonance, making it purely resistive and giving maximum signal pick-up at that signal frequency, by adding either a coil or a condenser in series.

Typical resonant receiving antennas are shown in Fig. *13;* current distribution curves for these are shown in dotted lines. At *A, B* and *C* are grounded $\lambda/4$ antennas, while at *D* and *E* are ungrounded $\lambda/2$ antennas; in each case the free ends have zero current. A receiving antenna which is at resonance when straight will remain at resonance even though a part of it is bent at an angle. A resonant half-wave antenna for reception at 49 meters should be 49 ÷ 2, or 24.5 meters (81 feet) long. A grounded quarter-wave antenna which is to be resonant at this same wavelength should be about 40.5 feet long.

A quarter-wave antenna which is resonant at 98 meters will be a half-wave antenna for signals at 49 meters and will be a full-wave antenna for signals at 24.5 meters. At wavelengths other than these values we can secure signal pick-up approaching that of a resonant antenna by introducing into the antenna system a condenser which will tune it to a lower wavelength, or by inserting a coil which will tune it to a longer wavelength. This practice is used quite often, especially when the antenna does not have the correct length for resonance at a desired frequency. For example, if an 81-foot length of wire is needed for a center-fed half-wave antenna and only 61 feet of room is available, the surplus 20 feet of wire can be wound in two coils of equal size, and one placed in series with each section of the antenna, near the center.

Directional Characteristics. Although the shape of a receiving antenna has little effect upon resonant conditions, shape does affect the directional characteristics of an antenna. If an antenna is short in comparison to the wavelength of the signals which it picks up (most of the antennas used for 500 to 1,500 kc. broadcast band reception are in this class), best signal pick-up is secured when the electric lines of force associated with the radio wave arrive *parallel* to the antenna wire. Thus, the vertical portion of a short antenna will respond best to vertically polarized electric fields, and the horizontal portion of a short antenna will receive horizontally polarized waves best. Only short antennas (shorter than one-quarter wavelength of the radio wave which is intercepted) have these properties, for they are acted

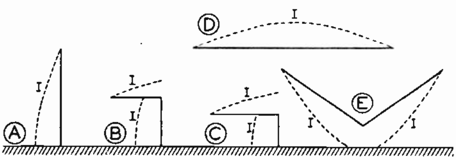


FIG. 13. These curves show that current distribution *I* along a quarter-wave or half-wave antenna is essentially independent of the shape of the antenna.

upon directly by the electric field and are not greatly influenced by surrounding objects or by the ground.

Radiation Patterns for Receiving Antennas. When the length of an antenna is one-fourth the wavelength of the signal picked up (or is longer than ¼ wavelength), special patterns must be used to show the directional characteristics. These patterns are called *radiation patterns* because they are usually secured by making measurements while the antenna in question is connected to a transmitter and is radiating signals, but each pattern applies to a particular antenna *regardless of whether it is used for transmitting or receiving purposes.* A horizontal radiation pattern for a receiving antenna indicates the effectiveness of signal pick-up in any direction along the ground. A vertical radiation pattern for a receiving antenna indicates the effectiveness of signal pick-up at various angles to the ground in one vertical plane passing through the center of the antenna system.

In Fig. *14A* is shown the radiation pattern in a vertical plane for a tern indicates that a vertical antenna receives ground waves equally well from all directions along the surface of the earth. When a grounded vertical antenna is shorter than λ/4, the center of a horizontal wire can be connected to the top of the vertical antenna to

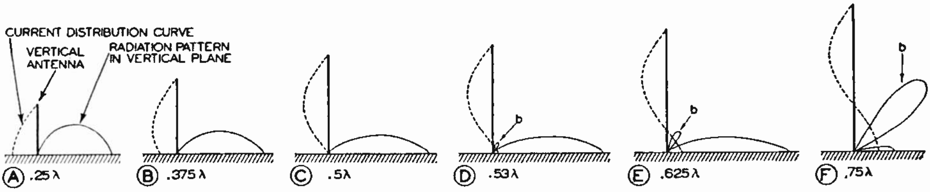


Fig. 14. Current distribution curves (dotted lines) and vertical radiation patterns (thin solid lines) at one particular frequency for grounded vertical antennas having various physical lengths.

grounded vertical λ/4 antenna; this pattern will be the same for vertical planes in all directions (north, east, south or west) for this particular antenna and height. As antenna height is increased above λ/4 the radiation pattern flattens out, indicating improved pick-up of the ground wave, as shown at *B, C, D* and *E* in Fig. *14*. When antenna height becomes more than λ/2 (.5λ), a lobe or ear directed up into the sky begins to form, however; this indicates that the antenna is beginning to favor reception of sky waves. If the height of the antenna is form the T antenna shown in Fig. *15B;* this does not affect the horizontal radiation pattern, but it does serve as a load which helps to tune the antenna to resonance. The current distribution curves show that currents are zero at the ends of the horizontal portion and increase gradually up to point *a*, where the two currents combine to flow down the vertical portion of the antenna These currents are equal for a symmetrical T antenna, and since they flow in opposite directions toward point *a* in Fig. *15B* they do not alter the nondirectional characteristics of the verti-

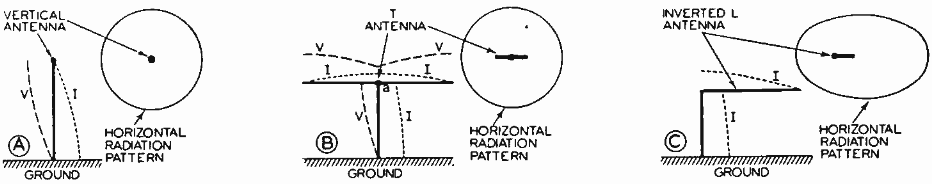


Fig. 15. Horizontal radiation patterns for grounded vertical, T and inverted L types of antennas.

increased beyond .75λ, only sky waves will be received effectively. Remember that these patterns are for grounded vertical antennas; when a vertical antenna is elevated above the ground, the patterns become quite different.

The horizontal radiation pattern for a quarter-wave grounded vertical antenna is shown in Fig. *15A*. This pattern indicates … cal portion. The T-type antenna is particularly desirable when it is impractical to erect a sufficiently high vertical antenna to give resonance. Resonant conditions produced by the antenna itself always give better signal pick-up than resonance produced by inserting coils or condensers.

A vertical antenna shorter than λ/4

can be increased in effective length by connecting to its top a single horizontal wire as shown in Fig. *15C*, giving an inverted L antenna. The horizontal portion serves to load the vertical portion; if its length is properly chosen, it will tune the antenna system to resonance at one desired signal frequency, giving maximum possible current at

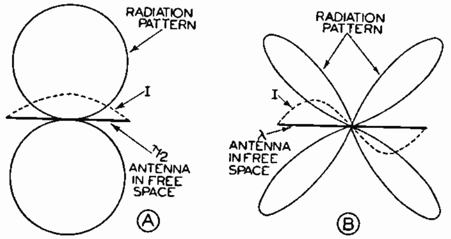


FIG. 16. Radiation patterns for $\lambda/2$ and λ antennas in free space. The patterns are the same for all planes passing lengthwise through the antennas.

the receiver. Radio waves arriving from the direction in which the horizontal section is pointing are favored, giving a slightly directional radiation pattern in the horizontal plane, as shown in Fig. *15C*. The natural wavelength of an L or T type antenna is determined by measuring from the ground to the end of the longest horizontal section.

The radiation pattern of a theoretically perfect half-wave antenna in free space will be the same in any plane passing through the antenna wire and will be a figure-of-eight pattern as shown in Fig. *16A*. A three-dimensional radiation pattern, showing the pick-up characteristics in all directions, would appear like two perfectly round balls touching opposite sides of the antenna wire at its center. The outstanding fact about a $\lambda/2$ antenna in free space is that it receives best from its sides, and has practically no signal pick-up from its ends. Practical doublet antennas have somewhat similar directional characteristics, and consequently should be kept broadside to a station from which maximum signal pick-up is desired.

The radiation pattern for a full-wave (λ) antenna in free space, shown in Fig. *16B*, resembles somewhat a four-leaf clover, indicating that best reception is restricted to four narrow beams, and that there is no reception either from the ends (in the plane of the antenna) or from the sides (at right angles to the antenna). More and more of these lobes appear in the radiation pattern as antenna length is increased in multiples of $\lambda/2$, with the lobes becoming longer and narrower; antennas longer than $\lambda/2$ are therefore unsuited for general reception in all directions.

It is practically impossible to erect a horizontal doublet receiving antenna which is high enough above the ground so it will act as if it were in free space. The average radio receiver owner would have difficulty in erecting a horizontal antenna which is higher than about 50 feet above the ground (about 15 meters). This would make the antenna $\lambda/4$ above the ground for a 60-meter wave. The radiation patterns in two vertical planes at right angles to each other for a $\lambda/2$ horizontal doublet antenna mounted a distance of $\lambda/4$ above the ground are shown in Fig. *17A*. These patterns tell us that sky wave reception is good and is essentially the same in all directions. The patterns might lead you to expect poor

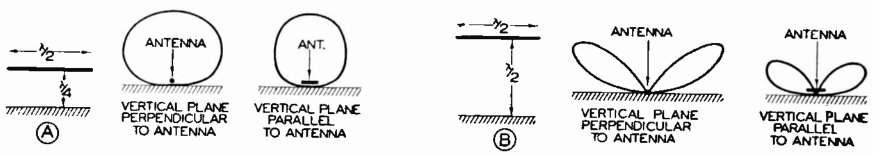


FIG. 17. Radiation patterns for a horizontal half-wave doublet antenna located one-fourth wavelength (*A*) and one-half wavelength (*B*) above a perfectly conducting ground.

ground wave reception, but ground waves are usually tilted sufficiently to induce ample voltage in an antenna of this type, giving quite good ground wave reception also. When the half-wave doublet antenna in Fig. *17A* is raised another ¼ wavelength, making it ½ wavelength above the ground, a decidedly directional radiation characteristic is obtained, as indicated in Fig. *17B*. Sky waves coming in at a reasonable angle (the usual condition for these waves) are picked up quite well, but waves arriving at high or low angles of elevation are poorly received. An antenna such as this would not be good for reception of signals broadcast by an airplane flying overhead, nor for reception of ground wave signals unless they were well tilted.

The angle at which maximum energy reaches a receiving antenna is the same as the angle at which maximum energy leaves the transmitting antenna. In other words, if a given transmitting antenna radiates maximum energy into the sky at a definite angle of elevation, maximum pick-up of signals from that antenna will be obtained with a receiving antenna which has maximum pick-up at that same angle of elevation.

Conclusion. Keep the following facts in mind when installing receiving antennas:

1. **A simple antenna having a pick-up portion which is $\lambda/4$ meters long or less and in one straight line gives best reception of radio waves whose electrical lines of force are parallel to the pick-up wire.**

2. **Horizontal doublet antennas having pick-up sections with a total length of $\lambda/2$ or less give best pick-up of signals arriving broadside to the antenna, but give fairly good pick-up from other directions as well at normal antenna heights above ground.**

Coupling The Antenna To The Receiver

Now that we have seen how the pick-up portion of an antenna can be made to produce maximum voltage and maximum current for a given radio wave, we are ready to consider how maximum signal can be transferred from the antenna to the radio receiver. For antennas less than a quarter-wave long, the solution is quite simple, involving merely a direct connection as shown in Fig. *18*. The entire length of the antenna system will pick up signals, and consequently length *b-c* must be added to length *a-b* when determining the operating wavelength of the system. For a $\lambda/4$ system, the current will be a maximum at the ground end; if the receiver is connected close to ground, maximum current will flow through primary coil *P* and will induce

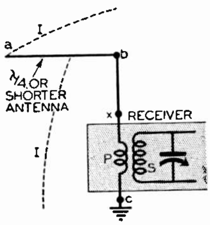


FIG. 18. Direct connection of an inverted L antenna to a receiver.

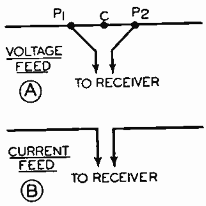


FIG. 19. Feed methods for a doublet receiving antenna.

the greatest possible voltage in secondary coil *S*. A long ground wire between receiver and ground moves the primary coil to a point where current is less, reducing the efficiency of the antenna; furthermore, an excessively long ground wire picks up noise and thus lowers the signal-to-noise ratio. Keep the ground wire as short as possible, and increase the length of the antenna itself up to ¼ wavelength if maximum pick-up is required at a given wavelength.

A $\lambda/4$ antenna for best reception of a 1,500 kc. (200-meter) signal should be 50 meters (165 feet) long. This length is rarely attained in the average receiving antenna, but a coil can be inserted in the lead-in wire (at point *x* in Fig. *18*) to offset this lack of length. On short-wave bands, however, even a 50-foot antenna is too long for $\lambda/4$ operation. When an antenna is only slightly longer than $\lambda/4$ (not more than about 3/8 wavelength long), the excessive length can be offset by inserting a variable condenser at point x and adjusting for maximum signal pick-up from the desired station (this tunes the antenna to resonance, making it equivalent to a $\lambda/4$ antenna at that station frequency). Tuning of an antenna complicates the operation of a receiver, so it is customary to design the primary coil so it will make the average broadcast antenna tune approximately to the broadcast band wavelengths, and provide means for reducing the size of this coil on short wave bands.

Voltage Feed For a Doublet Antenna. With a doublet antenna, it is quite possible to connect two wires (a transmission line) to points which are equally spaced on each side of the center, as shown in Fig. *19A,* in order to transfer to the receiver a portion of the r.f. voltage which is developed by the antenna. The voltages at P_1 and P_2 are opposite in polarity at any instant of time (see Fig. *11C*), and hence the voltage between P_1 and C will always add to that between P_2 and C. This connection is commonly referred to as a *voltage feed* to the receiver.

Current Feed. When a doublet antenna is cut at its center and two wires are used to connect the cut ends to the receiver, we have what is known as *current feed* to the receiver. Antenna current flows along one half of the pick-up section, down one lead-in wire to the receiver, through the antenna coil of the receiver, up through the other lead-in wire, and finally out over the other half of the pick-up section. Since current in a $\lambda/2$ or shorter antenna is a maximum at the center, this connection gives maximum current through the antenna coil of the receiver. Current feed is widely used with antennas for all types of receivers.

A $\lambda/2$ antenna which is designed for 80 meters will be a full-wave antenna at 40 meters, a $3/2\lambda$ antenna at 30 meters, and a 2λ antenna at 20 meters. Let us see if an antenna like this will work effectively at all three wavelengths with current feed. Figure *20* shows the current distribution for these four operating conditions; these curves show that current is a maximum at the center only for operation as a $\lambda/2$ or $3/2\lambda$ antenna. Current at the center is zero for λ or 2λ operation, which means that a current feed at the center will theoretically give no signal transfer to the receiver under these conditions; it

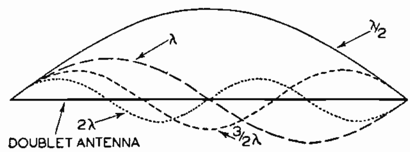


FIG. 20. Current distribution curves for $\lambda/2$, λ, $3/2\lambda$, and 2λ operation of a doublet antenna.

would be necessary to move the tap to an off-center point of maximum current in order to secure efficient signal pick-up. This explains why a single $\lambda/2$ antenna which is used for all-wave reception and has a current feed connection to the receiver will give excellent results at certain frequencies and will be very inefficient at other frequencies.

Transmission Lines

Antenna Resistance and Impedance. Any antenna which is tuned to resonance will act as a resistance source of r.f. signals; at the center of a $\lambda/2$ antenna this a.c. resistance will be about 72 ohms. For a grounded $\lambda/4$ antenna, the a.c. resistance at the ground (measured between the antenna lead-in wire and the ground wire) will be about 36 ohms. A voltage-fed $\lambda/2$ antenna will have a resistance considerably higher than 72 ohms; if the transmission line connections are made near the ends of the antenna, this resistance may be as high as 5,000 ohms. At off-resonant conditions, reactive components are added to these resistance values, making the impedance of an untuned antenna quite high.

Surge Impedance of Transmission Lines. Any two-wire transmission line is a combination of elemental resistances, inductances and capacities arranged as shown in Fig. *21A.* At low audio frequencies the inductances and capacities have a negligible reactive effect and the line simply has a d.c. resistance distributed along its length due to the resistance of the wire itself. At radio frequencies, however, the elemental inductances and capacities have much more effect upon the characteristics of the line than do the elemental resistances, and we can for practical purposes neglect entirely the presence of these resistances. The values of these elemental inductances and capacities control one extremely important characteristic rating of a transmission line—its *surge impedance,* usually designated as Z_0*. The inductance values are determined by the diameter of the transmission line wires and the spacing between them; the capacity values are determined by the diameter of the wires, the spacing between the wires, and by the nature of the dielectric materials between the two wires. Neither the frequency of the radio signal nor the length of the line ordinarily has any effect whatsoever upon the inductance and capacity values. This means that the surge impedance of a transmission line depends only upon the construction of a unit length of a transmission line, and is the same for any length of line and for any frequency. Increasing the distance between the two line wires will increase the surge impedance; reducing the diameter of the wires will increase the surge impedance; the use of a dielectric material which increases the capacity between the two wires will reduce the surge impedance.

If we were to measure the impedance between the input terminals of an extremely long (infinitely long) transmission line, we would get a value which is equal to the surge impedance of that line. Furthermore, this impedance would be purely resistive, for the large numbers of elemental inductances and capacities distributed over this infinitely long line make it act as a broadly tuned resonant circuit having the same impedance at all frequencies. This fact is illustrated in Fig. *21B.*

If we were to measure the input impedance of a practical transmission line (seldom more than one or two wavelengths long in radio work), we would probably get a value considerably different from the surge impedance of the line; actually the value of impedance which we measure would depend upon the length of the line and upon how it was terminated (the nature of the load at the output end of the line). It is possible to compute the input impedance of a transmission line having any length and any type of load at its output end, but the mathematical procedure involved is highly complicated and for all practical receiving antenna purposes is quite unnecessary.

We are not concerned with this input impedance of a practical transmission line, because there is a simple way to make this input impedance equal to the surge impedance of the transmission line. If the output end of a transmission line is terminated in a load having an impedance exactly equal to the surge impedance of the transmission line, the input impedance of that

*This impedance is also known as the *characteristic impedance* of a transmission line; "characteristic impedance" is a more readily understood term, but "surge impedance" is the term more widely used. The value of this impedance depends upon the ratio of elemental inductance to elemental capacitance.

transmission line will then be equal to the surge impedance of that line regardless of its length; this is illustrated in Fig. *21C*. If the input end of this line is now connected to a signal source having an impedance equal to the surge impedance of the transmission line, the impedance at each end of the transmission line will be equal to the surge impedance Z_0 regardless of the length of the line. This phenomenon is widely used in the design of transmission lines for connecting receiving antennas to receivers, for it simplifies construction considerably and gives at each end of the transmission line an impedance match which results in maximum transfer of power from the antenna to the receiver.

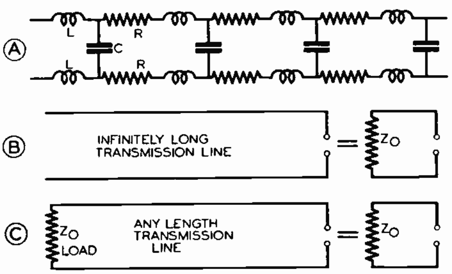


FIG. 21. **Important facts concerning the behavior of transmission lines.**

Typical Surge Impedance Values. A transmission line made up of two No. 18 wires spaced 2 inches apart will have a surge impedance of about 560 ohms. Two No. 10 wires separated by 2 inches have a surge impedance of about 440 ohms. No. 18 and No. 10 wires separated by 3 inches will have surge impedances of 610 ohms and 480 ohms respectively. These so-called "open" transmission lines are rarely used with receiving antennas, but are widely used with transmitter installations. When two No. 18 rubber-covered wires are twisted together or when one rubber-covered wire is placed inside a braided metallic covering, the surge impedance Z_0 will range between 70 and 150 ohms; by careful design, this impedance can be made equal to 72 ohms, making it possible to couple a current-fed $\lambda/2$ antenna directly to the transmission line, securing a perfect impedance match and maximum transfer of power from the antenna to the transmission line. If the receiver is made to serve as a 72-ohm load on the other end of this line, we will have maximum transfer of power from the antenna to the receiver regardless of the length of the transmission line.

It is not essential that a 72-ohm transmission line be used for maximum transfer of power. An r.f. impedance-matching transformer, usually called an *antenna transformer,* can be used at the antenna to match the antenna impedance to the surge impedance of the transmission line regardless of what their respective values may be, thereby securing maximum transfer of energy. Another impedance-matching transformer can be used at the receiver end to match the receiver input impedance to the transmission line surge impedance. When a receiver is designed for use with a definite antenna system, the first r.f. transformer in the receiver is designed to match the surge impedance of the transmission line, eliminating the need for a separate matching transformer.

Noise Reduction

It is useless to erect an antenna which will deliver a strong carrier signal to a receiver if this signal is "blanketed" by local man-made interference noise which is also picked up by the antenna. As a general rule, man-made interference produces electric fields which are *perpendicular* to the ground, just like the fields produced by a vertical transmitting antenna. If a horizontal antenna with a vertical down lead is used for reception, most of the interference noise will be picked up by the down lead; very little will be picked up by the horizontal section.

The chief problem in securing a noise-reducing antenna is that of preventing the down lead or transmission line from picking up noise signals.

With a doublet antenna, the transmission line inherently rejects noise signals. The two down leads of the transmission line are normally twisted together in the manner shown in Fig. *22A*, so that very little electric field can exist between adjacent wires in the transmission line. Any noise voltages which are induced in these vertical wires cause currents to flow in the same direction in both wires at any instant of time. Noise currents therefore flow in opposite directions through the primary of the receiver transformer to the center tap and then to ground; as long as these two noise currents are balanced, they cannot produce any flux in the receiver transformer. Some noise signals may be picked up by the entire antenna system acting as a vertical mast; an electrostatic shield is usually placed between the primary and secondary windings of the receiver input transformer to prevent these noise signals from being transferred to the secondary winding.

The antenna and receiver transformers in Fig. *22A* can give a perfect impedance match at only one frequency; the tuning action can, however, be made sufficiently broad by means of tight coupling in the transformers to give satisfactory reception over a wide range of frequencies.

Noise-reducing antenna systems for the 500 kc. to 1,500 kc. broadcast band are invariably of the single-wire horizontal type; a typical noise-reducing broadcast antenna is shown in Fig. *22B*. Since limitations of space in the vicinity of the average home would normally prevent the use of a horizontal pick-up section which is $\lambda/4$ meters in length, a more reasonable length of from 50 to 100 feet is usually employed, and the primary of the antenna transformer is designed to bring this length up to $\lambda/4$ for the highest frequency which the antenna is to pick up. The transmission line in this case is a single insulated wire surrounded by a flexible metal loom or shield; this shield is connected to the ground terminal of the receiver. A twisted 2-wire transmission line may be used if proper ground connections are made at the receiver, and the transmission line is properly connected to the antenna transformer. For maximum reduction of noise and the most favorable distribution of current in the antenna, the shielding metal loom must be grounded near the antenna, either to a vent pipe,

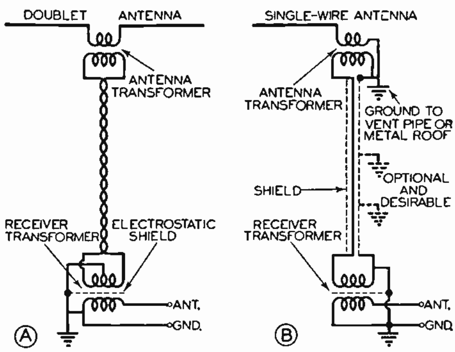
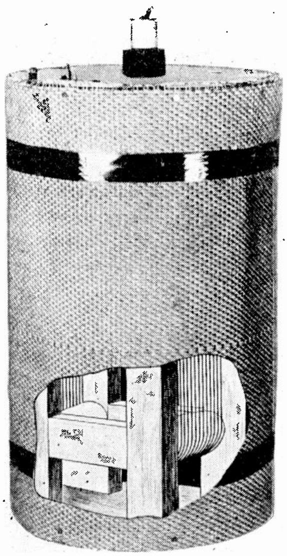


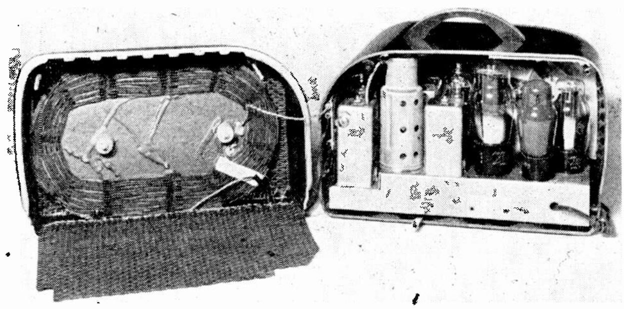
FIG. 22. Two types of noise-reducing antennas.

to the grounded metal roof of the building, or to a grounded gutter. Additional grounding of the shield at several points is optional, but should be done whenever the transmission line runs conveniently near a grounded object. This type of noise-reducing antenna may also be designed for all-wave reception.

Even though the vertical lead-in wires of an antenna system are carefully shielded against man-made noise fields, there is still a possibility that noise will be picked up by the antenna system. This is due to the fact that the electric fields produced by man-made interference may not always be exactly perpendicular to the earth; if they are slanted any appreciable amount and extend an appreciable distance above the ground, they will induce noise voltages in the horizontal pick-up wires. When a noise-reducing antenna system fails to give a satisfactory signal-to-noise ratio, the usual procedure is to *change the position of the horizontal pick-up portion of the antenna,* such as by increasing its height, changing its direction, or moving it to a location farther away from the source of noise.

Noise-Reducing Loop Antenna. Another solution to the problem of noise interference is the use of a shielded loop antenna which is built right into the cabinet of a radio receiver. To understand how this shielded loop can reduce noise signals, we must first consider the relative strengths of the electric and magnetic fields associated with radio waves. At points outside of the induction field produced by a transmitting antenna or source of noise interference, the electric and magnetic fields associated with the radiation field (the radio wave) are essentially equal. Close to the source, however, the electric component E is much greater than the magnetic component H; in fact, E may be as much as 70 times stronger than H. Noise interference sources are generally so close to the receiver that the vertically - polarized electric component E of the noise is much stronger than the magnetic component of noise, whereas the E and H components of the desired radio signals are equal. If we can remove the electric component E of both the noise signals and the radio signals, depending upon magnetic components only for reception, we will then have eliminated the noise almost completely without impairing reception of the desired radio signal. The chief purpose of the grounded Faraday shield which surrounds some types of built-in loop antennas is therefore to prevent *electric components of both station and noise signals from affecting the receiver.*





Courtesy General Electric Co.

FIG. 23 (Left). Typical shielded loop antenna (General Electric Beamascope) designed for installation inside a console model home radio receiver. Part of the Faraday shield is cut away to show the loop winding and its wood frame inside. This unit is rotated to a position of minimum noise pick-up at the time the receiver is installed in a home.

Courtesy Zenith Radio Corp.

Above: A compact shielded loop antenna mounted at the rear of this 5-tube superheterodyne table model receiver (Zenith Wavemagnet) eliminates the need for antenna and ground connections. The flat loop is wound on a spider-web type coil form, and is mounted between two flat shields woven with vertical copper wires and horizontal insulating cords. All shield wires are connected together at the bottom and grounded to the receiver chassis.

One commercial version of this shielded loop arrangement is shown in Fig. *23*. The Faraday shield is in the form of a closed cylinder with sheet metal discs covering the top and bottom faces and with the sides covered with a coarse woven material in which the vertical threads are wire and the horizontal threads are non-conducting fiber. Every vertical wire makes contact with the top metal disc, but only one of these vertical wires makes electrical contact with the bottom disc; this construction eliminates closed circuits in the vicinity of the loop, giving maximum pick-up by the loop of the magnetic component of radio signals. The shield is grounded, and consequently all signal and noise currents induced in its vertical wires by the E components are led off to ground without affecting the receiver. The well-known directional characteristics of a loop are utilized to give additional noise rejection; the loop is rotated for minimum noise, so its line of minimum pick-up is in the direction of the noise source. No external antenna or ground connections are necessary when one of these shielded loops is installed, but an outdoor antenna can be connected to the loop or in place of it if distant reception is desired. A loop of this type can be built right into the cabinet of a radio receiver, and can be tuned over the entire broadcast band by a main tuning condenser section which is adjusted to track with the oscillator; this tuning to resonance for each station increases the sensitivity of the loop very greatly.

All-Wave Antennas

Either horizontal doublet antennas or single-wire horizontal antennas with end feed may be used for all-wave reception. The doublet is ordinarily preferred, for its balanced two-wire transmission line gives inherent rejection of vertically-polarized noise signals. Both types of all-wave antennas favor slightly the reception of signals from certain directions, but these directional characteristics can ordinarily be neglected when installing an all-wave antenna for the average radio listener. It is far more important to place the horizontal pick-up section of the antenna *at right angles* to a nearby power line, in order to secure rejection of horizontally-polarized power line noise signals.

Types of All-Wave Antennas Commonly Used. Three distinct types of antenna systems are in common use for all-wave reception over the entire range from about 18 meters (16.5 megacycles) to 545 meters (550 kc.). These are:

1. An antenna system made up of two or more doublet antennas, each tuned to a different wave-length. With the customary broadness of tuning in doublet antennas, fairly uniform pick-up is obtained over the desired range. A typical system might employ three half-wave doublets, tuned respectively to 16, 25 and 49 meters.

2. A system employing a single horizontal doublet antenna cut at its exact center for current feed, and with a length which will keep it less than a full-wave antenna at any frequency in the range to be received. For example, if the receiver is to go down to 18 meters, a 50-foot horizontal doublet can be used, for it will be a full-wave antenna at about 15 meters and will have sufficient current at its center at 18 meters. At 30 meters this antenna would become a $\lambda/2$ unit; at all longer wavelengths it will be shorter than $\lambda/2$, and will have maximum current at its center even though the current is gradually reduced due to off-resonant conditions as wavelength is increased.

3. A system employing a single horizontal wire having a properly grounded antenna transformer at one end for current feed, and with a length which will keep the effective pick-up portion of the system less than a half-wave long at any frequency in the range to be received. For example, if the shortest wavelength at which reception is desired is 18 meters, a 25-foot horizontal wire would very likely be used (this would be a half-wave antenna at 15 meters).

An all-wave doublet antenna gives maximum pick-up at a frequency which makes it $\lambda/2$. Pick-up decreases gradually above $\lambda/2$, for the current at the center of the antenna goes down. At λ operation the current at the center is zero, and there is practically no signal pick-up. Above λ, pick-up increases again to a maximum at $3/2\lambda$, then drops to zero again at $2\ \lambda$. All this means that a doublet antenna will pick up stations having frequencies higher than that for λ operation, but reception will be erratic due to the highly directional and continually changing radiation patterns and to the dead spots in reception which occur at λ, 2λ, 3λ, 4λ, etc., operation.

A single-wire antenna acts in much the same way above its efficient operating length of $\lambda/4$; there will be dead spots in reception at $\lambda/2$, λ, $3/2\lambda$, 2λ, $5/2\lambda$, etc., for these operating lengths give zero current at the antenna transformer. Pick-up will be good at $\lambda/4$, $3/4\lambda$, $5/4\lambda$, $7/4\lambda$, etc., for these operating lengths give high currents at the antenna transformer.

Multiple Doublet Antennas. A typical all-wave doublet antenna system employing three doublet antennas is shown in Fig. *24*. Doublet A_1 serves for the shortest wavelength, A_3 for the longest wavelength and A_2 for the intermediate wavelength. (Coils L_A serve merely to increase the effective length of doublet A_3, improving reception at about 50 meters.) Although these three antennas work best at their own resonant wavelengths, they are sufficiently broad to give adequate pick-up at in-between wavelengths. The connections between one or more of the doublets and the transmission line are transposed, as is done for A_1 and A_2 in Fig. *24*, so that the signal voltages in the various doublets will add and give maximum transmission line current.

Whenever the wavelength of a desired radio signal is such as to give resonance for one of the doublet antennas in this system, the antenna impedance will be that of a normal doublet, which is 72 ohms. Since the transmission line is designed to have a surge impedance of about 72 ohms, a good match between the antenna and the transmission line is secured at resonant frequencies. When the desired signal does not give resonance for any one of the doublets, the impedance of the antenna will be much higher than 72 ohms, but there is one interesting characteristic of a transmission line which can be used to counteract this mismatch: A practical transmission line (only a few wavelengths long) has a high input impedance whenever its length is some multiple of $\lambda/2$ meters

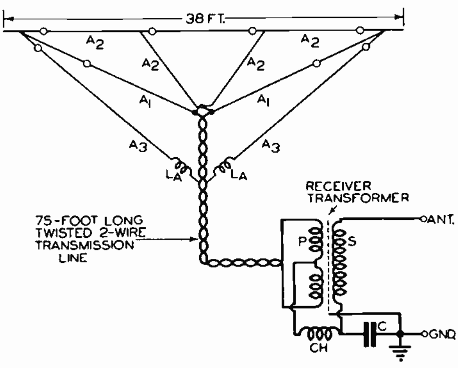


Fig. 24. All-wave noise-reducing antenna made up of three doublets. Because of its general resemblance to the web of a spider, this RCA-Victor product is commonly known as a spider-web antenna.

for a particular signal. By making the length of the transmission line a multiple of $\lambda/2$ for wavelengths in between the natural resonant frequencies of the three doublets, efficient transfer of signals from the antenna to the transmission line is obtained at in-between wavelengths as well. Whenever the manufacturer of an all-wave antenna specifies that the transmission line supplied with the system must not be cut, and that if too short it should be lengthened in equal lengths of a definite number of feet, you can be sure that the purpose is improvement of match at off-resonant frequencies.

With proper design it is possible to build a multiple-doublet all-wave antenna which is reasonably effective at all wavelengths between the lowest and highest natural wavelengths of the doublets employed. Response at wavelengths below this range can be obtained by adding shorter doublets. Fairly satisfactory response will be obtained at wavelengths above this range since all of the doublets will then be shorter than $\lambda/2$, and will have a maximum current at their centers. At broadcast band wavelengths, however, this maximum current becomes quite low even for the longest doublet; to offset this, the special receiver coupling transformer shown in Fig. *24* is employed to convert the entire antenna system into a T antenna for broadcast band reception.

Observe that the midpoint of primary winding *P* is connected to ground through choke coil *CH* and condenser *C*. At broadcast band frequencies, very little signal current is fed to the transmission line by the doublets; the entire system acts as a T antenna, and signal currents which are picked up by the transmission line flow down both transmission line wires in the same direction to the center tap of *P*, then through *CH* (which has a low reactance at broadcast frequencies), through secondary winding *S* to the antenna terminal of the receiver, and through the receiver input coil to ground. Condenser *C* has such a high reactance at low frequencies that it acts essentially as an open circuit. When an all-wave doublet antenna system is converted to a T antenna in this manner, the system of course loses the noise-reducing and directional properties of a doublet.

Single All-Wave Doublets. An antenna arrangement which gives satisfactory reception on short-wave bands and which automatically converts to a T type antenna at broadcast frequencies without losing its noise-reducing properties and without sacrificing an impedance match is shown in schematic form in Fig. *25A*. This system employs a single doublet antenna; it may be center-fed, in which case both sides of the horizontal doublet will be equal in length, or it may be fed from an off-center point, in which case the sides of the doublet will be unequal in length.

This unique system employs two transformers at the antenna and two at the receiver. At high frequencies, condensers C_1 and C_2 become so low in reactance that they short out coils L_9-L_{10} and L_{11}-L_{12}, making the two right-hand transformers ineffective at high frequencies; the transmission line circuit therefore takes the form shown

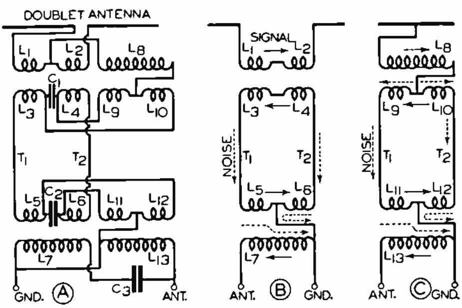


FIG. 25. Taco all-wave noise-reducing antenna system, made by Technical Appliance Corp. Actual circuit is shown at *A*; the effective circuit for short-wave bands is at *B*, while the effective circuit for the broadcast band is at *C*. Dotted arrows show directions of noise currents at one instant of time; solid arrows show directions of desired signal currents at one instant of time.

in Fig. *25B* at high frequencies (at short wavelengths). As you can see, this is a conventional doublet arrangement; if its length is $\lambda/2$ or less, current will flow along the entire antenna in the same direction at any instant of time. This current will flow through L_1 and L_2 in the same direction, inducing voltages in L_3 and L_4 which add together and cause current to flow down transmission line T_1 and up transmission line T_2 at one instant. The result is current flow through L_5 and L_6 in the same direction at any instant, inducing in L_7 a voltage which is applied to the input of the receiver. The transformers used in this system provide the desired broad impedance match for efficient transfer of power over a wide range of high frequencies. Noise currents flow through leads T_1 and T_2 in the same directions, then in opposite directions through L_5 and L_6 to their common terminal and to ground, so no noise signal voltages are induced in L_7.

At broadcast band frequencies, condensers C_1 and C_2 have high reactances, and hence have no shorting effect upon secondary windings L_9-L_{10} and L_{11}-L_{12}. Furthermore, at these low frequencies coil elements L_1, L_2, L_3, L_4, L_5, L_6 and L_7 have negligible inductive reactance and may be neglected, giving in effect the circuit shown in Fig. *25C*. Condenser C_3 in Fig. *25A* has a high reactance at broadcast band frequencies, and serves to prevent L_7 from shorting L_{13}. Again we find that noise signals picked up by the vertical down leads T_1 and T_2 are cancelled out at the receiver end of the transmission line (in primary windings L_{11} and L_{12}). The entire down lead system acts as a vertical or T antenna, with the flat top section serving merely as a load which produces a larger r.f. current at the point along the antenna to which coil L_8 is connected. This current flows down through L_8, then divides to flow through L_9 and L_{10} and through L_{11} and L_{12} to the mid-point and then to ground, as shown by the dotted line arrows. This is normal current distribution for a T type antenna, but of course it does not feed the receiver. The flow of antenna current through winding L_8 serves to induce voltages in L_9 and L_{10} which act in the same direction and serve to circulate a signal current through the entire transmission line circuit. This current flows through windings L_{11} and L_{12} in the same direction, inducing a strong radio signal voltage in L_{13}. This winding in turn feeds the voltage to the receiver.

Use of Counterpoise for Noise Reduction. Another arrangement of a single doublet antenna which gives satisfactory signal pick-up along with noise reduction on all bands is that which employs a counterpoise for picking up strong noise signals. These noise signals are fed through the receiver input circuit in such a way that they "buck out" or cancel the usual noise signals, giving essentially noise-free reception on bands in which the doublet is acting as a T.

The circuit diagram of a typical antenna-counterpoise installation on a three-band receiver is given in Fig. *26A*. Each band has a separate receiver matching transformer as a part of the receiver preselector (an antenna system like this can be used only with receivers designed especially for it). For short-wave reception, band-changing switch SW_1 is at position C, and we have a normal noise-reducing doublet antenna with L_1-L_2 serving as the receiver matching transformer. Condenser C_5 provides a path from the mid-point of L_1 to ground for noise signals, and 1-megohm resistor R_{26} allows static charges picked up by the antenna to leak off to ground gradually without causing noise.

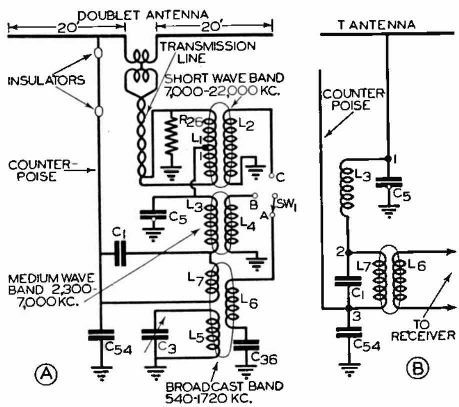


Fig. 26. All-wave noise-reducing antenna system employing a counterpoise (RCA-Victor Master Antenna as used with RCA-Victor model 99K receiver).

For broadcast band reception, switch SW_1 is at position A, and we have T antenna action. To simplify an analysis of the antenna system under these conditions, we can redraw the circuit as in Fig. *26B* to include only those parts which are effective during broadcast band reception. The length of the counterpoise is 10 feet longer than half the length of the transmission line, and consequently this lower portion of the transmission line (adjacent to the counterpoise) will pick up essentially the same amount of station and noise signals as the counterpoise. The upper portion of the transmission line is ordinarily quite high above the ground, out of the region of strong noise signals, but it will pick up and feed down through the transmission line a certain amount of noise along with the station signals. Let us trace the path taken by the noise signal currents, neglecting station signals for the time being.

Noise signals picked up by the T antenna will come down to point *1* in Fig. *26B* (corresponding to point *1* at the center tap of L_1 in Fig. *26A*) ; some will go through C_5 to ground, and the remainder will go through coil L_3 to point *2*. Again the noise currents divide, with some going through L_7 in a downward direction to point *3*, and others going through C_1 directly to point *3*. From here the noise currents either go to ground through condenser C_{54} or take a return path up the counterpoise to the T antenna again. Noise signal currents coming down the counterpoise divide at point *3*, with some going to ground through C_{54}, some going directly to point *2* through C_1, and some going through L_7 in the opposite direction to that taken by the T antenna noise currents. From point *2* these counterpoise noise currents go through L_3 to point *1*, from which some go to ground through C_5 and others take the return path up the T antenna and over to the counterpoise. By adjusting the value of trimmer condenser C_5, the division of the counterpoise and T antenna noise currents throughout this circuit can be made such that the noise currents sent through L_7 by the two pick-up systems will be exactly equal and opposite, and will therefore "buck out" or cancel each other.

In securing cancellation of noise signals in this manner, we also secure cancellation of any station signals which are picked up by the lower portion of the T antenna. This makes only the upper portion of the transmission line available for picking up signals of broadcast band stations; coil L_3 and condenser C_1 serve to compensate for this short effective pick-up length, to compensate for the detuning effect of C_5 and to equalize the amount of energy transferred to L_6 at different broadcast band wavelengths.

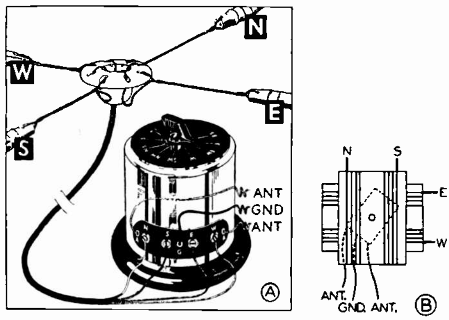


FIG. 27. Taco variable-directivity short-wave antenna, with a selector control which gives the same effect upon directional characteristics as would rotation of a single doublet antenna.

Variable-Directivity Antennas

A short-wave antenna system which is designed to have controllable directional characteristics is shown in Fig. *27A*. Two doublet antennas, each 60 feet long, are located at right angles to each other. At 37 meters they become $\lambda/2$ doublets and have maximum pick-up. At wavelengths longer than 37 meters they are less than $\lambda/2$ but still have maximum current at the center and give quite satisfactory signal pick-up. For wavelengths less than 37 meters they may become λ, $3/2\lambda$, 2λ, etc., antennas, with clover-shaped radiation patterns which make the directional adjustment more critical. Each doublet has a two-wire transmission line going to its own coil at the receiver end; the two coils are mounted at right angles to each other as shown in Fig. *27B*, with a third coil mounted in their center in such a way that it can be rotated for maximum coupling with either of the stationary coils or for any intermediate amount of coupling with both coils. In this way it is possible to control the direction from which maximum signal pick-up is secured. The performance is essentially the same as that of the rotatable beam antennas used by amateur radio enthusiasts and by commercial short-wave stations for long-distance radio communication.

TEST QUESTIONS

Be sure to number your Answer Sheet 33FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In addition to feeding strong signals from desired stations into a receiver, what other characteristic must a good receiving antenna have?
2. What two components does a radio wave have?
3. When a radio signal produces a half-sine-wave distribution of current along a receiving antenna, how many wavelengths long is the antenna?
4. What natural condition in space makes long-distance radio communication possible?
5. Describe briefly how sky waves cause fading at receiving locations near the limits of reliable ground wave reception from a given station.
6. At what point along a half-wave receiving antenna is r.f. signal current at maximum?
7. What information is given by the horizontal radiation pattern of a receiving antenna?
8. Why is an antenna transformer sometimes used to connect an antenna to a transmission line?
9. What change would you make in a noise-reducing antenna installation if it failed to give a satisfactory signal-to-noise ratio?
10. What is the chief purpose of the grounded Faraday shield which surrounds some types of built-in loop antennas?

FREQUENCY-MODULATED SIGNALS

THE F.M. RECEIVER

34FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE FUTURE OF F.M.

Radio engineers are constantly working toward the triple goal of giving to listeners a radio broadcasting service which is *free from interfering noises, free from interference between stations,* and *has true high fidelity.* Now, after years of research and development, radio engineers have brought forth an entirely different system of broadcasting, called *frequency modulation* (f.m.), which meets these three basic listener requirements more completely than ever before.

Although f.m. possesses many outstanding characteristics, it is extremely unlikely that f.m. stations will ever completely replace the present amplitude-modulated (a.m.) stations. One reason is the 200-kc. wide channel requirement for each f.m. station as compared to 10 kc. for an a.m. station. Channel assignments for f.m. broadcast stations have therefore been made by the Federal Communications Commission in an ultra-high frequency band extending from 42 to 50 megacycles, where there is room for 40 f.m. channels without crowding other radio communication services. (Only five f.m. channels could be placed in the present broadcast band.)

Ultra-high frequency signals have a definitely limited range, so each f.m. station can serve only its own local area within a radius of approximately 100 miles. Listeners in smaller cities and rural areas must depend upon a.m. broadcast stations for their radio programs until such time as local f.m. stations are economically feasible for all localities.

Even in large cities, f.m. cannot replace a.m. for many years to come, for the millions of existing a.m. receivers will not receive f.m. signals. Most of the owners of these receivers are entirely satisfied with present performance, and may refuse to buy f.m. adapters or costly new f.m. receivers as soon as an f.m. station comes to town. Furthermore, f.m. stations themselves are as expensive to erect and operate as a.m. stations. Unquestionably, f.m. is here to stay, but it will supplement and compete with present a.m. stations rather than replace them.

As you study this lesson, you will realize that f.m. systems employ the same basic radio principles, the same basic circuits, the same radio parts, and the same types of tubes as are employed in a.m. systems. Thus, everything you have studied so far in your course will be of value to you in mastering f.m.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

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Frequency-Modulated Signals

Brief Review of Amplitude-Modulated Signals

A THOROUGH understanding of the characteristics of a conventional amplitude-modulated (a.m.) signal will help you to picture in your mind the characteristics of a frequency-modulated (f.m.) signal.

The signal peaks of an unmodulated r.f. carrier will all have the same amplitude, as shown at the left in Fig. *1A*. When the r.f. carrier is amplitude-modulated with a single sine-wave audio frequency (such as that corresponding to a pure audio tone), the peaks of the r.f. signal will rise and fall in amplitude in accordance with variations in the audio signal, as shown at the right in Fig. *1A*.

A dash-dash line drawn through the positive peaks of the modulated r.f. signal in Fig. *1A* will give a curve known as the *envelope*, which has the same wave form as the original audio signal. (Another envelope having this same audio wave form is obtained by drawing a dash-dash line through the negative peaks, but at this time we need consider only the upper envelope. Both envelopes are shown for each signal in Fig. *1*.)

Horizontal line *XX* at the level of the unmodulated carrier peaks will be the reference line for this envelope. Thus, we can say that the positive peak of the envelope goes above reference line *XX*, and the negative peak of the envelope goes below reference line *XX*. Furthermore, with 50% modulation as in Fig. *1A*. the envelope peaks will have exactly one-half the amplitude of the unmodulated carrier peaks.

When the envelope peaks are equal in amplitude to the unmodulated carrier peaks, as in Fig. *1B*, we have 100% modulation of the carrier.

When the envelope peaks are greater in amplitude than the unmodulated carrier peaks, the modulation percentage is higher than 100% and the envelope becomes distorted, as shown in Fig. *1C*. When an over-

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A million-volt discharge of man-made lightning created a crashing roar which completely drowned out the musical program when this combination f.m.-a.m. receiver was tuned to a broadcast band a.m. station. When the set was tuned to an f.m. station carrying the same program, however, the music emerged from the loudspeaker clear and strong, with only a hardly noticeable static buzz in the background even though a million volts of electricity was dancing and sputtering a few feet away. Truly this is dramatic proof of the noise-reducing characteristics of an f.m. system.

modulated signal like this is demodulated in a receiver, the resulting audio signal will have the same distorted wave form as the dash-dash envelope in Fig. *1C*.

When the frequency of the audio signal is varied, the frequency of the envelope changes in a corresponding

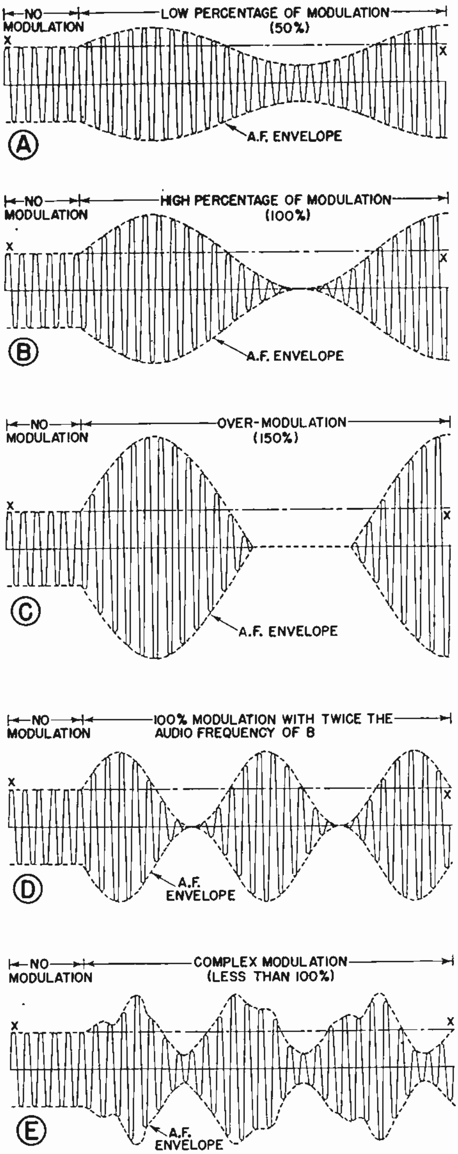

FIG. 1. Examples of amplitude-modulated signals.

manner. Thus, if we double the frequency of the sine-wave audio tone used for our first three examples in Fig. *1*, we secure for 100% modulation the condition shown in Fig. *1D*.

When voice or music is transmitted, the modulation envelope becomes far more complex, resembling that shown in Fig. *1E*. When this envelope is analyzed, it is found to have many different audio frequency components.

Side Frequencies. As you already know, an r.f. carrier signal which is modulated with a single fixed-frequency sine wave tone is equivalent to three different pure r.f. signals. One will have the assigned carrier frequency and constant amplitude. The other two, called *side frequencies*, will be respectively above and below the carrier frequency by the audio frequency value, and each one will vary in amplitude between zero and one-half the carrier amplitude as the percentage modulation varies between 0 and 100%.

Here is an example. If the highest frequency we wish to transmit is 5000 cycles (5 kc.), and the r.f. carrier frequency is 1000 kc., the three pure r.f. signals will be 1000 kc. (the carrier), 995 kc. and 1005 kc. (the side frequencies). If the lowest frequency to be transmitted is 100 cycles (.1 kc.), the two side frequencies going out with the 1000-kc. carrier will be 999.9 kc. and 1000.1 kc.

If a complex audio signal having many frequencies in the range from 100 cycles to 5000 cycles is being transmitted, there will be a 1000-kc. r.f. carrier signal traveling through space along with side frequencies ranging from 995 kc. to 999.9 kc. and from 1000.1 kc. to 1005 kc.

The percentage modulation for a complex signal varies from instant to instant; it is 100% when the sum of all the side frequency amplitudes at a particular instant of time is exactly equal to the carrier amplitude. Overmodulation occurs whenever the sum of all the side frequency amplitudes is greater than the carrier amplitude.

Characteristics of a Frequency-Modulated Signal

Modulation of an r.f. signal can also be accomplished by varying the

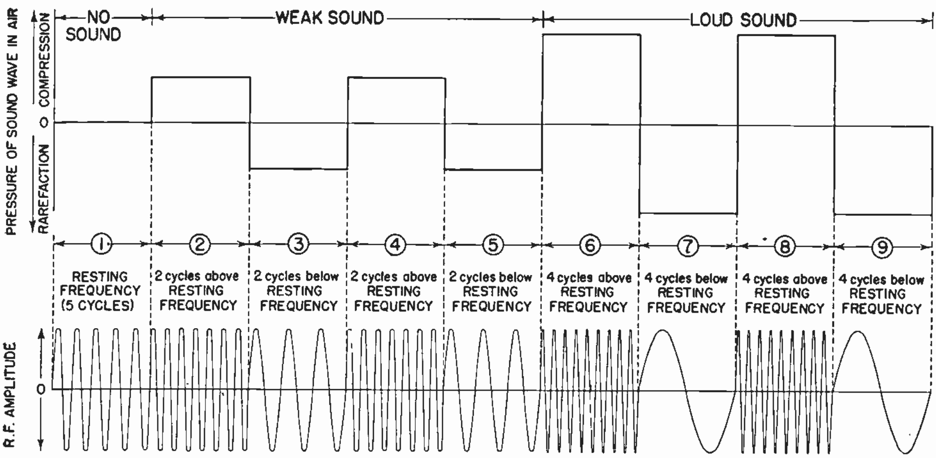

FIG. 2. Example showing how a sound wave having a square-wave form makes the r.f. signal frequency of an f.m. transmitter vary above and below the assigned resting frequency.

frequency of the r.f. signal in accordance with sound pressure, while keeping the r.f. amplitude essentially constant. This, basically, is *frequency modulation.*

Sound is an alternate compression and rarefaction of air particles. This means that air in the path of a sound wave is alternately being increased and decreased in pressure with respect to normal atmospheric pressure. When a sound wave in air is converted into its electrical equivalent by a microphone, we have a corresponding audio signal with positive and negative alternations, one alternation representing compression and the other rarefaction of air. The amplitude of an alternation depends upon the loudness of the original sound in air, and the frequency of the audio signal depends upon the pitch (frequency) of the original sound.

The Resting Frequency. With frequency modulation, the r.f. signal which is radiated by the transmitter is at an assigned r.f. value called the *resting frequency* or *center frequency* whenever no sound is being transmitted. The resting frequency thus corresponds to the instant when the air at the microphone diaphragm is at *normal atmospheric pressure.* This is illustrated graphically by time interval *1* in Fig. *2.* (The resting frequency of an actual f.m. transmitter would be some value above 42,000,000 cycles per second, but for illustrative purposes we arbitrarily choose 5 cycles to represent the resting frequency in this diagram.)

Although the compression half of a sound wave cycle in air could cause either an increase or decrease in the frequency of an actual f.m. transmitter (depending upon the number of a.f. stages and phase-reversing transformers which are between the microphone and the output of the modulator), it is a convenient and common practice among radio men to associate compression with an *increase* in f.m. transmitter frequency. We will follow this practice.

Frequency Deviation. When an a.f. signal is fed into an f.m. transmitter, the *frequency* of the r.f. signal thus swings *above* the resting value in proportion to increases in air pressure from the normal atmospheric value (compression). Likewise, the transmitter frequency swings *below* the resting value in proportion to decreases in air pressure from the normal atmospheric value (rarefaction). The amount of this swing above or below the resting frequency (the amount by which the instantaneous r.f. value differs from the resting value) is known as the *frequency deviation.* We illustrate these r.f. signal frequency changes in Fig. *2* for a sound having a square-wave form.

Square-Wave Example. Time intervals *2*, *3*, *4* and *5* in Fig. *2* represent two cycles of a weak sound having a square-wave form. During the first half cycle (interval *2*), the air directly in front of the microphone is compressed, and the r.f. carrier frequency for this interval is therefore *higher* than the resting frequency. We have indicated this by showing 7 complete cycles for time interval *2* (two more than for the resting frequency in interval *1*).

During the second half of the first sound cycle, we have rarefaction at the microphone, and the r.f. carrier frequency for this interval is *lower* than the resting frequency. We indicate this by showing 3 cycles for time interval *3* (two less than for interval *1*).

In the second cycle of the weak sound, the process repeats itself, with the r.f. carrier frequency going above the resting value for time interval *4*, and going below the resting value for interval *5*.

In an f.m. system, doubling the sound pressure of the original sound doubles the deviation in transmitter frequency from the resting value. Time intervals *6, 7, 8* and *9* in Fig. *2* illustrate this for the square-wave sound under consideration.

During the first half cycle of this louder sound wave (interval *6*), we have compression, and the r.f. signal frequency is twice as much above the resting frequency as it was for corresponding interval *2* of the weak sound. We indicate this in Fig. *2* by showing 9 complete cycles for time interval *6* (this is 4 cycles above the resting value).

For the rarefaction half of the loud sound cycle (interval *7*), the r.f. signal frequency swings just as much below the resting frequency as it swung above the resting frequency for the compression half cycle. Thus, we show 1 cycle for time interval *7*, this being 4 cycles below the 5-cycle value for the resting frequency.

The 4-cycle swing above and below the resting frequency is repeated for intervals *8* and *9* in Fig. *2*, to give the second cycle of the loud sound.

Sine-Wave Example. The square-wave audio signal in Fig. *2* showed how sudden changes in the amplitude of an audio signal affect the output signal frequency of an f.m. transmitter. Now let us see how gradual changes in amplitude, such as those occurring in the sine-wave audio signal shown in Fig. *3*, will affect an f.m. transmitter. This diagram can either represent variations in air pressure from a normal atmospheric value (as in Fig. *2*) or positive and negative a.f. signal voltage swings.

First of all, we can say that the r.f. signal will be at its resting value whenever the audio signal passes through zero, such as at points *a*, *e* and *g*.

As the audio signal increases in amplitude from *a* to *b* to *c*, the frequency of the r.f. signal will rise above the resting value in a similar manner, to a maximum r.f. value corresponding to peak amplitude *c*. As the audio signal decreases gradually in amplitude to zero again at point *e*, the r.f. signal frequency will drop gradually back to the resting value in a similar manner. Note particularly that for the entire interval of time from *a* to *e* when the a.f. signal is positive, the transmitter frequency is *above* the resting value.

When the a.f. signal goes through its negative half cycle from *e* to *f* to *g*, the r.f. signal frequency will decrease in a correspondingly gradual manner from its resting value to a minimum value corresponding to point *f*, then rise gradually again to the resting value to complete the sine-wave cycle.

Complex Voice or Music Signals. When a complex audio signal like that shown in Fig. *3B* is transmitted by an f.m. system, the transmitter frequency will vary above and below the resting value in accordance with the amplitude and polarity of the audio signal at each instant, even though this voice or music signal contains many different audio frequencies.

Thus, we can say that the r.f. signal frequency will be *above* the resting value whenever the audio signal is *positive*, with the deviation from the resting value being proportional to the positive amplitude at each instant. Likewise, the r.f. signal frequency will be *below* the resting value whenever the audio signal is negative, with the deviation being proportional to the negative amplitude at each instant.

Amount of Frequency Deviation. Keeping in mind the fundamental f.m. fact that the instantaneous deviation in the frequency of the r.f. signal is proportional to the instantaneous amplitude of the audio signal, let us now consider actual frequency values for f.m. as they are used today.

Theoretically, the full audio frequency spectrum with a full range of volume can be handled satisfactorily by an f.m. system regardless of how small or how large the maximum deviation value may be. In actual practice, however, the added requirements of a high signal-to-noise ratio and minimum inter-station interference at receivers make necessary a *high* value for the *maximum frequency deviation.* The greater the maximum frequency deviation employed for desired signals, the less noticeable to the listener will be a given frequency deviation due to an interfering signal.

The channels which have been made available to f.m. broadcast stations in the United States and its possessions by the Federal Communications Commission are .2 mc. apart in the ultra-high frequency band between 42 and 50 mc., with the first five assignments (42.1, 42.3, 42.5, 42.7 and 42.9 mc.) being reserved for non-commercial educational f.m. stations. Each channel assignment represents *the assigned resting frequency* of the station (the unmodulated signal frequency of the station).

A guard band at least 25 kc. wide is required by the F.C.C. beyond each extreme frequency swing of a station, which leaves a maximum of 75 kilocycles for the permissible frequency swing in either direction from the assigned resting frequency.

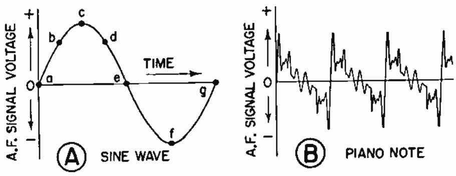

FIG. 3. A pure sine wave signal like that at *A* or a complex audio signal like that at *B* both make the frequency of an f.m. transmitter swing above and below its resting value exactly in proportion to the positive and negative swings of the audio signal.

To provide a margin of safety against swinging into the guard band, and to allow for some variation in f.m. receiver design, the deviation or swing in frequency of an f.m. station in either direction is usually kept at a maximum of about 65 kc. from the resting frequency. The total maximum frequency swing of an f.m. station will then be twice the deviation, or 130 kc.

Percentage modulation, as we know it in connection with the a.m. system of broadcasting, does not exist in an f.m. system. Since the greatest permissible frequency deviation for a loud sound is 65 kc., some engineers are saying that a 65-kc. swing from the resting frequency corresponds to 100% modulation of an f.m. transmitter. Over-modulation (a deviation greater than 65 kc.) will not cause distortion in receivers, however, unless it makes the signal sweep beyond the linear portion of the S curve for discriminator action (to be considered later in this lesson).

The monitor engineer in an f.m. studio has meters before him which tell when the loudness level at the microphone is exceeding the value which gives the full 65-kc. deviation. Whenever necessary, he reduces the gain of the studio a.f. amplifier enough to prevent the transmitter from swinging more than 65 kc. off from the resting frequency. Likewise, the monitor increases the a.f. gain when the loudness level at the microphone drops way down for appreciable periods of time. Thus, the goal of the monitor engineer is essentially the same, for both f.m. and a.m. systems: To keep the audio level at receivers as high as is practical without making the program sound unnatural and without causing over-modulation at the transmitter.

Actual Example. Suppose that an f.m. station is assigned the 45.1-mc. channel, and its microphone is picking up a loud 1000-cycle sound. The resting frequency of this station will be 45.1 megacycles, and the maximum permissible deviation will be 65 kc. (.065 mc.) above and below this resting value. Thus, the r.f. signal frequency will go up to 45.165 mc. for the positive peak of each audio cycle, and will drop down to 45.035 mc. for the negative peak of each audio cycle. Since the audio signal passes through 1000 complete cycles in each second, the f.m. transmitter will go through 1000 complete swings (from 45.1 to 45.165 to 45.1 to 45.035 to 45.1) in each second in order to follow the positive and negative amplitude variations of the audio signal.

If the lowest loudness level to be transmitted in this example is 1/100 of the loudest level, the deviation for this weakest audio signal will be .065 mc. divided by 100, or .00065 mc. For this weak signal, then, the r.f. signal frequency will vary from 45.10065 mc. to 45.09935 mc. and there will be 1000 complete swings like this in each second.

If the f.m. station in our example is transmitting a loud 100-cycle audio signal, the deviation will still be 65 kc. on each side of the resting frequency, but now there will be only 100 complete swings back and forth between the two extreme frequencies in each second.

F.M. Side Frequencies. Mathematical computations as well as actual measurements tell us that the continually varying r.f. signal frequency for an f.m. transmitter is equivalent to a carrier frequency and an infinitely large number of side frequencies. Fortunately, however, the essential side frequencies needed for high-fidelity reproduction are within the 130-kc. deviation range over which the r.f. signal sweeps. Receivers are designed for reception of this range, and consequently they receive the essential side frequencies.

Side frequencies more than 65 kc. off from the resting frequency might create interference with adjacent-channel stations if these stations were in the same locality, but the Federal Communications Commission prevents interference of this nature by keeping channel assignments at least 400 kc. (.4 mc.) apart for f.m. stations in the same service area.

Technical Data on Side Frequencies. When the carrier of an f.m. transmitter is modulated with an audio signal having a constant frequency of *f* cycles per second, the r.f. signal swinging above and below the resting frequency is equal to the following fixed-frequency signals: A signal having the resting frequency of the transmitter; two side frequencies, one above and one below the resting frequency by the audio value *f*; two side frequencies, above and below the resting frequency by twice the audio value *f*; two side frequencies, above and below the resting frequency by three times the audio value *f*; etc.

Here is an example. If the resting frequency of an f.m. transmitter is 43.5 mc. and the audio modulation frequency is 10,000 cycles (.01 mc.), the equivalent individual frequencies will be: 43.5 mc., 43.49 mc. and 43.51 mc., 43.48 mc. and 43.52 mc., 43.47 mc. and 43.53 mc., etc., down to zero and up to infinity.

In your work with f.m. apparatus, however, you will find it more convenient to think of an f.m. signal as a single r.f. signal which is continually varying in frequency above and below its resting frequency. (We do this in amplitude modulation when we consider a modulated r.f. signal as a single r.f. signal which is varying in amplitude from instant to instant as in Fig. *1A*.)

Multiplex F.M. Operation. Frequency modulation has the added advantage of permitting multiplexing, the sending of two or more programs or types of intelligence by the same transmitter, without increasing the required band width for the station and without interference between the programs being transmitted.

Here is an example: To transmit code messages along with a broadcast program, a 20-kc. oscillator signal (above the audio range) could be made to vary in amplitude in accordance with the code modulation, and this modulated 20-kc. secondary carrier then fed into the transmitter along with the regular voice or music program. At the receiver, the voice or music program would pass through the stages in the conventional manner, and the 20-kc. modulated code signal would be taken out ahead of the audio amplifier, and demodulated by conventional means in a separate detector stage. Filters would be used to keep the 20-kc. signal out of the regular a.f. amplifier, to prevent overloading of a.f. stages.

How F.M. Systems Reduce Interference. At any instant of time, we can consider that an f.m. signal has a definite frequency, above or below the resting frequency of the transmitter. We can therefore represent a desired f.m. signal at the input of an f.m. receiver by a vector, as shown in Fig. *4A*. The amplitude (length) of this desired-signal vector *D* will be constant, and the rate at which the

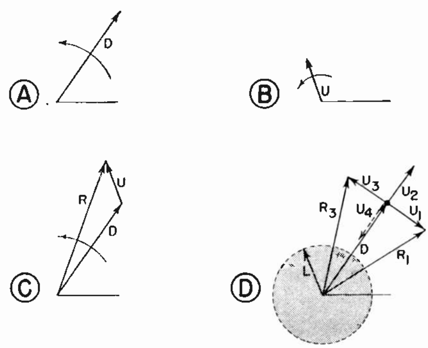

FIG. 4. Vector diagrams showing how an undesired signal *U* can affect the frequency and amplitude of a desired f.m. signal *D*.

vector rotates counter-clockwise will correspond to the frequency of the r.f. signal at the instant of time under consideration. The position of the vector with respect to the horizontal reference line in the diagram is unimportant.

Now, let us suppose that we also have at the input of our f.m. receiver an undesired signal. It may be due either to noise interference or to an undesired r.f. carrier signal from some other station, but nevertheless we know that this undesired signal has both frequency and amplitude. Let us say that at the instant of time under consideration for Fig. *4A*, the undesired signal has the amplitude and phase represented by vector U in Fig. *4B*.

When we combine undesired-signal vector U with desired-signal vector D, as shown in Fig. *4C*, we obtain resultant vector R. The amplitude of vector R is greater than that of desired-signal D, showing that an interfering signal can affect the amplitude of a desired incoming signal. Furthermore, vector R is ahead of vector D, indicating that the sudden arrival of this interfering signal makes desired-signal vector D increase its rotational speed suddenly; this means that during the time interval in which vector D is moving to its new position corresponding to vector R, the frequency of the desired signal is higher than it should be.

Interference vector U in Fig. *4B* may have any phase relationship whatsoever throughout the entire range of 360°. It may be in phase with desired-signal vector D, as indicated by interference vector U_2 in Fig. *4D*; it may be 180° out of phase, as indicated by interference vector U_4 in Fig. *4D*; it may lead the desired vector by 90°, as indicated by U_3, or it may lag the desired vector by 90°, as indicated by U_1. These are the four extremes which could exist, and an analysis of them will take care of intermediate undesired-signal vector positions as well.

Careful study of the vector diagram in Fig. *4D* reveals that when the interfering signal is *in phase* with the desired signal, it *increases* the amplitude of the resultant signal without changing its frequency. When the interfering signal is *180° out of phase* with the desired signal, it *decreases* the amplitude of the resultant signal without changing its frequency. When the interfering signal leads the desired signal, the resultant will be speeded up in frequency, and the amplitude will generally also be altered. Finally, when the interfering signal lags the desired signal, the resultant will be slowed down in frequency and will likewise be altered in amplitude. We thus come to the conclusion that an interfering signal in an f.m. system can change both the *frequency* and the *amplitude* of the desired f.m. signal.

You will learn later in this lesson that the limiter stage of an f.m. receiver reduces all incoming signals to a constant low amplitude corresponding to radius L in Fig. *4D*. Since changes in amplitude due to noise vectors are all outside of this acceptance area, the limiter stage of a properly

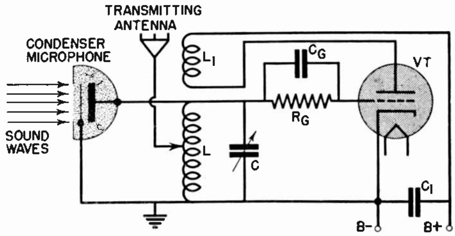

FIG. 5. Simple f.m. transmitter circuit, employing a condenser microphone shunted across the tank circuit of a conventional tuned-grid r.f. oscillator.

designed and adjusted f.m. receiver wipes out amplitude changes due to noise.

Any change in frequency due to noise will show up in the output of an f.m. receiver, for changes in frequency are not affected by the limiter section of the receiver, and are converted into corresponding changes in amplitude by the following frequency discriminator section. By using a high maximum deviation value, however, changes in the frequency of the desired signal due to an interfering signal in the receiver can be made negligibly small with respect to frequency changes due to the desired audio program.

Field tests have proved that the ratio of desired to undesired signals increases as the maximum frequency deviation of the system is increased. Tests have also proved that with a maximum deviation of about 65 kc. (a total swing of 130 kc.), interfering signals become quite imperceptible at the loudspeaker when the desired signal is at least twice as strong as the undesired signal.

An Elementary F.M. System

The F.M. Transmitter. In beginning our study of actual f.m. systems, let us first consider one of the simplest possible transmitter circuits capable of producing frequency-modulated signals.

A conventional vacuum tube oscillator circuit employing a coil-condenser resonant circuit can be tuned to frequencies in either direction from a reference frequency without appreciably changing the amplitude of the output signal. By taking a simple oscillator circuit like this and shunting its resonant circuit with a condenser microphone in the manner shown in Fig. *5*, a simple but effective f.m. transmitter is obtained. Sound waves apply to the movable diaphragm of the microphone a varying pressure which makes this diaphragm move alternately towards and away from the fixed plate. This changes the capacity of the condenser microphone in accordance with variations in sound pressure, thereby alternately raising and lowering the frequency of the r.f. oscillator to give the desired frequency-modulated signal.

There are a number of drawbacks to this simplified f.m. transmitter circuit. The condenser microphone would have to be close to the oscillator, to prevent pick-up of stray signals by the microphone leads. Each condenser microphone would have to be designed to give a definite frequency deviation with its particular oscillator, and even with this precaution the amount of deviation would vary with the particular performer using the microphone. Undoubtedly these problems could be solved by engineers if necessary, but fortunately there are more practical means for securing frequency modulation of a carrier signal. One such scheme will now be considered.

Inductance-Tube Type of F.M. Transmitter. A vacuum tube circuit can be made to act like an inductance, simply by adjusting circuit voltages so that *the r.f. current drawn by the tube will lag the r.f. voltage applied to the tube.* (This scheme is widely employed in the automatic frequency

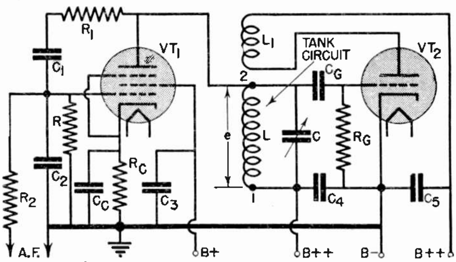

FIG. 6. This practical f.m. transmitter circuit employs an oscillator control circuit consisting of a vacuum tube which acts like an inductance shunted across the r.f. tank circuit. The effective inductance value varies from instant to instant in accordance with variations in the amplitude of the a.f. signal, thereby giving frequency modulation.

control circuits of some radio receivers.) By connecting across the coil-condenser resonant circuit of an r.f. oscillator the vacuum tube circuit which is acting like an inductance, and by making the inductance of this vacuum tube circuit vary at a desired audio rate, we secure frequency modulation.

An inductance-tube type of f.m. transmitter circuit is given in Fig. *6*. Triode vacuum tube VT_2 is connected into a conventional tuned-grid r.f. oscillator circuit, with L and C forming its tank circuit. Pentode tube VT_1 serves as the oscillator control tube which acts like an inductance; its plate is connected directly to terminal *2* of tank inductance L, and its cathode is connected to terminal *1* of this coil through r.f. by-pass condensers C_C and C_4 and the grounded chassis.

Now let us see how oscillator control tube VT_1 can act as an inductance in shunt with tank circuit L-C. First of all, r.f. tank voltage e in Fig. *6* must be considered as the r.f. voltage source acting upon the oscillator control circuit. The two r.f. signal paths connected in parallel across r.f. voltage source e are the plate-cathode path of oscillator controle tube VT_1 and path R_1-C_1-C_2-C_4.

At radio frequencies, path R_1-C_1-C_2-C_4 is essentially resistive (the reactances of all three condensers are low with respect to the resistance of R_1), and hence the r.f. current flowing over this path is *in phase with its r.f. source voltage e.* This r.f. current develops across condenser C_2 an r.f. voltage which *lags* the r.f. current, and hence lags r.f. voltage e. (The a.c. voltage across a condenser always lags the condenser current.)

The r.f. voltage across C_2 acts on the control grid of VT_1, making the tube pass an r.f. plate current which is *in phase with the applied r.f. grid voltage.* The r.f. plate current drawn from L by the oscillator control tube *therefore lags the r.f. voltage across L.* This is exactly the same phase relationship as for an inductance load across L; the oscillator control tube thus acts like an additional inductance shunting the tank circuit, and serves to *increase* the frequency of the r.f. oscillator.*

The a.f. modulation voltage which is applied to the control grid of VT_1 through R_2 varies the transconductance of the tube, and hence makes the a.c. plate current vary at an audio rate. Consequently, *the inductance of this tube also varies at an audio rate.* This in turn makes the frequency of the r.f. oscillator swing above and below its resting value at an a.f. rate, giving frequency modulation of the r.f. carrier without appreciable variation in the r.f. amplitude. When the a.f. signal is removed or drops to zero, the r.f. oscillator returns to its resting frequency, which is determined by the size of inductance L, the normal inductance of the oscillator control circuit, and the tank circuit capacity.

Resistor R_2 prevents the a.f. source from shorting the input of the inductance tube; it is really an isolating resistor.

By adjusting the initial C bias on the oscillator control tube (varying the ohmic value of R_C) and by monitoring properly the a.f. voltage fed into the oscillator control tube, the maximum deviation in frequency can be made any desired amount. The circuit of Fig. *6* is therefore a suitable signal source for an f.m. system which is to be employed in transmitting intelligence. The f.m. signal would be taken either from terminal *2* or from a link which is coupled to tank circuit inductance L.

The F.M. Receiver. Up to the point at which frequency-modulated signals are converted into amplitude-modulated signals, an f.m. receiver uses essentially the same circuits as a corresponding a.m. receiver. The a.f. amplifier and loudspeaker are likewise essentially the same for both systems. The important new action in an f.m. receiver is the conversion of the f.m. signal into the desired audio signal, so let us consider now the basic

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* When two inductances are in parallel, the combined inductance is less than that of the smaller inductance. Lowering the total tank circuit inductance raises the oscillator frequency. If one of the parallel inductances is reduced in value, the oscillator frequency will increase; if one of the parallel inductances is increased in value, the oscillator frequency will decrease.

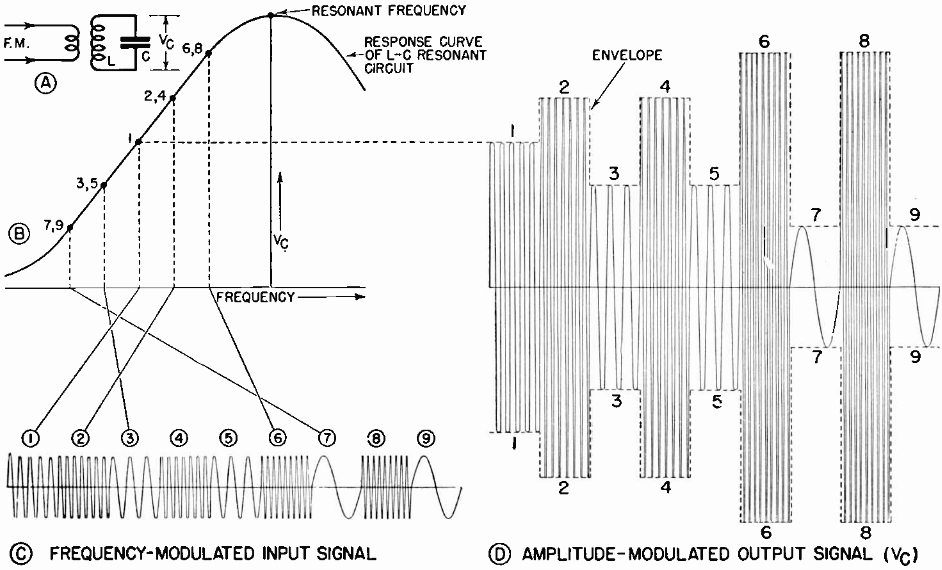

FIG. 7. These diagrams illustrate how a simple resonant circuit can convert an f.m. signal into an a.m. signal.

principles involved in this conversion.

If a frequency-modulated r.f. signal is introduced into an *L-C* resonant circuit which is tuned slightly above *the highest deviation frequency*, the r.f. *voltage* developed across the resonant circuit will vary with the *frequency* of the induced f.m. signal. An ordinary resonant circuit like the *L-C* circuit in Fig. *7A* is thus a simple means for converting an f.m. signal into an a.m. signal.

A portion of the resonant response curve for this *L-C* circuit is shown in Fig. *7B*. By applying to this curve in the proper manner the f.m. signal shown at the bottom of Fig. *2* (having a square-wave audio modulation), we can get a graphical picture of how the *amplitude* of r.f. output voltage V_C varies with the *frequency* of the incoming f.m. signal.

Let us assume that when the f.m. transmitter is at its resting frequency (time interval *1* in Figs. *2* and *7C*), the operating point is at *1* in Fig. *7B*. The vertical distance from *1* down to the horizontal reference line then determines the amplitude of r.f. voltage V_C across the resonant circuit, so we show the r.f. output voltage for time interval *1* as an r.f. signal having this same amplitude and the same resting frequency value, as at *1* in Fig. *7D*.

When the frequency of the f.m. signal increases to the value for time interval *2* in Fig. *7C*, we move up to point *2* on the response curve, and thereby secure the output signal at *2* in Fig. *7D*. Likewise, the input signal frequencies for time intervals *3, 4, 5, 6, 7, 8* and *9* in Fig. *7C* give the output signal amplitudes shown at *3, 4, 5, 6, 7, 8* and *9* respectively in Fig. *7D*.

Note that the signal frequency is unchanged by the resonant circuit, but the *amplitude* of the output signal varies in proportion to the frequency deviations of the input f.m. signal. A dash-dash line drawn through the positive peaks of the r.f. output voltage in Fig. *7D* gives the original square-wave audio modulation of Fig. *2*, showing that we now have an amplitude-modulated r.f. signal which can be demodulated with a conventional amplitude detector circuit. The fact that our output signal also varies in frequency does not matter, for the amplitude detector circuit removes all r.f. components.

A complete circuit capable of converting an f.m. signal into an audio signal is shown in Fig. *8*; this circuit can appropriately be called an *f.m. detector*. The final i.f. amplifier stage is also shown, and employs a 6SK7 pentode, with a double-tuned i.f. transformer (C_3-L_3-L_2-C_2) in its input circuit. Resistor R_L across the primary of this i.f. transformer provides the loading required to flatten the response over the 130-kc. range through which

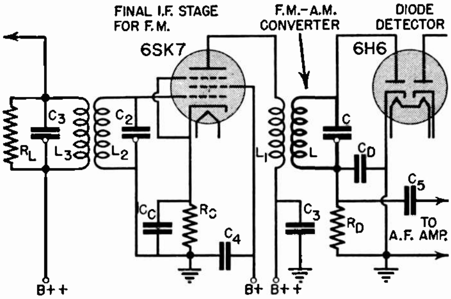

FIG. 8. This diagram shows how a resonant circuit can be used to convert the f.m. output signal of the i.f. amplifier into an a.m. signal which can be demodulated by a conventional diode detector.

the f.m. signal is varying during loud audio loudness levels.

Plate current of the final i.f. tube flows through coil L_1, inducing an f.m. signal voltage in coil L of the L-C resonant circuit in which frequency-to-amplitude conversion takes place. The r.f. voltage across this L-C circuit therefore varies in amplitude in accordance with variations in the original audio signal amplitude. This amplitude-modulated r.f. voltage is demodulated by one section of the 6H6 tube, and the resulting a.f. output voltage appears across diode load resistor R_D. Condenser C_D removes r.f. variations across R_D, so that only the desired a.f. voltage is fed into the a.f. amplifier.

Additional Requirements in an F.M. System

The f.m. transmitter and receiver arrangements just described represent the absolute minimum required in an f.m. system. Transmitters must have some type of crystal control, so as to maintain the assigned resting frequency value within the limits prescribed by law, and receivers must also have additional features which insure high fidelity and operating stability, reduce noise and simplify tuning.

The remainder of this lesson will be devoted chiefly to practical f.m. receiver circuits, but basic principles of highly stable modern f.m. transmitters will be covered briefly at the end of this lesson text to make your f.m. training more complete.

Resonant circuits have proved unsatisfactory for f.m.-a.m. separating purposes, chiefly because the slopes of their response curves are not sufficiently linear for high-fidelity purposes. Instead, we find in modern f.m. receivers a variation of the discriminator circuit used in a.f.c. circuits. This discriminator circuit is simple to adjust, gives linear operation, and *converts f.m. signals directly into audio signals,* thereby eliminating the need for an amplitude detector.

In a practical f.m. receiver, an additional section called the limiter is required just ahead of the discriminator to restore constant amplitude, so that all amplitude rises due to noise or station interference will be removed.

The limiter is a vacuum tube amplifier which is so designed that all desired signals will cause plate current saturation. This action of the limiter stage also levels out the response of the r.f. system.

Since the limiter in an f.m. receiver delivers the same amplitude for both weak and strong incoming signals, the loudspeaker volume level does not change when tuning from one f.m. station to another. This means that it is unnecessary to use an a.v.c. system in an f.m. receiver to prevent blasting or counteract fading. Most f.m. receivers do have a.v.c., but this is primarily to prevent extremely strong input signals from driving the grids of r.f. or i.f. amplifier tubes positive and thereby causing blocking or interference. If grid current were allowed to flow during positive grid voltage values, the resulting distortion of the incoming f.m. signal would produce harmonics which could beat with oscillator harmonics and other station signals to produce interfering signals at the i.f. value for f.m.

Another requirement in a modern f.m. receiver is a tuning indicator (either a meter or a cathode ray tuning indicator tube). F.M. resonant circuits are so broad due to loading that the average person would have difficulty in tuning in an f.m. station by ear alone.

The F.M. Receiver

Types of F.M. Receivers. Radio receivers which are capable of receiving f.m. signals can be divided into three groups, as follows:

1. Sets designed exclusively for f.m. reception. These can be table models or consoles, for listeners who already have good a.m. receivers.

2. Combination f.m.-a.m. receivers, providing all-wave a.m. reception along with f.m. reception. These will usually be large console sets and may also have automatic record changers, television, facsimile or sound-recording features.

3. F.M. converters, which are simply f.m. receivers without audio amplifiers or loudspeakers. They provide f.m. reception when connected to the a.f. input terminals of an ordinary a.m. receiver.

All f.m. receivers should have high sensitivity in order to operate the limiter at saturation for the widest frequency swings of the weakest signal to be received, and hence superheterodyne circuits are invariably employed.

Typical circuits used in combination f.m. and a.m. receivers will now be analyzed.

Combination F.M.-A.M. Receiver

A block diagram of a typical combination a.m. and f.m. superheterodyne receiver is given in Fig. *9.* The circuits now to be considered will be

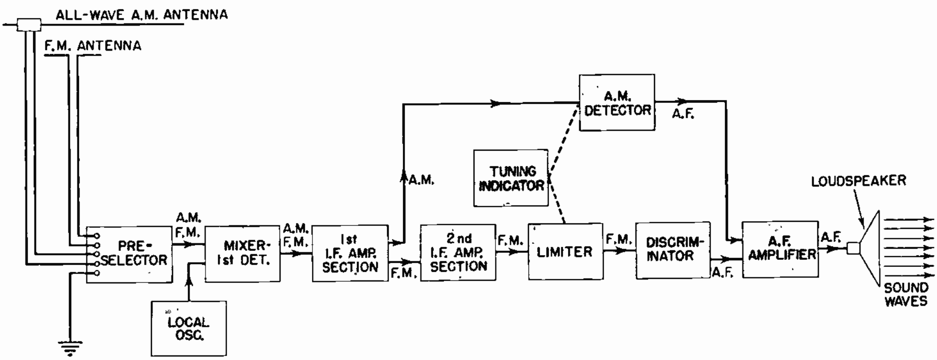

FIG. 9. Block diagram of a typical combination f.m. and a.m. receiver.

those employed in this particular receiver arrangement.

Note first of all that there are two antennas, one for regular all-wave a.m. signal pick-up, and the other for ultra-high-frequency f.m. signal pick-up. The band-selecting switch automatically connects the correct antenna to the receiver. (Fairly satisfactory results can be obtained with a single combination antenna on some sets, as you will later learn.)

For amplitude-modulated signals, the local oscillator will operate about 455 k.c. above the incoming a.m. signal frequency, while for frequency-modulated signals, it will operate at 4.3 mc. below the incoming f.m. signal frequency.* The i.f. signal produced by the mixer-first detector (about 455 kc. for a.m., or 4.3 mc. for f.m.) passes through the first i.f. amplifier section to a switching circuit.

For f.m. reception, the signals are fed into a second i.f. amplifier section, which raises the signal level the required amount for the limiter stage. The constant-amplitude output of the limiter is fed into the discriminator, and the resulting a.f. output signal is fed directly into the input of the a.f. amplifier.

For a.m. reception, the output of the first i.f. amplifier section is fed directly into a conventional a.m. detector, and its a.f. output is likewise fed into the input of the a.f. amplifier. The tuning indicator, if used, would be connected through the band-changing switch to the a.v.c. source for either the f.m. or a.m. channel. A common power pack serves all sections.

F.M. Receiving Antennas

The antenna for f.m. reception will ordinarily be a doublet of the correct length to give half-wave operation at an average frequency in the f.m. band. Since commercial f.m. stations are assigned to frequencies between 43.1 and 49.9 mc., a doublet which resonates at about 47 mc. will ordinarily be used. With proper design, its response will normally be broad enough to give satisfactory coverage of the entire f.m. band.

A frequency of 47 megacycles corresponds to a wavelength of 6.4 meters (wavelength in meters is equal to 300 divided by frequency in megacycles). A half-wave f.m. doublet antenna will therefore have a total length of about 3.2 meters; multiplying this value by 3.28 gives about 10.5 feet as the total length for an average f.m. doublet receiving antenna.

The simplest possible f.m. doublet is that shown in Fig. *10A*, in which the transmission line is connected to the center of the 10.5-foot long doublet. Since a half-wave doublet has a resistance of about 72 ohms at its center, a transmission cable having a surge impedance of approximately this same value would ordinarily be used. Slight mismatches can be tolerated, however; in fact, a cable with a surge impedance of about 100 ohms will make the antenna response characteristic more uniform over the entire f.m. band. The transmission cable is connected to the receiver through a matching transformer.

At ultra-high frequencies, line-of-sight paths give the best transmission of radio waves, but, fortunately, reliable f.m. reception is possible con-

* Although 4.3 mc. is the recommended i.f. value for f.m. receivers at the present time, you will also encounter i.f. values of 2.1 mc., 5.25 mc. and other values. Engineers recommend even higher i.f. values for f.m. receivers, with 8.26 mc. being proposed for sets having two tuned circuits ahead of the converter, and either 11.45 mc. or 13.5 mc. when there is only one tuned circuit ahead of the converter. These higher values minimize chances for interference between the various signals which are picked up by the receiving antenna or produced in the receiver by superheterodyne action.

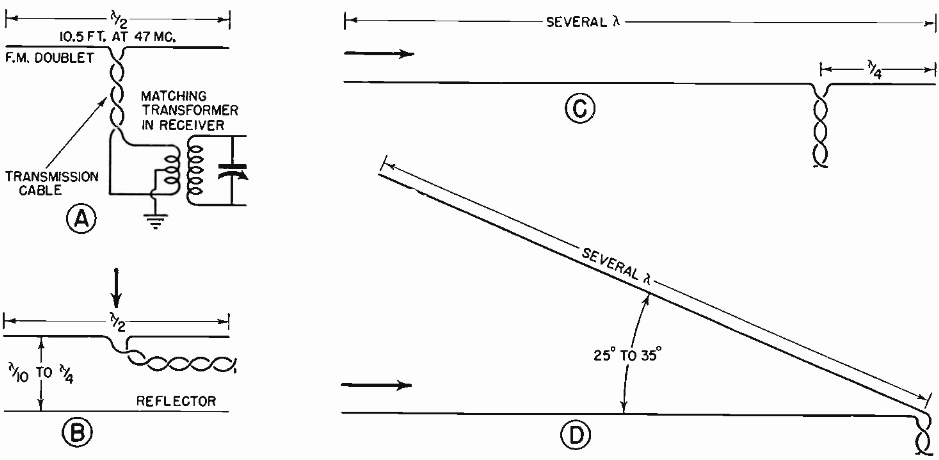

FIG. 10. Types of f.m. receiving antennas. The heavy arrow in each case indicates the direction (along the surface of the earth) from which signals are best received. The symbol λ represents "wavelength."

siderably beyond the line-of-sight range from a transmitter. (With a line-of-sight path, it should be possible to see the transmitting antenna with a telescope on a clear day from the position of the receiving antenna.)

A compact ultra-high frequency antenna built into the console cabinet of an f.m. receiver will often give adequate signal pick-up of stations up to about ten miles away. Even a quarter-wave vertical antenna can sometimes be used when signals are strong.

In locations considerably beyond the line-of-sight limit, the position of the receiving antenna becomes important. The half-wave horizontal f.m. doublet should then be as high as possible, and broadside (at right angles) to the path over which f.m. signals are arriving.

In remote locations where all of the desired f.m. signals are coming from essentially the same direction, such as from a single large city, a reflector like that shown in Fig. *10B* can be used with a conventional doublet to increase the signal pick-up from the desired direction. The doublet is always placed between the reflector and the transmitter.

The antenna arrangements shown in Figs. *10C* and *10D* give even better signal pick-up at remote locations. In Fig. *10C*, one section of the doublet has the usual length of $\lambda/4$ (one-quarter wavelength), while the other section is several wavelengths long. The long section is aimed directly at or slightly above the transmitter.

In the V doublet arrangement of Fig. *10D*, both horizontal sections are equal, several wavelengths long, and aimed in the general direction of the transmitter.

Before mounting an f.m. doublet permanently, it is always a good idea to move the antenna toward or away from the transmitter a distance of about 5 feet, and tilt it at various angles while an assistant is checking signal strength at the receiver by watching the tuning indicator or using a meter, to find the position which gives maximum signal strength. Cancellation due to reflected waves arriving over different paths will then be a minimum.

The Preselector

A preselector having at least one r.f. amplifier stage is just as desirable in an f.m. superheterodyne receiver as in an a.m. set, for r.f. amplification ahead of the mixer-first detector in an f.m. receiver provides much needed extra sensitivity and minimizes converter noise. Just as with a.m. receivers, the higher-priced f.m. receivers will usually have an r.f. stage in the preselector. Less expensive f.m. sets will have a simple antenna transformer with tuned secondary, feeding directly into the mixer-first detector.

The circuit of a typical r.f. amplifier stage for a combination f.m.-a.m. receiver is shown in Fig. *11A*. To simplify the diagram, only one all-wave a.m. range is shown; additional contacts on the three sections of the band-changing switch and additional input and output r.f. transformers would be provided for other a.m. ranges.

When the three switches (S_1, S_2 and S_3) are set to position *1*, as shown in Fig. *11A*, the entire preselector is connected for f.m. reception. The half-wave f.m. doublet feeds its f.m. signal into the grid circuit of the 6SK7 r.f. amplifier tube through f.m. antenna matching transformer L_1-L_2, with secondary winding L_2 being tuned to the incoming f.m. signal frequency by gang condenser section C_1. The amplified r.f. plate current of the 6SK7 tube flows through winding L_3 of the f.m. input transformer for the mixer, inducing in secondary winding L_4 a corresponding r.f. voltage. Gang condenser section C_2 tunes L_4 to resonance at the desired station frequency, and the resulting f.m. signal voltage across this resonant circuit is applied to the grid and cathode of the mixer-first detector tube. Automatic C bias for the 6SK7 tube is provided by R_2 and C_9.

Setting the three switches in the preselector circuit of Fig. *11A* to position *2* automatically connects the circuit for a.m. reception on one band. Switch S_1 disconnects the secondary of the f.m. matching transformer from the r.f. amplifier tube grid, and connects the grid instead to the secondary of the a.m. antenna matching transformer. The all-wave a.m. doublet feeds its a.m. signal to the r.f. amplifier tube through a.m. matching transformer L_5-L_6, with secondary winding L_6 being tuned to resonance by gang condenser sections C_3 and C_1 in parallel. (The conventional condenser section for a.m. is split into two sections, C_3 and C_1, so that one low-capacity section will be available for f.m. to give a favorable L-to-C ratio.) The r.f. output of the 6SK7 tube is fed to the mixer through a.m. input transformer L_7-L_8, with secondary winding L_8 being tuned by C_4 and C_2 in parallel.

When the switches are at position *2* for a.m. reception, a.v.c. voltage is applied to the r.f. and mixer tubes through L_6 and L_8 respectively. No a.v.c. is used on these two tubes during f.m. reception in this circuit, but engineers are now recommending that a.v.c. be provided for the r.f. amplifier tube of an f.m. receiver to prevent overloading of any tubes by extremely strong f.m. signals. The a.v.c. voltage for f.m. would be supplied by the *limiter* section.

A variation of the preselector circuit of Fig. *11A* which makes possible the use of one doublet antenna for both f.m. and a.m. reception is shown in Fig. *11B*. The remainder of the preselector circuit is not shown, since it is identical with that in Fig. *11A*. The connections are such that doublet antenna action is secured for f.m. reception, but the antenna is automatically converted into a plain vertical antenna for a.m. reception. Resonant circuit *L-C* is tuned to the mid-frequency of the f.m. band (about 47 mc.); since it is a series resonant circuit, it has a low impedance at or near resonance, and has the

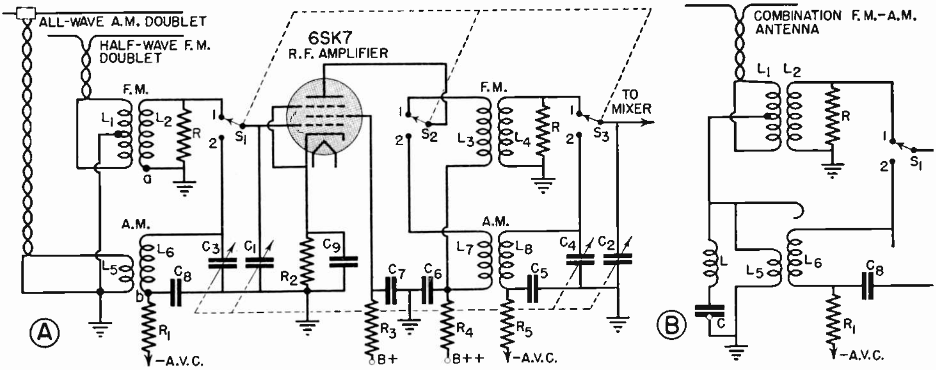

FIG. 11. Typical preselector circuit arrangements for a combination f.m.-a.m. receiver. If the r.f. amplifier tube is to have a.v.c., terminal *a* of f.m. coil L_2 is connected to terminal *b* of a.m. coil L_6 instead of to ground. A switch at the two a.v.c. sources (shown in Fig. *20*) insures that the correct a.v.c. voltage (for f.m. or for a.m.) will be fed to this tube.

effect of grounding the center tap of winding L_1. Under this condition, the antenna acts as an ultra-high-frequency doublet for the f.m. band.

For a.m. bands, usually below 20 megacycles, the series *L-C* circuit is considerably off resonance, and hence has a high capacitive reactance. Winding L_1 is therefore ungrounded, and signal currents picked up by the two sections of the doublet flow through the two sections of L_1 to the center tap, then through winding L_5 to ground (L_5 has much lower reactance than the *L-C* circuit). The a.m. signal current through L_5 induces a corresponding r.f. voltage in L_6, and this is fed through the r.f. amplifier tube to the mixer in exactly the same manner as for the circuit of Fig. *11A*.

Observe that a resistor (*R*) is shunted across each f.m. resonant circuit in Figs. *11A* and *11B*. These resistors serve to load the resonant circuit, providing broad resonance which gives essentially uniform response at all frequencies within the deviation range of an incoming f.m. signal. Ordinarily, resistor *R* has an ohmic value somewhere between 10,000 and 20,000 ohms, with the higher value being preferred in order that the preselector will have good selectivity. When no r.f. amplifier stage is used, a band-passed preselector circuit ahead of the frequency converter is highly desirable, to broaden the response and at the same time improve selectivity.

The Frequency Converter

In any superheterodyne receiver, the local oscillator and the mixer-first detector constitute a section commonly called the *frequency converter.* The local oscillator feeds into the mixer-first detector an unmodulated r.f. signal which beats with the incoming modulated signal to produce the correct i.f. signal.

A number of different circuit arrangements can be employed in the frequency converter of a combination f.m.-a.m. receiver. Some designers will use a pentagrid converter tube, some will use a combination triode-pentode tube, and some will use separate tubes for the oscillator and mixer-first detector.

It is customary to operate the local oscillator *below* the incoming signal frequency for f.m. reception, to secure greater stability and prevent local oscillator signals from creating interference in the television band above 50 mc. On a.m. bands, however, the oscillator is usually operated *above* the incoming signal frequency.

Switching sections must be provided on the band-changing switch of a combination f.m.-a.m. receiver to insert the correct inductance and variable capacity in the oscillator tuning circuit of the frequency converter. The oscillator would thus be tuned 4.3 mc. (or whatever other i.f. value is used for f.m.) *below* the incoming signal frequency for f.m. reception, and about 455 kc. *above* the incoming signal frequency for a.m. reception.

An example of a conventional frequency converter circuit employing a type 6K8 combination triode-pentode tube is given in Fig. *12*. This circuit could be connected directly to the

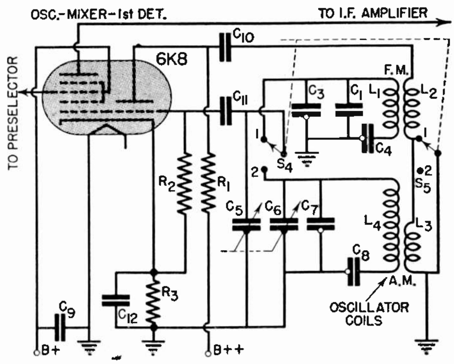

FIG. 12. Typical frequency converter circuit for a combination f.m.-a.m. receiver.

preselector circuit of Fig. *11*, with all tuning condenser sections being controlled by one tuning knob and all switches being controlled by the band-changing knob.

When switches S_4 and S_5 in Fig. *12* are at position *1* for f.m. reception, oscillator tank circuit inductance L_1 is tuned 4.3 mc. below the incoming f.m. signal frequency by tuning condenser section C_5. The high-frequency trimmer is C_3, and the low-frequency padder is C_4, while C_1 serves as a temperature-compensating condenser. (Condenser C_1 changes its capacity in a definite manner with temperature, thereby minimizing oscillator frequency drift by compensating for other capacity changes which occur as the set comes up to normal operating temperature after being turned on.)

Feed-back from the oscillator plate circuit is provided by inductance L_2. Automatic C bias for the oscillator is provided by the flow of grid current through grid resistor R_2 and grid condenser C_{11}. D.C. blocking condenser C_{10} prevents the plate supply voltage of the oscillator triode from sending direct current through oscillator feed-back coil L_2 to ground.

All leads in the f.m. oscillator section of the circuit should be as short as possible, so that resonance effects will be localized to the desired L_1-C_5 tuning circuit. All grounded elements in a section should be connected to a common point on the chassis. At ultra-high frequencies, long leads have appreciable inductance and capacity to the chassis, and hence might form additional resonant circuits which create trouble.

When switches S_4 and S_5 in Fig. *12* are at position *2* for reception on one of the a.m. bands, the oscillator tank circuit inductance is L_4. The tank circuit is tuned 455 kc. above the incoming a.m. signal frequency by tuning condenser sections C_5 and C_6 in parallel. C_7 serves as the high-frequency trimmer, and C_8 serves as the low-frequency padder. Feed-back energy from the plate circuit is now supplied by L_3, for removal of the short across L_3 by S_5 allows r.f. plate current to flow through both L_2 and L_3 to ground.

The I.F. Amplifier. In a combination f.m. and a.m. receiver, it is impractical to use the standard 455-kc. i.f. value for both f.m. and a.m. reception. The gain of a 455-kc. i.f. amplifier drops entirely too much when it is band-passed sufficiently to pass a 130-kc. wide f.m. signal. Furthermore, the selectivity of this band-passed 455-kc. i.f. amplifier would be way too poor for standard a.m. reception. A 4.3-mc. i.f. amplifier is satisfactory for f.m., but its selectivity is likewise too poor for a.m. reception.

To meet these conflicting requirements in a combination f.m.-a.m. receiver, separate i.f. transformers can be used for f.m. and a.m., so that a.m. signals will pass through standard 455-kc. i.f. transformers, and f.m. signals will be served by 4.3-mc. i.f. transformers. With the exception of the first i.f. transformer primary, the connections can be such that signals will take the correct transformers in traveling through the i.f. amplifier. It is even possible to mount both the f.m. and a.m. transformers for a given stage in the same shield can.

When corresponding windings of the i.f. transformers for f.m. and a.m. are connected in series as shown in Fig. *13*, signals will automatically take the correct path. Thus, when a 455-kc. a.m. signal is coming through, the transfer of signals will be accomplished by the 455-kc. a.m. transformer L_3-C_3-L_4-C_4, because L_1 will be essentially a short-circuit path. When 4.3-mc. f.m. signals are coming through, signal transfer will be through f.m. transformer L_1-C_1-L_2-C_2, because C_3 will be essentially a short-circuit path. In each case, the i.f. transformer not in use will be so far off resonance that its effect will be negligible.

I.F. Switching. During broadcast band a.m. reception, the local oscillator produces a signal somewhere between about 1000 and 2000 kc. (1 and 2 mc.) when the local i.f. value for a.m. is 455 kc. The third harmonic of the oscillator will then cover 3 to 9 mc., and there will be one tuning dial position at which this oscillator signal coincides with the 4.3-mc. i.f. value for f.m.

With the series arrangement of 455-kc. and 4.3-mc. i.f. windings, this strong oscillator third harmonic would get through the first i.f. transformer for f.m., and drive the self-bias so far beyond cut-off (due to increased plate current through the cathode resistor) that the desired 455-kc. i.f. signal would be blocked. The result would be a "dead spot" in the broadcast band at the setting which made this oscillator third harmonic equal to 4.3 mc.

The second and fourth harmonics of the local oscillator can likewise create dead spots at different broad-

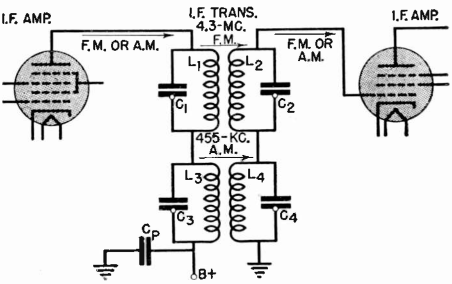

FIG. 13. I.F. transformer arrangement suitable for a combination f.m.-a.m. receiver. Separate i.f. transformers with corresponding windings connected in series are used for f.m. and a.m. No switches are employed, for desired signals automatically take the correct path due to circuit impedance values.

cast band dial settings, and hence it is necessary either to disconnect or short out the 4.3-mc. first i.f. transformer during broadcast band reception. When a switch is provided at the i.f. amplifier input for this purpose, only the desired i.f. signal passes through the first i.f. tube to the other i.f. transformers, and hence no additional i.f. switches are needed.

An example of a complete i.f. amplifier section which has provisions for disconnecting the unused first i.f. transformer primary is shown in Fig. *14*. Section S_1 of the band-changing switch connects to the converter the correct i.f. transformer primary winding (L_1 or L_7) for the particular signals being received. All other pairs of i.f. windings are still connected in series just as in Fig. *13*, however.

The i.f. input switch can just as well be between the grid of the first i.f. amplifier tube and the secondary windings of the first i.f. transformers, or can be used to short out the primary or secondary winding of the unused first i.f. transformer.

Note that the i.f. transformers for a.m. have fixed condensers, with tuning being accomplished with adjustable iron-core inductances. Pulverized iron cores are not effective at the 4.3-mc. i.f. value for f.m., but at a high frequency like this a low-resistance non-ferrous core (such as copper, aluminum or brass) can be used instead to vary the inductance. Non-ferrous cores of this type are inserted from the grounded end of the i.f. coil; they vary the inductance due to eddy currents induced in the core, and also add capacity to the tuning circuit. Non-ferrous cores can also be used for r.f. coils in f.m. circuits.

Sometimes the final i.f. stage is used only during f.m. reception. A simple method for eliminating this stage during a.m. reception involves grounding point *a* in Fig. *14* permanently, and connecting secondary L_{10}-C_{10} of the second 455-kc. i.f. transformer directly to the a.m. second detector. Transformer L_{11}-C_{11}-L_{12}-C_{12} would be omitted.

Both i.f. amplifier tubes in Fig. *14* have resistors in their cathode leads to provide automatic C bias for both f.m. and a.m. reception. During a.m. reception, however, the diode a.m. detector supplies an a.v.c. voltage to the first i.f. amplifier tube, as well as to preceding tubes. (During f.m. reception, the a.v.c. voltage is provided by the limiter stage.)

Double Superheterodyne. To obtain additional r.f. gain under stable conditions, a modified double superheterodyne circuit arrangement is sometimes used in f.m. receivers. One example of this is the General Electric Model JFM-90 f.m. converter, for which a simplified circuit is given in Fig. *15*.

The gang tuning condenser of this f.m. unit has three sections: C_1 in preselector tuning circuit L_1-C_1, C_2 in oscillator tank circuit L_2-C_2, and C_3 in i.f. tuning circuit L_3-C_3 between the two converters. Rotating this gang condenser tunes the preselector over the f.m. range of 42 to 50 mc., tunes the oscillator over the range

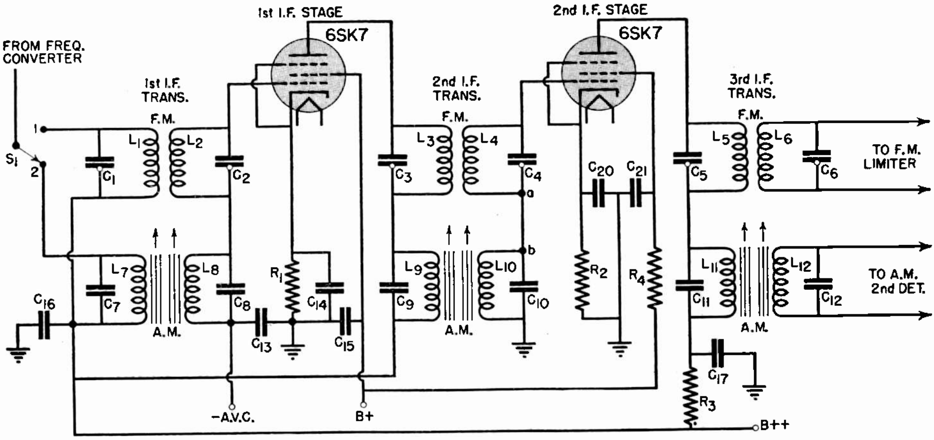

FIG. 14. Circuit diagram of a complete i.f. amplifier for a combination f.m.-a.m. receiver. Note the use of a switch for the primary windings of the first i.f. transformers. The groups of three parallel lines with arrows on a.m. transformers represent adjustable pulverized iron cores; these are adjusted in the same way as ordinary i.f. trimmers during i.f. alignment.

from 18.85 mc. to 22.85 mc., and tunes the i.f. coupling circuit L_3-C_3 over the range from 23.15 mc. to 27.15 mc.

The oscillator signal is inductively transferred to the grid circuit of the first converter, where it mixes with

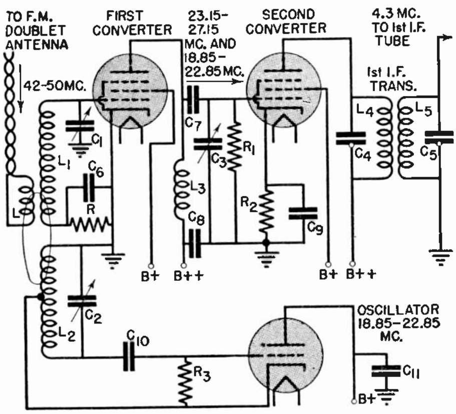

FIG. 15. Simplified diagram showing how a double superheterodyne circuit employing two converters and a single oscillator can be used to provide considerably more gain than is obtainable from a single converter stage, without sacrificing stability. The C bias for the first converter is produced automatically by grid current flow through *R* and C_6.

the incoming signal to produce an i.f. beat frequency which will be somewhere between 23.15 mc. and 27.15 mc., depending upon the setting of the f.m. tuning dial. The i.f. coupling circuit is broad enough so that the 18.25-22.85-mc. oscillator signal can pass through into the second converter along with the 23.15-27.15-mc. i.f. signal. In the second converter, these two signals mix together to produce the final and constant i.f. value of 4.3 mc. This 4.3-mc. signal is then amplified in the conventional manner by a 4.3-mc. i.f. amplifier.

Note that the local oscillator tunes over a frequency range of only 4 mc. when the preselector is tuned over the 8-mc. f.m. band. This makes the first i.f. signal vary over a 4-mc. range. With the first i.f. signal and the oscillator signal varying over a 4-mc. range and with the oscillator always 4.3 mc. below the first i.f. signal, the second converter produces the desired constant 4.3-mc. final i.f. signal.

The Limiter. The purpose of the limiter section in an f.m. receiver is *to remove amplitude variations from the f.m. signal* at the output of the i.f. amplifier, so that the signal fed into the discriminator will have constant amplitude. Ir serving this purpose, the limiter automatically corrects deficiencies in the frequency response of the preceding r.f. and i.f. stages. The limiter also provides *an a.v.c. voltage* for use during f.m. reception.

A typical single-tube limiter stage is shown in Fig. *16A*. To understand how the 6SJ7 pentode in this circuit can function as a limiter, we must first consider the E_g-I_p characteristic curves for this tube under various operating conditions.

When a 6SJ7 pentode is operated at normal voltages for amplifying purposes, such as with a 250-volt d.c. plate voltage and a 100-volt d.c. screen grid voltage, the static E_g-I_p characteristic of the tube will be like curve *1* in Fig. *16B*. This curve is essentially linear up to the highest plate current which can safely be passed by the

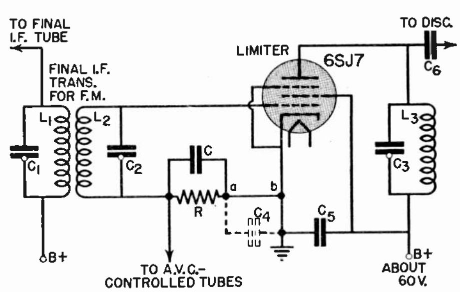

FIG. 16A. Simplified one-tube limiter circuit for an f.m. receiver. Condenser C_4 is provided for alignment purposes, as will be explained later.

tube, and consequently the plate current increases in proportion to positive grid voltage values. This is of no value for limiter action; we desire a characteristic which will make the plate current essentially constant regardless of how much the grid is driven positive, and hence the tube must be operated in such a way that plate current saturation occurs at a low positive grid voltage value.

When the d.c. plate and screen grid voltages of the 6SJ7 pentode are about 60 volts, we secure the desired condition whereby saturation begins at a fairly low positive grid voltage value, as indicated by curve *2* in Fig. *16B*. This curve is for the tube alone, and would be obtained from the circuit of Fig. *16A* only if resistor *R* and condenser *C* were shorted out so as to give static conditions.

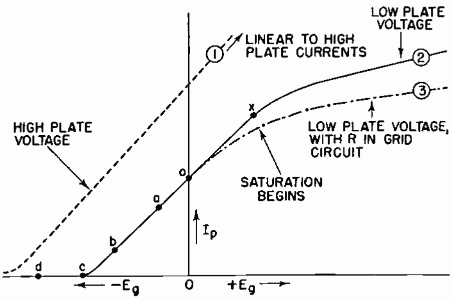

FIG. 16B. Static characteristic curves of a vacuum tube for high *(1)* and low *(2)* plate voltages, and dynamic characteristic curve *(3)* for a limiter circuit using a low plate voltage and a resistor *R* (but no condenser *C*) in the grid circuit. The plate load resistance for the static curves is assumed to be equal to the resistance of the plate load resonant circuit at resonance during dynamic operation.

If a strong sine wave signal is applied to the grid of the 6SJ7 tube when it is operated with characteristic curve *2* in Fig. *16B*, the operating point will be at *o*, negative peaks of the input signal will swing beyond cut-off (beyond *c*), and positive peaks will swing into the saturation region of the curve (beyond point *x* at which saturation begins). As a result, both the positive and negative peaks of the plate current will be cut off, and we will secure a certain amount of the desired limiting action on strong signals.

Now let us return to the basic limiter circuit in Fig. *16A*, and consider its operation first with resistor *R* in the grid circuit but with condenser *C* removed. First of all, we can see that during half cycles which swing the grid negative, there is no grid current flowing through resistor *R*, and consequently the circuit acts essentially the same as if resistor *R* were shorted. In other words, our characteristic curve with *R* in the circuit will be the same for negative grid voltages as it was without *R*. For half cycles which make the grid swing positive, however, the flow of grid current through *R* will develop across it a voltage drop which opposes the applied positive grid voltage, and which consequently serves to provide a negative bias which is at each instant proportional to the positive applied voltage. The characteristic curve for this condition will be like curve *3* in Fig. *16B*, which is flatter than curve *2*. The saturation effect is considerably more pronounced now, and plate current during positive half cycles is limited by the negative bias across *R* as well as by the saturation characteristic of the tube at the low d.c. operating voltages used.

With *R* alone in the limiter circuit, the bias developed across it would follow individual r.f. positive peaks, and would consequently be varying continually. In a practical limiter circuit, resistor *R* in Fig. *16A* would be shunted by condenser *C*, with the time constant of *R* and *C* being equal to the time of several r.f. cycles. Under this condition, the *R-C* circuit assumes a definite negative bias voltage which is maintained relatively constant over several cycles of the r.f. input voltage, and which hence exists for negative half cycles as well as for positive half cycles.

An automatic bias of this nature gives a characteristic curve which will be somewhere between curves *2* and *3* in Fig. *16B*; with *R* and *C* large in electrical size so as to give a long time constant, the dynamic characteristic curve will approach static curve *2* because we are approaching a fixed-bias condition, but with low electrical values for R and C, the dynamic characteristic will approach curve *3* because the bias will now vary almost instantaneously with input signal strength.

A typical dynamic characteristic curve for a single-tube limiter stage is shown in Fig. *17*. With this characteristic, the bias voltage developed across R and C will be proportional to the average signal strength over several r.f. cycles, and consequently the operating point might be at a, b,

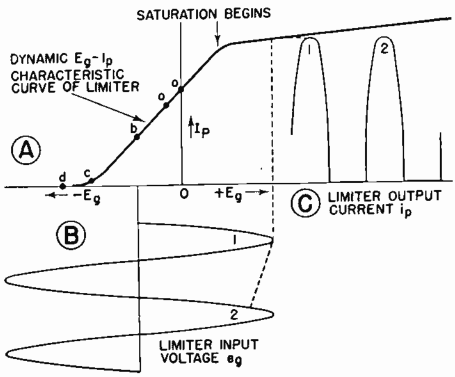

FIG. 17. These diagrams will help you to understand the action of the basic one-tube limiter circuit in Fig. *16*.

c, or even beyond cut-off at d, depending upon the r.f. signal strength. Thus, with a sine wave input voltage e_g which places the operating point at point b, the wave form of the resulting plate current i_p will be as shown at C in Fig. *17*. This plate current is far from being sinusoidal like the input voltage, but we will still secure a sinusoidal output voltage across plate resonant circuit L_3-C_3 in Fig. *16A* because this circuit is tuned to the 4.3-mc. i.f. value for f.m. It has a high Q factor, and therefore responds only to the desired fundamental frequency of the plate current pulses, rejecting the harmonics.

With the dynamic characteristic curve of Fig. *17* for a limiter stage, two things happen when the strength of the input signal increases: *1*. The increased negative bias makes negative half cycles swing beyond cut-off for a longer period of time during each cycle, thereby reducing the operating angle during which plate current does flow; *2*. The amplitude of the plate current pulses increases slightly, because an automatically produced bias can never completely counteract an increase in signal strength. The increased positive voltage on the grid produces a slight increase in the amplitude of the plate current pulses because the characteristic curve rises slightly in the saturation region, rather than being perfectly flat.

It is possible to design a limiter circuit so that for any reasonable increase in the r.f. input voltage to the limiter, the operating angle for plate current will decrease just enough to counteract the increase in the amplitude of the plate current pulses. The energy fed into plate resonant circuit L_3-C_3 in Fig. *16A* at the fundamental intermediate frequency for f.m. will then be constant, and the desired i.f. output voltage across this limiter resonant circuit will likewise be constant.

When this goal in limiter circuit design is realized, the over-all dynamic characteristic curve for the limiter will be like curve *1* in Fig. *18A*, in which the r.f. output voltage of the limiter is plotted against the r.f. input voltage to the limiter. With this characteristic, the i.f. output voltage remains essentially constant regardless of input voltage, for all input voltage values which reach saturation (swing beyond point s in Fig. *18A*).

If the design of the limiter circuit is such that the operating angle decreases faster than the plate current pulse amplitude increases, we have over-compensation and secure the over-all characteristic represented by curve *3* in Fig. *18A*. Likewise, if the amplitude of the plate current pulses increases faster than the operating angle decreases, we have under-compensation and secure the over-all characteristic represented by curve *2* in Fig. *18A*. The values employed for *R* and *C* in the limiter circuit of Fig. *16A* determine which over-all characteristic will be obtained, and hence these two parts in a limiter circuit are highly important.

Since the d.c. voltage produced across limiter grid resistor *R* is proportional to the strength of the f.m. signal at the limiter input, this d.c. voltage can be used for a.v.c. purposes during f.m. reception.

Now suppose that the r.f. system ahead of the limiter has the sharply peaked response characteristic shown in Fig. *18B*. The vertical scale gives peak amplitude values; thus, if a strong input signal gave a 20-volt output peak amplitude at the resting frequency, this peak amplitude at the limiter input would drop down to 5 volts during the maximum deviation of 65 kc. (from *b* to *a* to *c*). With the limiter characteristic of Fig. *18A*, all signal peaks above 5 volts would be cut down to 5 volts by the limiter, and the solid-line curve in Fig. *18C* would then represent the response characteristic of the r.f. system and limiter combined, for a strong f.m. input signal. Since this is flat over the desired

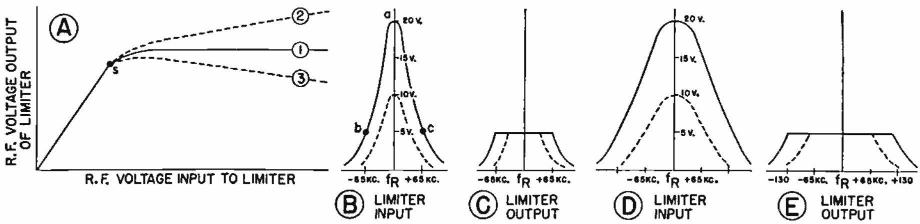

FIG. 18. These curves show how the limiter can correct the over-all response characteristic of the entire r.f. system (including the i.f. amplifier and the receiving antenna system) in an f.m. receiver.

A limiter must be *fast-acting* (must have a *short time constant*) if it is to block out sudden noise surges. This assumes that there is sufficient r.f. amplification in the f.m. receiver so that the weakest desired signal will swing the limiter grid beyond the point at which saturation begins.

To show how the limiter can flatten the response characteristic of the r.f. system, let us assume that the limiter stage under consideration has a flat over - all grid voltage - plate voltage characteristic curve like *1* in Fig. *18A*. Assume further that under this condition, all limiter input signals having peaks higher than 5 volts cause plate current saturation. (Positive grid swings will then go beyond point *s*, at which saturation begins.)

band width of 130 kc., it is obvious that the limiter has flattened the highly-peaked response of the r.f. system.

Now suppose the receiver is tuned to a weaker f.m. signal, which gives a resting-frequency peak of only 10 volts at the output of the r.f. system. The dash-dash response curve in Fig. *18B* would then give peak values for various deviations. When this weaker signal is fed into the limiter, the output response would be as shown by the dash-dash line in Fig. *18C*. The band width over which we have uniform response is now obviously insufficient for standard f.m. signals, and distortion will occur during loud portions of the program.

On the other hand, if the r.f. system has the broadly-peaked response characteristic shown in Fig. *18D*, a signal having a 20-volt peak would give a combined r.f.-limiter response corresponding to the solid line in Fig. *18E* after passage through the limiter. This response is ideal, being flat for a frequency swing of about 250 kc. If the input signal should now drop to a maximum peak value of 10 volts, the input and output response characteristics would be as shown by the dash-dash lines in Fig. *18D* and *18E;* even at this lower signal level, however, the combined r.f.-limiter response is still flat over a wide enough range to allow the entire frequency swing of 130 kc. to exist at the limiter output without changes in amplitude.

We thus arrive at the important conclusion that a broad over-all response for the r.f. and i.f. sections enables the limiter to handle weaker signals satisfactorily. Almost any sort of peak response is permissible if the r.f. and i.f. sections have sufficient gain, however, for *the limiter will then flatten the over-all response of the preceding sections over the entire range of deviation frequencies.*

Time Constant of Limiter. The time constant of the R-C circuit in the limiter is ordinarily made equal to the time of a few r.f. cycles, so the limiter will respond to general changes in the amplitude of the incoming signal without actually following individual r.f. cycles.

The importance of having a fast-acting limiter can be made clear by considering an f.m. signal which is varying in frequency from 65 kc. below to 65 kc. above its resting frequency (maximum deviation, corresponding to maximum loudness). With a receiver having a sharply resonant r.f. response like that in Fig. *18B*, and with a peak limiter input of 20 volts at the resting frequency, the amplitude of the signal fed into the limiter will vary from 5 volts (at points *b* and *c*) to 20 volts (at *a*).

With the 20-volt input, the limiter will probably be operating near plate current cut-off, but this cut-off bias would be far too great to give the desired constant output amplitude when the limiter input drops to 5 volts. In order to keep the limiter output amplitude constant over the entire deviation range of 130 kc., the C bias should automatically reduce itself as the limiter input signal amplitude drops.

Noise surges which enter an f.m. receiver are oftentimes strong but of extremely short duration. If these surges are to be blocked out, the limiter must be able to increase its own negative bias automatically for the duration of each surge. This action can occur only if a fast-acting limiter (with a short time constant for *R* and *C*) is used.

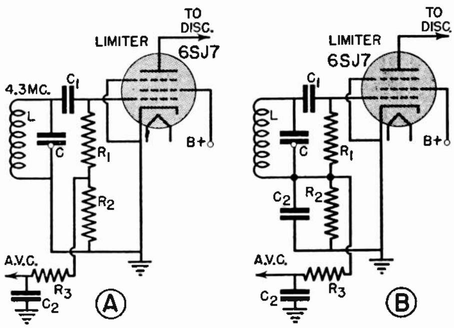

FIG. 19. Typical one-tube limiter circuits.

The C bias produced by the R-C grid network of the limiter stage can change fast enough to flatten the r.f. response and squelch noise only if its time constant is kept very short (within the time of a few r.f. cycles).

Fast-Acting Limiter Circuit. In Fig. *19A* is a practical limiter circuit employing a grid resistance $(R_1 + R_2)$ between the grid and cathode of the limiter, with condenser C_1 and the grid-cathode capacity of the tube acting with the grid resistance to provide the required time constant for fast limiter action. This is attained by using a low capacity value for C_1 and a low ohmic value for the grid resistance. A portion of the d.c. voltage developed across the grid resistance (the d.c. voltage across R_2) is used for a.v.c. purposes during f.m. reception. R_3 and C_2 form the conventional a.v.c. filter which keeps r.f. components out of the a.v.c.-controlled tubes.

Dual-Action Limiter Circuit. In the limiter circuit arrangement shown in Fig. *19B*, both C_1 and C_2 have low reactances at ultra-high frequencies. R_1 and R_2 in series form the grid return path. R_1 and C_1 together have a time constant equal to a few r.f. cycles, and hence provide a rapidly changing bias equivalent to the fast limiter action of the circuit of Fig. *19A*. R_2 and C_2 have a much longer time constant, and act to change the C bias voltage in accordance with the average strength of an incoming f.m. signal. In other words, R_2 and C_2 take care of the major changes in signal amplitude such as those occurring when tuning from a weak distant f.m. station to a strong local f.m. station, while R_1 and C_1 take care of changes in signal amplitude due to a peaked r.f. response characteristic or to noise interference. This circuit arrangement thus provides independent control over two of the important factors which affect the design of a limiter circuit.

Limiter with Tuning Indicator. A more complete single-tube limiter circuit is shown in Fig. *20*. This arrangement includes an electric eye for tuning purposes during both a.m. and f.m. reception. The output circuit of the i.f. amplifier is also shown, and is identical with that in Fig. *14*. The limiter input circuit is the same as that shown in Fig. *19A*.

The a.v.c. voltage developed across R_2 in Fig. *20* is fed to the tubes which are to be a.v.c.-controlled during f.m. reception through a.v.c. filter R_8-C_3 and switch S (in position *1* for f.m. reception), and is also applied to the control grid of the type 6U5 cathode ray tuning indicator tube.

For a.m. reception, the output of the i.f. transformer for a.m. is fed into the diode detector (a 6H6 tube with both plates tied together), and the a.f. voltage component across R_5 is fed to the a.f. amplifier through d.c.

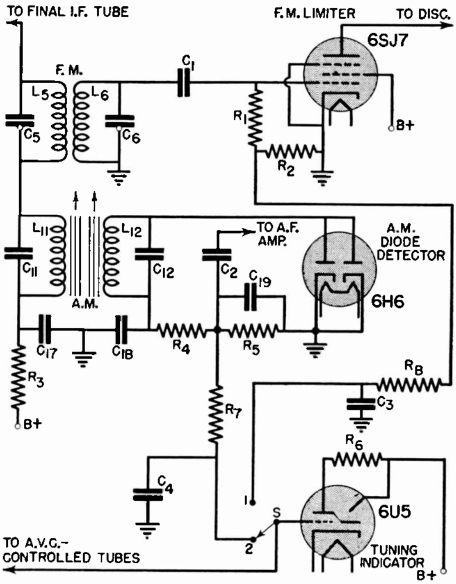

FIG. 20. One-tube limiter circuit with tuning indicator. I.F. amplifier connections to the conventional diode detector for a.m. reception are also shown.

blocking condenser C_2. The d.c. voltage across R_5 is fed to the a.v.c.-controlled tubes through a.v.c. filter R_7-C_4 and switch S (in position *2* for a.m. reception), and is also applied to the tuning indicator tube.

Cascade Limiter. Improved limiter operation both for weak and strong signals, along with considerably higher gain, can be secured with two limiter tubes connected as shown in Fig. *21*, in what is known as a *cascade limiter* circuit. The action of the first limiter tube is essentially like that of the limiter circuit in Fig. *19A*, with the grid resistor and condenser being chosen to give an even shorter time constant so this first limiter will effectively reduce impulse noise. Whatever amplitude variations exist in the output of the first limiter tube are removed by the second limiter tube, so that the f.m. signal which the limiter section feeds into the discriminator has essentially constant amplitude. Listening tests have shown that this cascade limiter reduces impulse noises far more than any single-tube limiter circuit.

One engineer recommends that the r.m.s. value of limiter output voltage be at least 20 volts for effective noise reduction. The minimum voltage gain for the entire r.f. system including the limiter should be at least 20,000,000 times to permit reception of weak desired f.m. signals without noise interference. To provide this amount of amplification, an r.f. amplifier stage ahead of the frequency converter is highly desirable.

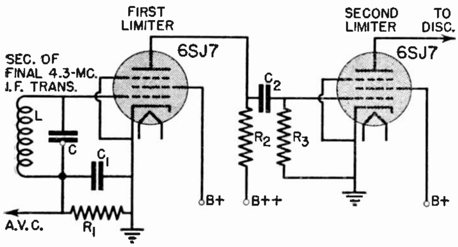

FIG. 21. Cascade limiter circuit employing two limiter tubes. The a.v.c. voltage is obtained from the first tube. The General Electric Model JFM-90 f.m. converter is one example of f.m. units employing this cascade limiter arrangement.

The F.M. Detector. The f.m. detector or discriminator circuit which is used in an f.m. receiver to convert f.m. signals into audio signals is much like the frequency discriminator circuit employed in the a.f.c. system of a conventional a.m. superheterodyne receiver. Technically speaking, the discriminator converts deviations in frequency from an assigned resting value into positive and negative d.c. voltages corresponding to the original audio signal.

Although the action of a.f.c. discriminator circuits has been covered elsewhere in the course in connection with a.m. receivers, the action will be reviewed briefly here in connection with the typical f.m. discriminator circuit given in Fig. *22*.

Discriminator transformer T_1 is of

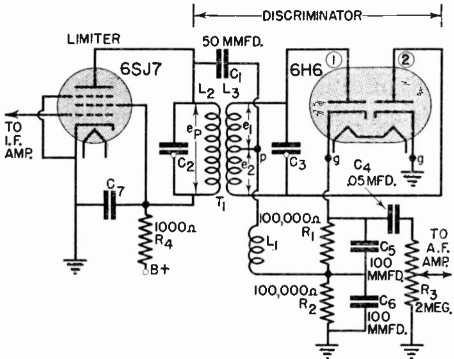

FIG. 22. Typical discriminator circuit for an f.m. receiver. Arrows indicate the directions of electron flow through discriminator load resistors R_1 and R_2.

special design, with its primary winding L_2 tuned to the 4.3-mc. i.f. value by C_2, and with a center-tapped secondary winding L_3 tuned to the same i.f. value by C_3. The limiter output current flowing through L_2 induces a corresponding f.m. voltage in L_3, and resonant step-up produces across the two sections of L_3 the voltages e_1 and e_2, which are always equal in magnitude and are 180° out of phase with each other when considered with respect to center-tap *p*.

Limiter output voltage e_P in series with e_1 is applied to diode section *1* of the 6H6 double-diode tube. (D.C. blocking condenser C_1 provides an r.f. path from the upper end of L_2 to *p*, while the chassis and r.f. by-pass condensers C_5, C_6 and C_7 complete the path for r.f. signals from the lower end of L_2 to the cathode of diode section *1*. Thus, e_P exists across choke coil

L_1, and acts in series with e_1 or e_2 on either diode.) Likewise, limiter output voltage e_P in series with e_2 is applied to diode section *2*.

The net voltage applied to each diode section is, therefore, the *vector sum* of the two individual voltages acting on that section. Each diode section rectifies its net applied r.f. voltage and produces a proportional d.c. output voltage across its load resistor.

The load resistor for diode section *1* is R_1, and the load resistor for diode section *2* is R_2. The chassis provides the connecting path between the lower end of R_2 and the cathode of diode section *2*.

Electrons flow in opposite directions through R_1 and R_2, as you can readily verify by tracing the diode circuits. This means that the combined voltage across both R_1 and R_2, which is the output voltage of the discriminator, will at each instant be the difference between the individual voltages. If the individual voltages are equal, the discriminator output voltage will be zero; if the voltages across R_1 and R_2 are different, the combined voltage will have the polarity of the larger of the two individual voltages, and will be equal in magnitude to their numerical *difference*.

Let us consider now the factors which make the output voltage of one diode higher than that of the other. First of all, we must choose some voltage or current for reference purposes. Since e_P is common to all circuits under study, we can use it as our reference voltage.

Phase relationship in this discriminator circuit must be considered for three different conditions: *1.* When the limiter output signal frequency is equal to the i.f. resting frequency to which the discriminator resonant circuits are tuned; *2.* When the limiter output frequency is *less than* the i.f. resting frequency; *3.* When the limiter output frequency is *higher than* the i.f. resting frequency. The vector diagrams for these three conditions are shown at *A*, *B* and *C* respectively in Fig. *23*, with primary voltage e_P serving as the reference vector in each case.

The r.f. voltage e_S which is induced in secondary winding L_3 is 180° out of phase with the primary r.f. voltage e_P, hence e_S is shown 180° out of phase with reference vector e_P in each of the vector diagrams in Fig. *23*.

When the limiter output signal is *exactly at* the i.f. resting value of 4.3 mc. to which the discriminator circuits are tuned (when no sound is being transmitted), secondary tuned circuit L_3-C_3 is at resonance, and secondary

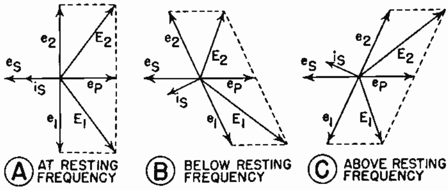

FIG. 23. These vector diagrams will help you to understand the action of the discriminator in an f.m. receiver.

current i_S flowing through L_3 will be in phase with e_S, as indicated in Fig. *23A*. The voltage produced across the entire secondary winding by this secondary current will therefore *lead* both i_S and e_S by 90°. The resulting secondary voltage (e_1+e_2) across L_3 is utilized only in connection with the center tap of L_3, however, so if we show e_1 leading i_S by 90°, we must show e_2 as lagging e_1 by 180°, just as in Fig. *23A*.

Adding e_P and e_2 vectorially gives E_2 as the resultant voltage acting upon diode section *2*. Likewise, adding e_P and e_1 vectorially gives E_1 as the resultant voltage acting upon diode section *1*. The vector diagram in Fig. *23A* shows that these two voltages are equal for the no-modulation condition, and hence the d.c. voltages developed across R_1 and R_2 by the two diode sections are equal in magnitude. The resultant voltage across both R_1 and R_2 is therefore zero, just as it should be, since no a.f. signal should be obtained when there is no a.f. modulation at the transmitter.

When the limiter output signal frequency is *lower* than the i.f. resting value to which resonant circuit L_3-C_3 is tuned, this circuit becomes *capacitive,* and i_S leads e_S, as shown in Fig. *23B*. Since voltages e_1 and e_2 must be 90° out of phase with i_S, we have the unequal resultant voltages E_2 and E_1, as in Fig. *23B*. With diode section *1* getting the higher r.f. voltage E_1, we secure a higher d.c. voltage across R_1 than across R_2, and the combined voltage across R_1 and R_2 is therefore *positive* with respect to ground. The more the limiter output frequency swings *below* the i.f. resting frequency, the greater will be this positive voltage applied to the a.f. amplifier input.

By a similar analysis, we obtain the vector diagram shown in Fig. *23C* for the condition wherein the limiter output frequency is *higher* than the i.f. resting frequency. The net voltage applied to the input of the a.f. amplifier by R_1 and R_2 combined is now *negative* with respect to ground.

The frequency discriminator circuit shown in Fig. *22* thus produces at its output a d.c. voltage which is at each instant proportional to the deviation in the incoming signal frequency from its resting value, and having a polarity determined by the direction in which this frequency deviation occurs. The discriminator thus converts an f.m. signal directly into the original audio signal voltage used for modulation purposes at the f.m. transmitter.

R.F. by-pass condensers C_5 and C_6 in Fig. *22* must have a low reactance at 4.3 mc., and yet must have a high reactance at audio frequencies so there will be no serious shunting effect upon the a.f. voltage developed across R_1 and R_2. This a.f. voltage is fed to volume control R_3 through d.c. blocking condenser C_4, which prevents the C bias voltage of the first a.f. amplifier tube from entering the discriminator circuit and prevents the d.c. discriminator output voltage from acting on the grid of the first a.f. tube.

S Curve for Discriminator Action. The solid-line curve in Fig. *24* shows the relationship between the incoming r.f. signal frequency of an f.m. receiver (with respect to the resting value) and the d.c. output voltage of the discriminator. Because of the similarity of this curve to the letter S, it is commonly known as an S curve.

This curve, representing the characteristics *of the f.m. receiver up to the input of the audio amplifier,* should be linear over the entire deviation range of the incoming f.m. signal, for otherwise amplitude distortion would be present in the a.f. output of the discriminator.

The linearity of the S curve in Fig. *24* depends upon two things, the design of the discriminator transformer, and the over-all response characteristic of all the stages ahead of the discriminator. The over-all response is determined chiefly by the dynamic characteristic of the limiter; the response of stages ahead of the limiter affects the limiter only when signals are too weak to cause saturation of the limiter for the entire deviation range.

In designing the discriminator transformer, the Q factor of each resonant circuit and the coupling between the two windings are particularly important; these factors must make the discriminator characteristic combine with the r.f.-limiter characteristic in such a way that the individual resultant voltages, E_1 and E_2, will at each instant be proportional to the frequency deviation. When this condition is attained, the combined discriminator output voltage across R_1 and R_2 will be proportional to the frequency deviation, thereby giving across these resistors the desired a.f. voltage without amplitude distortion.

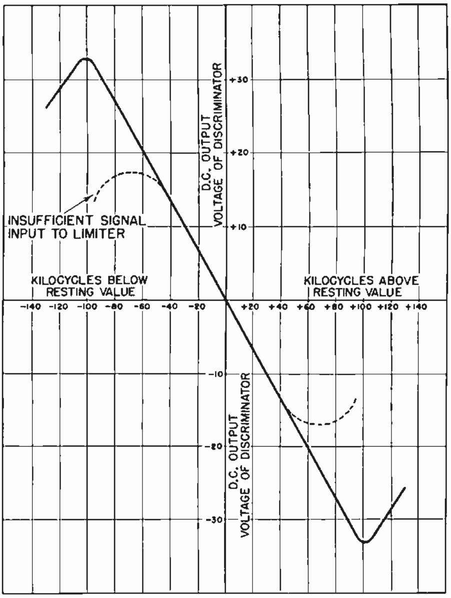

FIG. 24. S curves for an f.m. receiver, showing how the discriminator output voltage varies with frequency deviation. Curves like this are obtainable only if the over-all grid voltage-plate voltage characteristic of the limiter is flat beyond the point at which saturation begins (like curve *1* in Fig. *18A*). When this over-all limiter characteristic is not flat (is like *2* or *3* in Fig. *18A*), the angles which the curves make with the horizontal axis will be different (giving either lower or higher discriminator output voltages), and the curves will no longer be linear (resulting in distortion of the audio output signal). You will often find an S curve like this drawn from the lower left to the upper right. Reversal of connections to the discriminator diode plates gives this result; either connection is satisfactory, for the polarity of an a.f. signal cannot be detected by human ears.

It is desirable to have the S curve linear over a somewhat wider range than the maximum deviation, to compensate for inaccuracies in tuning, frequency drift in the local oscillator, or misalignment of the discriminator resonant circuits.

A falling off in the amplitude of the limiter output near the deviation limits, due to too weak a signal at the limiter input, will reduce the frequency range over which the S curve is linear. The dash-dash S curve in Fig. *24* illustrates this condition.

When the S curve for discriminator action has too short a linear region for weak signals, reproduction will still be satisfactory at medium and low program loudness levels, but *amplitude distortion will occur during loud sounds.* Thus, all sounds loud enough to cause a deviation of more than 40 kc. will swing the signal frequency beyond the linear region of the dash-dash curve in Fig. *24*. This is why it is so important that the limiter in an f.m. receiver deliver a constant-amplitude output signal over the entire deviation range. The goal of the f.m. receiver designer is to provide sufficient voltage gain ahead of the limiter so that the limiter can maintain constant output amplitude for the weakest desired incoming signal.

Alignment of Limiter and Discriminator Stages. During servicing of an f.m. receiver, the limiter and discriminator can only be aligned for best possible operation. Little can be done to alter the linearity of the discriminator, for this linearity is controlled chiefly by the limiter characteristics and the design and construction of the discriminator transformer.

Alignment Procedure. Connect a signal generator to the input of the final i.f. amplifier stage for f.m., set this s.g. to the i.f. resting frequency (usually 4.3 mc.), then open the grid return lead of the limiter circuit, insert a .01-mfd. condenser at this point, and connect across the condenser a 0-200-microampere d.c. meter.* (In circuit diagrams of f.m. receivers,

* With limiter circuits which also provide an a.v.c. voltage, a vacuum tube voltmeter connected to the a.v.c. source can be used in place of the microammeter. The adjustment would be made for maximum a.v.c. voltage, as this would then correspond to maximum grid current.

you will often find in the grid return lead of the limiter stage a condenser, about .01 mfd., shorted out by a lead. This condenser is inserted for measuring the grid current during alignment of the limiter; the service technician simply unsolders the shorting lead, then connects his microammeter across the condenser. This is illustrated in Fig. *16*, where C_4 would be the .01-mfd. condenser provided for measuring purposes. The microammeter would be connected to points a and b, after first opening the lead between these two points.)

With these preliminary connections made, turn on all apparatus, adjust the limiter input trimmers (C_1 and C_2 in Fig. *16*) for maximum grid current as indicated by the meter, adjust the signal generator output voltage so that the meter reading is at least 50 microamperes, then readjust C_1 and C_2 a final time for a maximum meter reading. This 50-microampere or larger current is necessary *so the limiter will provide normal loading on the preceding resonant circuit.*

Without changing the s.g. settings, remove the microammeter (or vacuum tube voltmeter) from the limiter input circuit and restore the connection between points a and b. Now connect a high-resistance voltmeter across one of the diode load resistors (across either R_1 or R_2 in Fig. *22*), and adjust the discriminator transformer primary trimmer (C_2 in Fig. *22*) for maximum output voltage.

Next, connect the high-resistance voltmeter across both R_1 and R_2 (a connection between the cathodes of the diode sections in Fig. *22* will do this), and adjust the discriminator transformer secondary trimmer (C_3 in Fig. *22*) for zero d.c. output voltage. This last adjustment is usually quite critical.

This completes the alignment of the limiter and discriminator stages. The remainder of the tuned circuits in an f.m. receiver are then aligned, usually for peak response, by adjusting each alignment trimmer in turn either for maximum a.v.c. voltage or for maximum grid current in the limiter.

The Audio System. The over-all fidelity of an f.m. receiver is determined to a great extent by its audio system. If the receiver is intended only for f.m. reception with a minimum of noise, and high fidelity is not required, an ordinary a.f. amplifier and loudspeaker will probably be employed. When high-fidelity f.m. reception is desired, however, the audio amplifier will be designed to handle a frequency range from about 30 cycles to about 15,000 cycles, and a specially designed reproducing system will be used to handle this extremely wide range of audio frequencies.

The sound-reproducing system in a high-fidelity f.m. receiver will usually employ at least two loudspeakers, one to handle low and intermediate frequencies, and the other to handle the higher frequencies. These loudspeakers will be coupled to the audio amplifier output stage through special networks, in order to secure proper division of output energy to the two loads. The entire sound-reproducing system will be housed in an acoustically corrected cabinet. The normal rating of the audio system will ordinarily be at least 15 watts, to secure sufficient power for proper reproduction of loud bass notes.

Somewhere in the audio system of a high-fidelity f.m. receiver, there will be an attenuator for high audio frequencies. In the transmission of f.m. signals, it is customary to accentuate or pre-emphasize the higher-frequency notes at the transmitter, so that these will over-ride noise. The high-frequency attenuator (usually a simple resistor-condenser circuit) compensates for this pre-emphasis at the transmitter and thus restores the normal balance between highs and lows.

In a combination f.m.-a.m. receiver, a single audio system will serve for both types of reception. A switch like that shown in Fig. *25* will ordinarily be provided to connect the audio amplifier input circuit to the detector stage being employed for a particular

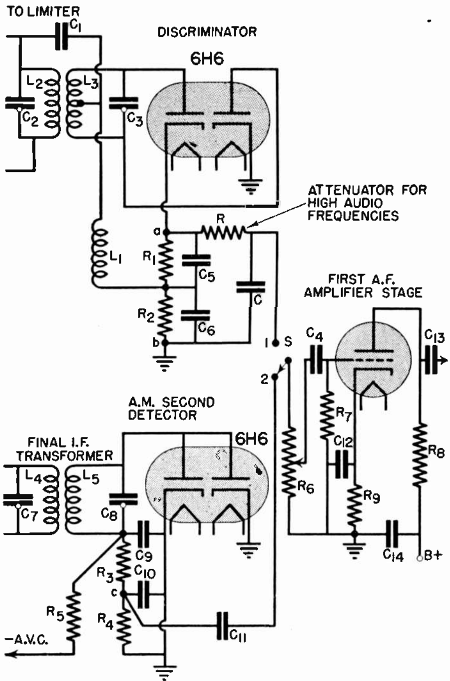

FIG. 25. This diagram shows how section *S* of the band-changing switch in an f.m.-a.m. receiver can be used to connect either the discriminator or the a.m. second detector to the input of the audio amplifier. Note that volume control R_6 is effective at both switch settings.

program. This switch will be ganged to the main band-changing switch in the r.f. system, so as to make detector switching automatic.

In the circuit of Fig. *25*, 50,000-ohm resistor *R* and .001-mfd. condenser *C* in the f.m. channel form the attenuator which counteracts f.m. transmitter pre-emphasis of high audio frequencies. All commercial f.m. transmitters will have the same amount of pre-emphasis, and this will be such that an attenuator having a time constant of 100 micro-seconds will restore normal receiver response for high audio notes. Normal attenuation of the a.f. amplifier at high audio frequencies, due to stray shunt capacities between circuit leads and ground, must be taken into account when designing the attenuator. Thus, the values used for *R* and *C* in Fig. *25* give a time constant of only 50 micro-seconds, but the a.f. amplifier has stray shunt capacities which make the total attenuation equivalent to that of a 100-micro-second attenuator.

If no switch were employed at the a.f. amplifier input (if both points *1* and *2* in Fig. *25* were connected to the a.f. amplifier input permanently), the diode detector not in use would place an additional load on the other diode during positive peaks, causing amplitude distortion of the audio signal. For example, if an f.m. signal were being received, point *a* in Fig. *25* would be made alternately positive and negative with respect to point *b* and the chassis by the audio signal. This in turn would make point *c* in the unused a.m. detector alternately positive and negative with respect to the chassis. Since point *c* is connected to the plates of the unused diode through resistor R_3, the plates would likewise be positive for half of each cycle, and would be conductive. The path through R_3 and the diode would then be a load on the f.m. detector during each positive a.f. peak, thus reducing the positive peaks. To prevent this condition, the detector switch is used.

Modern F.M. Transmitters

Although the method shown in Fig. *6* for producing frequency modulation of a carrier signal is simple and effective, it lacks frequency stability; an r.f. oscillator shunted by an inductance tube in this manner will drift in frequency with variations in temperature and with variations in the d.c. supply voltage.

In commercial f.m. broadcast stations, it is essential that the transmitter return to its assigned resting frequency whenever there is no modulation at the transmitter, and that the frequency deviation from this resting frequency be at all times proportional to the sound level at that instant.

Two different methods for securing frequency modulation with the required stability and linearity are widely used. One involves the use of an inductance tube and an automatic crystal monitoring control, while the other, suggested by Major Armstrong, starts with a crystal oscillator and utilizes a phase-shifting circuit. Let us analyze each method in turn.

Inductance Tube Transmitter. A block diagram of a commercial f.m. transmitter of the inductance tube type is given in Fig. *26*. In this system, the oscillator is of the conventional L-C type, with temperature-compensated parts in its tank circuit (no crystal). This r.f. oscillator is tuned to some fraction of the assigned resting frequency of the f.m. station, and frequency-multiplying stages are employed ahead of the final amplifier to bring the frequency up to the assigned resting value. Thus, in the f.m. transmitter chosen as an example for Fig. *26*, the r.f. oscillator is operated at one-ninth the assigned resting frequency, and its output is fed into two frequency tripler stages which bring the signal up to the correct frequency.

The inductance tube in the modulator stage is connected across the tank circuit of the L-C oscillator, and hence any change in the grid voltage of the inductance tube will change the frequency of the oscillator. Two voltages act upon the grid of this inductance tube; one is the audio signal voltage applied by the speech input amplifier, and the other is a d.c. voltage produced by the discriminator in the following manner.

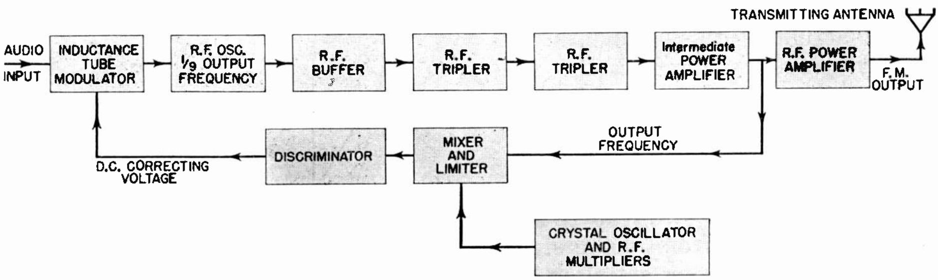

FIG. 26. Block diagram of an f.m. transmitter employing an inductance tube in the modulator stage. The main oscillator stage is of the ordinary L-C type, but its frequency is corrected automatically by the auxiliary crystal oscillator acting through an automatic frequency control system.

Let us assume that the L-C oscillator is at exactly one-ninth of the assigned resting value, and that there is no audio modulation. By means of weak capacitive coupling to some point in the r.f. amplifier, the signal at the assigned resting value is fed into a mixer stage, where it beats with a lower fixed r.f. signal produced by a temperature-controlled crystal oscillator acting through frequency-multiplying stages. The result is a signal at the difference frequency, corresponding to the i.f. signal in a superheterodyne receiver.

The mixer output signal is fed into a discriminator circuit which is tuned exactly to this difference frequency, and which therefore produces a d.c. voltage which is proportional to deviations from this difference frequency. With the L-C oscillator exactly correct, there is negligible deviation, and the d.c. output voltage which the discriminator applies to the grid of the inductance tube is therefore zero.

When the L-C oscillator drifts in frequency, the discriminator produces a d.c. voltage which is proportional to the magnitude of the frequency drift and has a polarity determined by the direction of the drift. This d.c. voltage changes the inductance of the inductance tube exactly enough to correct the frequency drift.

The action of this automatic frequency-correcting circuit is the same when audio modulation is present, for a condenser filter in the discriminator prevents audio signals from traveling from the discriminator to the inductance tube. Only the d.c. voltage actually due to drift from the assigned resting frequency can act upon the inductance tube.

Sometimes a portion of the audio output of the discriminator is utilized to provide inverse feed-back which compensates for distortion occurring in the transmitter. In this case, a special coupling circuit would be used to apply both the d.c. and a.f. components of the discriminator output to the inductance tube grid.

The frequency-tripling stage is simply an r.f. stage operated as a class C amplifier, with its plate resonant circuit tuned to the third harmonic of the input frequency.

Any tendency for the f.m. transmitter to drift from its assigned resting frequency thus produces a d.c. voltage which acts upon the grid of the inductance tube in such a manner as to correct the tendency toward drift. A zero-center type of voltmeter connected across the discriminator output indicates when the drift is getting dangerously great, thus warning the operator to retune the L-C oscillator manually before the discriminator loses control.

Armstrong Phase-Shift Transmitter. The basic principle underlying the Armstrong method is: When a signal having a definite frequency is flowing through a circuit, and another signal having this same frequency but 90° out of phase is suddenly sent into the circuit, there is an instantaneous phase shift in the original signal, with the result that the frequency of the combination either increases or decreases. We can illustrate this principle by

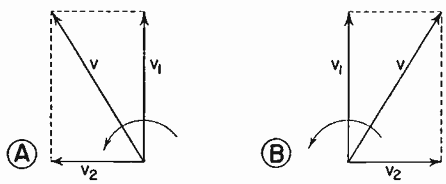

FIG. 27. Vector diagrams showing how a frequency-modulated signal can be produced by the Armstrong phase-shift method.

means of the vector diagrams in Fig. *27*.

Vector V_1 in Fig. *27A* represents the original signal, having a definite frequency and a constant amplitude. As this vector rotates in the conventional counter-clockwise direction at a rate corresponding to its frequency, let us suddenly introduce into the circuit a voltage V_2 which has the same *frequency* as voltage V_1 but leads V_1 by exactly 90°. The sudden introduction of this new voltage V_2 causes the net voltage V of the combination to shift in a counter-clockwise direction, corresponding to a momentary *increase* in frequency. If voltage V_2 is suddenly increased in amplitude after it is introduced into the circuit, resultant vector V speeds up again, producing another momentary increase in frequency.

On the other hand, if the suddenly-introduced V_2 lags V_1 by 90°, the resultant vector V will move clockwise, corresponding to a momentary decrease in frequency, as indicated by the vector diagram in Fig. *27B*. If vector V_2 is varying continually in both amplitude and polarity in accordance with a sine-wave audio signal, resultant voltage vector V will swing above and below its original frequency in a corresponding manner.

All this means that we can produce frequency modulation of a carrier signal by combining it with another signal *which has the same carrier frequency but is alternately 90° leading and 90° lagging the original signal in accordance with positive and negative swings of an audio signal, and varies in amplitude in accordance with variations in the amplitude of the audio signal.*

In order to make the deviation in frequency dependent only upon the *amplitude* and *polarity* of V_2, an attenuator is introduced into the audio amplifier of the transmitter so as to make the audio output voltage decrease gradually as the audio frequency increases. This insures that a 1-volt audio signal at 10,000 cycles will produce the same frequency deviation as a 1-volt audio signal at 1000 or 100 cycles.

As a rule, both V_1 and V_2 in an f.m. transmitter of this type will have relatively low frequency values, and frequency multipliers will be used to bring the f.m. signal up to the correct frequency for the transmitting antenna.

The basic Armstrong circuit for securing frequency modulation by means of this phase shift method is given in Fig. *28*. Vacuum tube VT_1 in a crystal oscillator circuit produces the initial low r.f. carrier value (200 kc. would be a typical value) with negligible frequency drift. The output of this crystal oscillator is fed into r.f. amplifier tube VT_4 and also into the balanced r.f. stage including tubes VT_2 and VT_3.

Note that the grids of this balanced stage are fed *in phase,* while the output of this stage goes to an untuned r.f. transformer having a center-tapped primary L_2-L_3. With in-phase plate currents flowing in opposite directions through the primary to the center tap, and with the tubes balanced so that the currents in the two

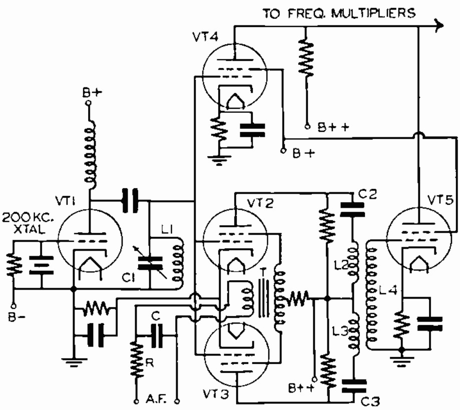

FIG. 28. Basic circuit used in the Armstrong phase-shift type of f.m. transmitter.

sections of the primary are normally equal in magnitude, the resultant flux linked with secondary winding L_4 is zero, and no voltage is induced in this winding for transfer to the frequency multipliers through amplifier stage VT_5.

The values of the parts in the plate circuits of the two balanced amplifier tubes are such that the r.f. current in each half of the primary lags the a.c. grid voltage by approximately 90°; in other words, the plate loads for VT_2 and VT_3 are essentially pure inductances.

The operation of this circuit depends upon the basic fact that when the a.c. resistance of a tube is varied, its a.c. plate current will vary correspondingly. We can change the a.c. plate resistance of a tube by varying the screen grid voltage.

In the circuit of Fig. *28*, the screen grid voltages for both VT_2 and VT_3 in the balanced amplifier stage are applied through the secondary winding of audio transformer T. With this arrangement, an a.f. voltage applied to the primary winding will make the screen grid voltage on one tube increase, and make the screen grid voltage on the other tube decrease. This causes an unbalance in the r.f. plate currents flowing through L_2 and L_3, and consequently we secure a resultant flux which links with L_4.

The resultant current flowing through both L_2 and L_3 will either lag or lead the a.c. grid voltage by 90°, depending upon which coil current is greatest. This means that the r.f. voltage induced in secondary winding L_4 will either lead or lag the a.c. grid voltage by 90°, depending upon whether the a.f. input voltage is swinging positive or negative, and the amplitude of this r.f. voltage in L_4 will vary in accordance with the amplitude of the a.f. input signal. The voltage across L_4 thus corresponds to vector V_2 in the diagrams of Fig. *27*.

Amplifier stage VT_5 merely provides a means for securing the proper relationship between the amplitudes of r.f. voltages V_1 and V_2. These two voltages, from tubes VT_4 and VT_5, are fed in parallel into the frequency multiplier system. They combine to give the desired frequency-modulated signal, as was explained in connection with the vector diagrams in Fig. *27*.

TEST QUESTIONS

Be sure to number your Answer Sheet 34FR-1.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. To secure a high signal-to-noise ratio with minimum inter-station interference at receivers, should the maximum frequency deviation in an f.m. system be *high* or *low?*

2. In what two ways can an interfering signal affect a desired f.m. signal?

3. What is the purpose of the discriminator in an f.m. receiver?

4. What section in an f.m. receiver produces the a.v.c. voltage?

5. What section in an f.m. receiver removes amplitude variations from the f.m. signal?

6. What characteristic should a limiter have in order to block out sudden noise surges?

7. Why is it permissible to have a peaked over-all response for the r.f. and i.f. sections in a properly designed f.m. receiver?

8. Describe the type of distortion which occurs when the S curve for discriminator action has too short a linear region for weak signals.

9. Why is it essential that grid current be drawn by the limiter tube during alignment of the resonant circuit ahead of the limiter?

10. Why is an attenuator for high audio frequencies used in the audio system of an f.m. receiver?

AUTOMATIC TUNING CONTROL SYSTEMS

35FR-1

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Automatic Tuning Control Systems

Introduction

AUTOMATIC tuning, which permits tuning in a desired station accurately and more or less instantly simply by pressing a lever or button, is rapidly reaching the point where it is being considered essential in a receiver. The average listener soon learns that he can obtain practically all desired programs from a few nearby broadcasting stations, with a clarity and freedom from interference which cannot be obtained in the case of distant or foreign stations. This listener then wants to be able to change quickly from one station to another without having to bother with accurate tuning, so he can choose the most interesting program. In making these things possible, automatic tuning has fulfilled a real need among radio listeners.

Automatic Tuning Systems

Although manufacturers are using many different schemes for providing automatic tuning, we can divide these into three groups according to the operating principle employed, as follows:

1. *Mechanical Automatic Tuning Systems.* By pressing a button or rotating a telephone-type dial, the listener himself provides the force required to rotate the gang tuning condenser to the setting for a desired station. This is a purely mechanical action, with no electrical switching whatsoever; tuning is essentially instantaneous.

2. *Electrical Automatic Tuning Systems.* Pressing a button switches an entirely new set of condensers, pre-adjusted to a particular station, into the tuning circuit of the receiver in place of the gang tuning condenser. The action here is entirely electrical, hence tuning is instantaneous.

3. *Electro-Mechanical Automatic Tuning Systems.* Pressing a button closes the circuit to a small electric motor, which then rotates the gang tuning condenser to a desired station. Electrical switching here causes a mechanical force to be applied to the gang tuning condenser. A certain amount of time is required, once a button is pressed, for the motor to complete the tuning process.

In all three systems, the initial adjustments which insure accurate automatic tuning to desired stations must be made by the radio dealer at the time of the installation. Printed tabs having the call letters of the desired stations are attached to the push-buttons themselves or to the escutcheon surrounding the buttons, to identify the station selected by each button.

Problems of Automatic Tuning

Proper design and installation of an automatic tuning device does not insure accurate automatic tuning indefinitely; many other factors must be considered in the tuning device itself and in the circuits which are controlled.

Mechanical Vibration. All three automatic tuning systems are subject to vibrations and jars, especially at the time the buttons are pressed, which may alter the initial adjustments. The inaccuracies of tuning introduced by vibration may not be noticeable when local stations are tuned in on a receiver having a reasonably broad response, but when automatic tuning is employed on a highly selective receiver for the reception of semi-local or distant stations we really have a serious problem. Automatic frequency control (A.F.C.) is an effective solution, though somewhat expensive; improvements in the mechanical design of the automatic tuning system can greatly reduce undesirable effects of vibration, making tuning sufficiently accurate without A.F.C. provided that automatic tuning is restricted to local stations.

Frequency Drift. Changes in the output frequency of the local oscillator due to changes in temperature present another serious automatic tuning system problem, particularly when A.F.C. is not used. Oscillator frequency drift is most noticeable in the high-frequency bands of an all-wave receiver, but there can be appreciable frequency drift in the broadcast band as well. In a conventional manually tuned receiver, this frequency drift can be compensated for by shifting the tuning dial setting slightly after the receiver has warmed up and reached a constant internal temperature, but with automatic tuning systems the listener has no means of correcting for this drift.

Investigation has revealed that the chief cause of oscillator frequency drift in an ordinary superheterodyne receiver is *the fact that a rise in temperature will increase the dielectric constants of insulating materials which are present in the oscillator circuit.** Some dielectric materials are affected more than others by changes in temperature; when materials such as molded plastics, bakelite, low-grade rubber insulation and waxed paper insulation are present in the oscillator circuit, the result is an increase in the effective capacity in the oscillator tuning circuit as temperature goes up, producing a reduction in the oscillator output frequency and consequently lowering the I.F. signal frequency.

By using only dielectric materials like mica and ceramics (which are little affected by temperature) for oscillator circuit parts, engineers have succeeded in reducing frequency drift. In addition, special temperature-compensating condensers are often shunted across the regular condensers in the oscillator tuning circuit. These condensers are each made up of a fixed metal plate and a movable plate to which is connected a bi-metallic strip. Air forms the dielectric between the two plates of this compensating condenser. Increases in temperature cause corresponding changes in the shape of the bi-metallic strip, and these in turn cause the movable plate to move farther away from the fixed plate, reducing the capacity. The amount and nature of compensation required to offset frequency drift due to temperature changes varies with each receiver design.

Muting. In some mechanical and electro-mechanical tuning systems the receiver is tuned quite slowly through many stations before the desired one is reached, creating an annoying situation if the receiver is not silenced in some way during the actual tuning process. It is for this reason that the audio system is often silenced or muted during the time the tuning mechanism is being rotated.

Eliminating A.F.C. While Tuning. An A.F.C. circuit tends to hold on to stations while passing through them, so it is perfectly possible for a receiver to "hang on" to a station adjacent to that corresponding to a particular push button. For this reason a switch is built into the automatic tuning mechanism to disconnect the A.F.C. system temporarily while the station is being tuned in.

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* As you will recall from earlier lessons, the dielectric constant of a material is equal to the capacity of a condenser with that material between its plates divided by the capacity of the same condenser when only air is between the plates. The higher the dielectric constant of the material used in a condenser, the higher will be its capacity.

Mechanical Automatic Tuning Systems

Mechanical automatic tuning systems may be divided into two general groups according to the manner in which they are operated by the listener:

1. *Rotary or telephone dial types,* in which the listener himself provides the rotary motion which turns the tuning mechanism to the correct setting for a desired station. Automatic stops prevent him from moving beyond the correct setting.

2. *Direct push types,* in which the listener applies a direct push or force to a button or lever. Either a gear, cam or lever arrangement is used to convert this force into the rotary motion required to turn the tuning condenser to the correct setting for a desired station.

Telephone Dial Type. The basic principles involved in a telephone dial type of mechanical automatic tuning system are illustrated in Fig. *1.* An analysis of the problems involved in this purely imaginary system will make it easier for you to understand the more complicated systems actually used.

In Fig. *1A* the rotor and stator of a conventional tuning condenser are shown in the minimum-capacity or highest-frequency position. As the rotor meshes more and more with the stator plates, the capacity increases and the receiver tunes to a lower frequency. A circular metal disc, on the rear side of which are several metal pins or pegs, is attached to the shaft of this tuning condenser. Suppose that a 1300 kc. station can be tuned in by rotating the rotor clockwise through the angle marked θ_1; if the pin on this circular metal disc makes contact with a stop stud the instant this tuning condenser setting is reached, we can readily see that this 1300 kc. station will be tuned in automatically.

Now suppose that turning the tuning condenser rotor through an angle θ_2 tunes in a 1100 kc. signal. A pin placed at the position marked *1100* on this circular disc will automatically stop the rotor at the correct position for this station. As many additional pins as are desired can be placed upon the circular metal disc, one for each station.

At once we see a mechanical difficulty. The pin for the 1300 kc. station will prevent the rotor from turning to the positions required for lower-frequency signals. Suppose, however, that the pin is made in the manner shown in Fig. *1B*, with a spring which normally holds the pin outward so it can pass over the stop stud. Pressing in the button and rotating the entire mechanism clockwise causes this pin to strike the stop stud, stopping the rotor at exactly the correct position for a desired station.

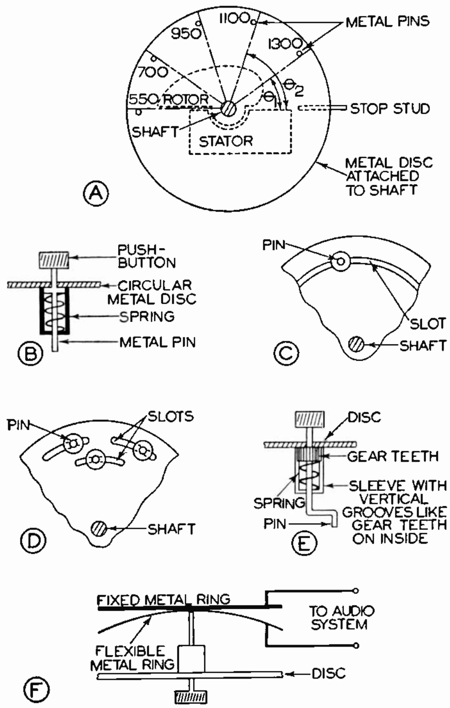


FIG. 1. Basic principles of the telephone-dial type mechanical automatic tuning system.

Still another mechanical difficulty arises. With the construction shown in Fig. *1A*, the positions of the pins cannot be changed and consequently the choice of stations is limited to those selected at the time of construction. We could eliminate this objection by mounting the pins in a circular slot like that shown in Fig. *1C*, so they could be moved to the correct position for a desired station. This arrangement prevents selecting adjacent stations, however (each push-button has a certain minimum thickness), but we could overcome this difficulty with a staggered arrangement of slots, as illustrated in Fig. *1D*.

Obviously, a staggered slot arrangement would not give a pleasing arrangement of push-buttons on the receiver dial. A symmetrical arrangement can be secured, however, by utilizing the construction shown in Fig. *1E*; here the position of the button is fixed on the metal disc, and the pin is made in the form of a crank arm which can be rotated to any desired position when the button assembly with its gear teeth is pulled out of the correspondingly grooved sleeve. In this way the effective end portion of the pin can be set at any position within the swing area of this crank arm, eliminating entirely the need for slots in the circular metal disc.

To silence or mute the receiver when a button is pressed and the mechanism rotated, the pin could well be made to depress a flexible metal ring as it moves, causing this ring to contact a fixed metal ring behind and thus short the input of an audio amplifier stage, as illustrated in Fig. *1F*. Releasing of the push-button after the station setting has been reached would open the audio circuit muting switch.

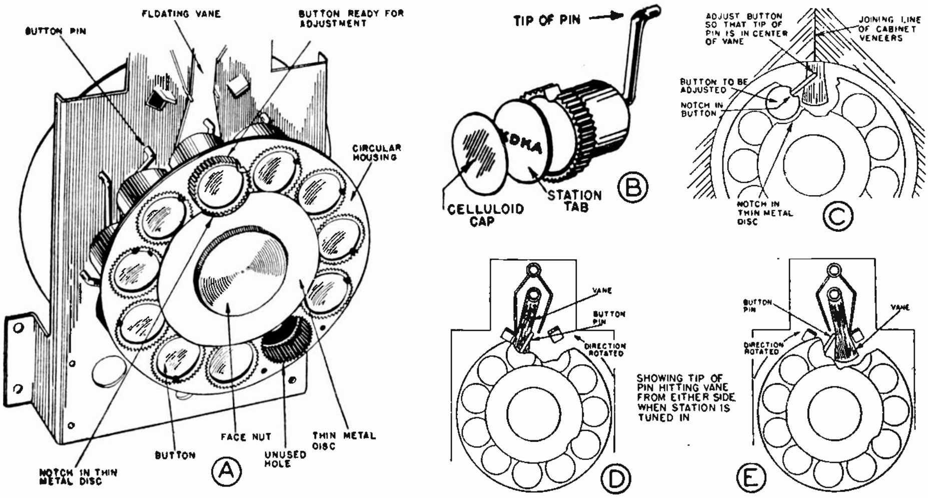
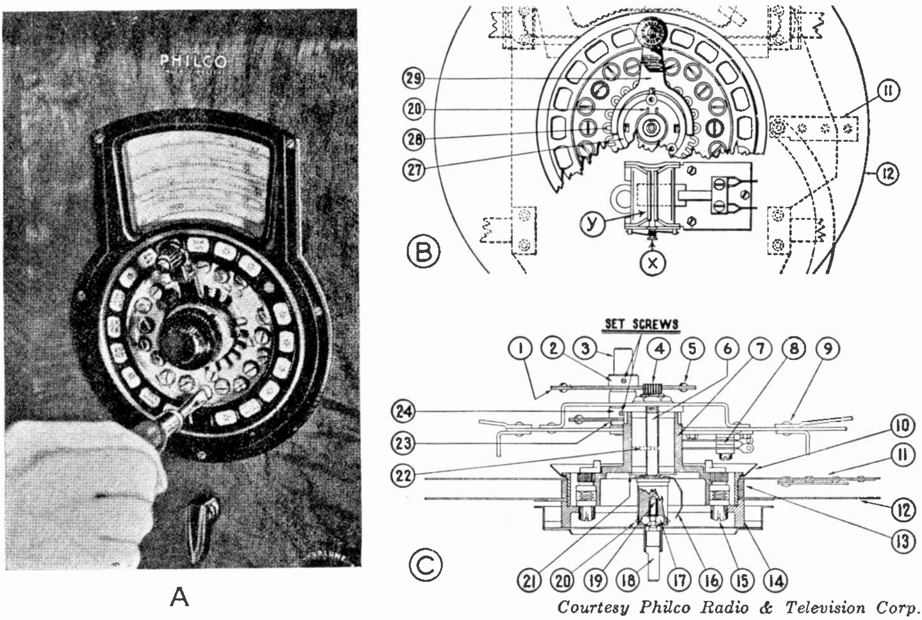


FIG. 2. Constructional details of the Emerson automatic dial mechanism as used in models AT-170, AT-181 and other Emerson receivers. When a station is tuned in, the button selected for that station will be near the top of the dial. One of the eleven holes shown at *A* is not used, and is covered by a blank space on the bakelite cover plate. When operating this dial mechanism, the direction in which the dial is rotated must be such that the blank space does not have to pass across the top of the dial, for the rotor plates are then either completely meshed or completely unmeshed, and cannot be rotated farther. Since this dial rotates through 360°, and ordinary tuning condensers rotate only through 180°, it is obvious that a gear drive is used between the dial shaft and the condenser shaft.

Emerson Automatic Dial. A mechanical automatic tuning system of the telephone dial type is used on a number of Emerson receivers. The operating principle is essentially the same as that illustrated in Fig. *1E*.

Constructional details of this Emerson automatic dial mechanism are shown in Fig. *2A*. A number of push-buttons, each mounted on a pin which is shaped like a crank arm (see Fig. *2B*), are arranged symmetrically on the circular dial. A station call letter tab, protected by a transparent celluloid cap, fits into a circular recess in the top of each button. The genious pivoted or floating vane serves to stop the tuning condenser assembly at exactly the same point regardless of the direction in which the dial mechanism is rotated. A spring normally holds the vane in the middle position shown in Fig. *2C*, and serves also to absorb the shock when the button pin is suddenly forced against the vane. Fixed stops, shown on each side of the vane in Figs. *2D* and *2E*, prevent the vane from swing-



Courtesy Philco Radio & Television Corp.

FIG. 3. Three views of an automatic tuning system used on a number of Philco receivers which also have A.F.C. The numbered parts on these diagrams are all identified in the Philco service bulletin on automatic tuning; the important parts are also identified in this lesson.

sides of each button are grooved in much the same manner as a gear, as also are the holes in which the buttons slide; this procedure prevents a button from turning in its hole yet allows it to be moved in or out.

To operate this Emerson automatic tuning dial, the button corresponding to the desired station is pressed and the entire dial then rotated until the pin hits a stop which prevents further rotation; this tunes in the desired station correctly. In this unit an ingenious

ing beyond a definitely limited angle.

Since this particular mechanism is used chiefly on inexpensive receivers which do not employ A.F.C., no provisions are made for blocking the audio system or shorting the A.F.C. system during the tuning process.

Philco Automatic Tuning Dial. The general appearance of the Philco telephone type automatic tuning dial with cover plate removed is shown in Fig. *3A*. In using this unit, the lever arm is swung to the position corresponding to the call letters of the desired station, the knob on the end of the lever is pushed in (engaging the lever with the tuning dial) and the entire mechanism is rotated in either a clockwise or counter-clockwise direction (only one direction will be correct) until a stop is reached. A click will be heard an instant before the knob reaches its final position, signifying that a spring-operated

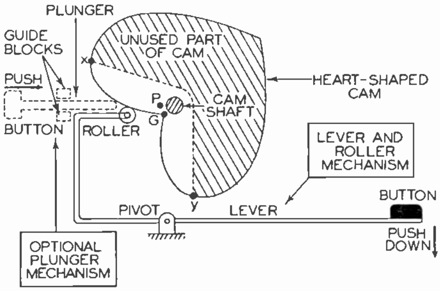


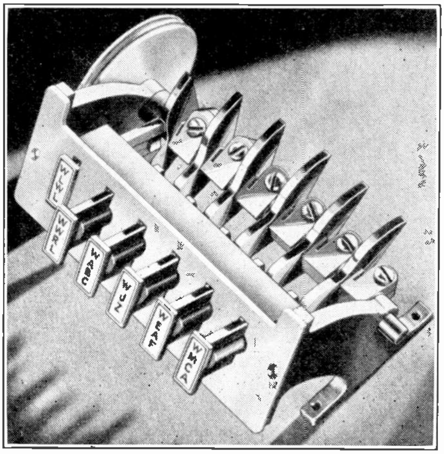
FIG. 4A. Operating principles of direct push types of mechanical automatic tuning systems employing a cam with either a lever and roller or a plunger. Pressure on the button in the direction indicated by the heavy arrow serves to rotate the gang tuning condenser (geared to the cam shaft) to the correct setting for the station assigned to that button.

switch has temporarily shorted the A.F.C. system in order to allow the desired station to "take hold."

Constructional details of this mechanism can be seen by studying the front-view diagram of Fig. *3B* and the cross-section view in Fig. *3C*. Pushing in the knob at the upper or outer end of the lever *29* does three things: *1*, it causes a metal pin on this lever to set itself in one of the holes marked *28* (Fig. *3B*); *2*, it depresses the key corresponding to the desired station (one of these keys is shown as item *15* in Fig. *3C*); *3*, it causes insulated switch blade *16* to make contact with shaft bushing *19*, thus shorting the audio system during the tuning process.

With the lever button depressed, the entire dial mechanism is rotated until the depressed key engages with the stop assembly (*x* in Fig. *3B*). Note the long slit which locks the key pin. On this assembly, item *y* is a pivoted flapper; movement of the pin over this closes switch contacts *8* in Fig. *3C*, shorting the A.F.C. system temporarily. When the pin falls into the recess between the two flappers, this switch opens, and the A.F.C. system then makes the final correction in tuning. Releasing the pressure on the knob and lever opens the audio shorting switch, making the program audible.

In setting up this Philco automatic dial tuning system, a station is first



Courtesy A. W. Franklin Mfg. Corp.

FIG. 4B. Franklin direct push type automatic tuning unit, an example of the mechanism shown in dotted lines at the left in Fig. *4A*. Note that all cams are on the same cam shaft, with a separate locking screw holding each cam in its correct position for a particular station. The cams used here have the same shape as that shown in Fig. *4A*, except that the unused part of each cam (the shaded portion in Fig. *4A*) is cut away.

tuned in the conventional manner, with the A.F.C. or magnetic tuning control in its "out" position. The key (item *15*) at the bottom of the dial is then adjusted by inserting a screw driver in its slot, pressing the key in slightly so it is free to rotate, then turning the key until a click is heard. The receiver is now tuned for maximum output by turning the key back and forth slightly. This procedure is repeated for each other station selected.

Direct Push Types of Mechanical Automatic Tuning Systems. A number of different mechanisms are being used to convert an ordinary direct push on a button into rotation of a tuning condenser to the correct setting for a desired station; let us look over a few of them.

First of all, keep in mind that a gang tuning condenser must be rotated through an angle of 180° (one-half of a complete revolution) to cover an entire tuning band. Because of the mechanical difficulties involved in converting a direct push into a full 180° of rotation, it is customary to use an auxiliary shaft which can be rotated through a maximum angle of 90° or less, with the gears between this shaft and the tuning condenser shaft to step up this rotation to the required amount.

Heart-Shaped Cam with Lever and Roller. In receivers employing this

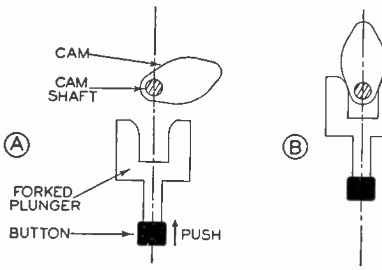


FIG. 5. Egg-shaped cam and plunger mechanism used in the mechanical automatic tuning systems of some Philco receivers.

particular tuning unit, there will be one complete set of parts like those in Fig. *4A* for each station which is to be tuned automatically. A downward pressure on the station-selecting button is applied to the heart-shaped cam through a roller at the other end of the lever arm, forcing the cam to rotate to a position which brings the roller to point *G*, closest to the center of the shaft. For example, with the cam in the position shown, pressure on the button will cause the cam and shaft to rotate clockwise. The cams for the different stations are mounted side by side on a cam shaft which is geared to the tuning condenser shaft,

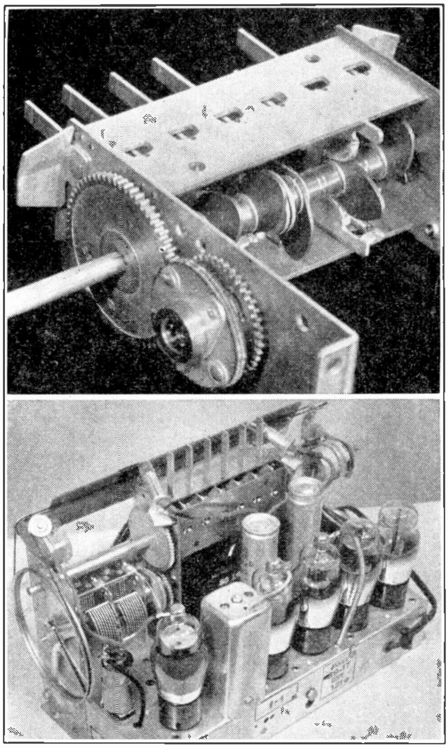


FIG. 6A (above). Mechanical automatic tuning unit used in a number of Philco receivers. One plunger is in its depressed position, and its forked end is holding the corresponding cam in the position shown in Fig. *5B*.

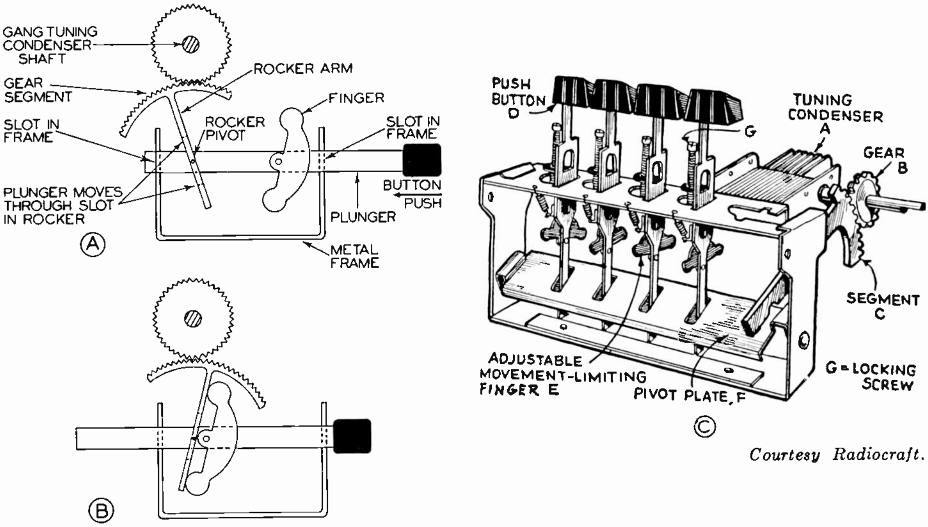
FIG. 6B (below). Chassis of Philco model 39-17 superheterodyne receiver, with automatic tuning mechanism visible at the right of the gang tuning condenser. Bakelite buttons are pushed over the ends of the six plungers after the chassis is mounted in its cabinet. Note the gear drive between the cam shaft and the tuning condenser shaft. The tuning control knob is placed on the cam shaft; the locking screw which holds all cams rigidly in position (by friction with spacing washers) fits into the center of this knob.

the cams being separated by spacing washers and held in position by friction. A mechanical locking device is provided for locking each cam rigidly in position once it is adjusted for a station.

Cam with Plunger. In some systems a straight plunger, with or without a roller, is used in place of the lever, as indicated by the dotted lines at the left in Fig. *4A*. The push-button tuner shown in Fig. *4B* is an example of this particular mechanism; a $5/8$-inch movement of the button here provides a 60° maximum rotation of the cam shaft, and this can be stepped up to 180° with a 3-to-1 gear ratio.

Egg-Shaped Cam with Forked Plunger. In another system of the direct push type, illustrated in Fig. *5A*, the cam is somewhat egg-shaped and the roller is replaced by a U-shaped or forked metal piece. Pressing the button makes the forked plunger take the position shown in Fig. *5B*, holding the cam in a definite position. Photographs of the Philco version of this arrangement appear in Figs. *6A* and *6B*. The gear drive between the cam shaft and the tuning condenser shaft is clearly visible in this photo.

Finger and Rocker. A finger and rocker mechanism which provides mechanical tuning in still another manner is illustrated in Figs. *7A* and *7B*, "a sketch of this unit" is shown in Fig. *7C*. For each station there is a plunger (flat metal strip) sliding freely through two slots in opposite sides of a metal frame. At one end of this plunger is the push-button; clamped to one face of the plunger is a metal "finger" which can be set at any desired angle to the plunger and held in position by a locking screw and clamp arrangement (omitted from Figs. *7A* and *7B* to simplify the diagrams, but shown in Fig. *7C*). Pressing in a button makes the rocker rotate to the same angle as the finger; on the rocker is a gear segment which meshes with a gear on



Courtesy Radiocraft.

FIG. 7. The diagrams at *A* and *B* show one of the finger and rocker units used in the mechanical automatic tuning systems of some Crosley receivers (including the Crosley Safety-Tune auto radio), while the sketch at *C* shows the complete tuning unit with a gear drive to a gang tuning condenser. Tightening the screw on the plunger locks the finger rigidly in position. To set up a button for a station, this screw is loosened so the finger can rotate, the button is pushed all the way in, the station is tuned in manually, and the screw is tightened to lock the finger at the correct angle. A spring returns the button to its normal position when pressure is released, leaving the tuning condenser at the correct setting for the desired station.

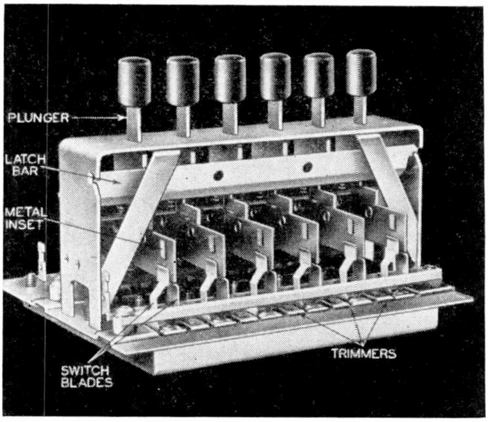
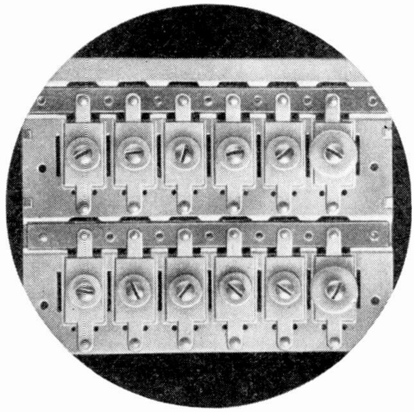


FIG. 8A. Sprague electrical automatic tuning unit with built-in trimmer condensers. The switch blades in the foreground are normally held apart by the strip of insulating material mounted on each plunger; when a button is pressed, the metal inset moves down between the blades, shorting them and closing the circuit to one set of trimmer condensers.



Courtesy Sprague Products Co.

FIG. 8B. Bottom view of the Sprague unit, showing the trimmer condensers and their adjusting screws. Each push-button controls one upper and one lower trimmer on this gang assembly. One terminal of each trimmer is grounded to the frame of the unit, and this frame is in turn grounded to the receiver chassis.

the tuning condenser shaft and thus provides the correct tuning condenser setting for the station assigned to that button.

In many of the receivers which incorporate a mechanical automatic tuning system, some form of compensating condenser is employed in the oscillator circuit to compensate for temperature changes which might otherwise alter the accuracy of the automatic tuning system. The tuning action is so rapid that audio silencing switches are usually omitted.

Electrical Automatic Tuning Systems

Instead of rotating the tuning condenser when a new station is desired, electric automatic tuning actually removes the variable condensers in the tuned circuits and replaces them with new condensers which were previously adjusted to the correct values for that particular desired station.

Push-button switching mechanisms like that shown in Fig. *8A* are used in electrical automatic tuning systems. When one of the buttons on this unit is pressed down, the button which formerly was down is released, removing that set of condensers, and an entirely new set of condensers is switched in. The entire process of switching is practically instantaneous. It is common practice to mount the set of pre-adjusted condensers right on the switching mechanism. In Fig.

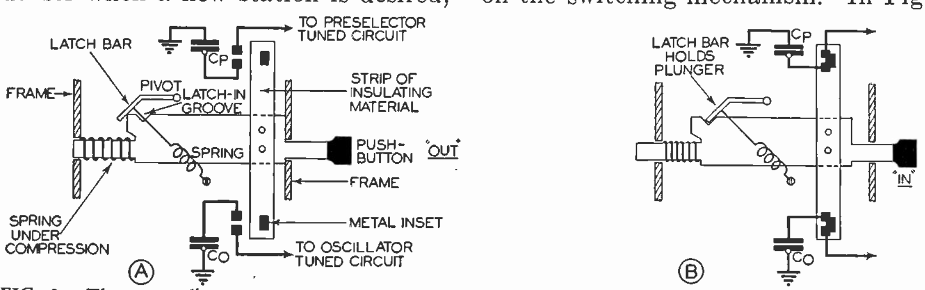


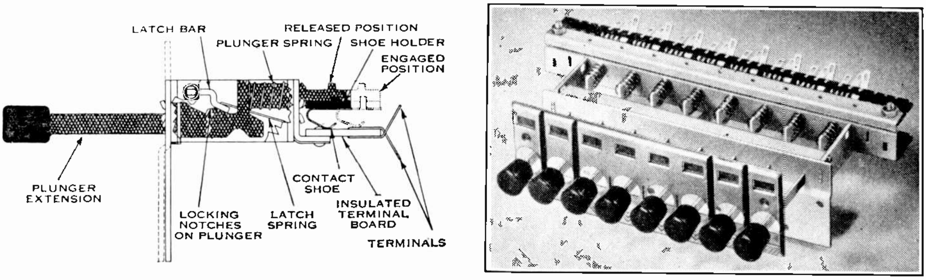
FIG. 9. These two diagrams show the construction of one of the push-button assemblies in the Sprague unit (Fig. *8*) and also show the relative positions of the parts when the button is in its normal or "out" position (*A*) and when the button is pushed "in" (*B*).

8B is a bottom view of the unit in Fig. *8A;* as you can see, there are two trimmer condensers, each adjusted by a screw, for each of the buttons on the unit.

Now let us see exactly what happens when one of the push-buttons in the unit shown in Fig. *8* is pressed. The diagram in Fig. *9A* gives a side view of the button assembly in its *out* and *open* position, while that in Fig. *9B* shows the same assembly with the button pushed in. First of all, observe that the button is on the end of a sheet metal plunger which slides freely in and out through slots in the frame of the switching unit. A spring under compression, acting between the plunger and the left-hand frame in Fig. *9A*, normally holds the plunger entirely out. When the button is pushed in, a pivoted flapper or latch bar falls into a groove in the plunger, as indicated in Fig. *9B*, preventing the plunger from returning to its normal *out* position.

A strip of insulating material, with a U-shaped metal piece set into each end, is attached to the plunger. Pressing in the button causes each metal piece to move between a pair of switch contacts, shorting the contacts and thus inserting a set of pre-adjusted trimmer condensers in the tuned circuit of the receiver. The fact that one terminal of each tuning condenser section in a receiver is grounded makes it possible to use this simple switching system.

A separate push-button and plunger assembly like that shown in Fig. *9A* is required for each station which is to be automatically tuned, but only one latch bar is needed for the complete switching mechanism. Pressing of any button lifts up the latch bar; this serves to release any other plunger which may have been previously pushed in and held by the latch bar. Since stations can be tuned in just as fast as the buttons can be pressed, there is no need for audio silencing switches or A.F.C. releasing switches.



Courtesy P. R. Mallory & Co., Inc.

FIG. 10. Photo and cross-section diagram of Mallory-Yaxley multiple push-button switch. Trimmer condensers are not built into this unit, but can be mounted either on the sides or at the rear of the unit; each trimmer must then be connected to one of the soldering lugs on the insulated terminal board. This unit is available with many different combinations of contacts and terminals, and can be used to switch in three trimmer condensers at a time in receivers having three tuned circuits.

Although many different forms of switching mechanisms are being used for condenser substitution purposes in electrical automatic tuning systems, all have essentially the same construction as that shown in Fig. *9.* There will be some form of plunger for each push-button, with switching contacts or blades mounted on the plunger but usually insulated from it. Likewise there will always be a latch bar to hold a plunger in when a button is pressed. A photograph of one other switching mechanism employing these principles, together with diagrams showing its construction, are given in Fig. *10*.

Typical Circuits. In Fig. *11* is shown the circuit for the preselector and oscillator sections of a typical superheterodyne receiver employing two tuned sections. Tube *VT* is a conventional pentagrid converter. Condenser C_P of the gang tuning condenser tunes the preselector coil L_2 to resonance, while C_O tunes the oscillator coil L_3. Only three connections need be made to this circuit to incorporate electrical automatic tuning; one lead from the push-button switching mechanism goes to point *x*, which is the stator terminal for preselector tuning condenser C_P. Another lead goes to point *y*, which is the stator terminal of the oscillator tuning condenser C_O, and the third lead is grounded to the tuning condenser frame or to the chassis.

Semi-Automatic Connection. Observe that the gang tuning condenser section in Fig. *11* is still present in the circuit after the push-button pushing mechanism is connected; this is known as a semi-automatic connection, because the gang tuning condenser must be turned to its minimum-capacity (highest frequency) setting before automatic tuning can be used. When this is done, pressing of any one of the four station buttons serves to tune in a station. For example, pressing button *1* places trimmer condenser C_{P1} across the preselector tuned circuit and places trimmer condenser C_{O1} across the oscillator tuned circuit.

Since an automatic tuning system provides for reception of only a limited number of stations, it is obvious that some means for restoring manual tuning must be incorporated in the receiver. (Manual tuning cannot be used when the automatic tuning system is connected, because of the fact that one set of trimmer condensers will always be in shunt with the gang tuning condenser section.) An extra button is often provided on a push-button tuning for the sole purpose of restoring manual tuning. This button is designated as *M* in Fig. *11*, and serves to open the two ungrounded leads to the push-button switching mechanism. Pressing button *M*, which is often marked

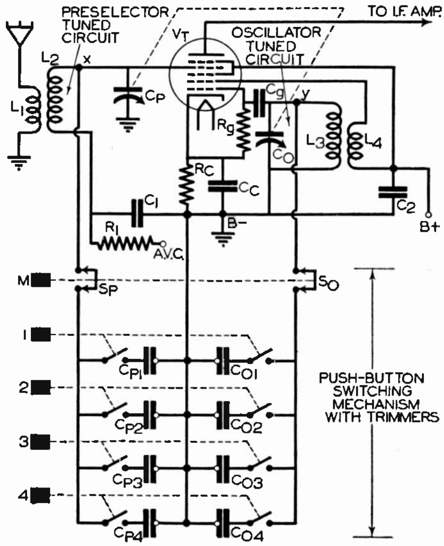


FIG. 11. This circuit shows a semi-automatic connection of an electrical automatic tuning unit to a superheterodyne receiver employing a pentagrid converter tube. Pressing button *M* restores manual tuning; pressing any other button inserts a set of preadjusted trimmer condensers (one trimmer for the oscillator tuning circuit and one for the preselector) in the tuning circuits of the receiver, after first breaking previous trimmer connections. Each set of trimmers is adjusted initially to exact resonance for one desired station.

MANUAL, opens switches S_P and S_O and at the same time releases any other button which may have been pressed in.

Full-Automatic Connection. Naturally, it is somewhat of a nuisance to turn the tuning dial to its highest frequency setting whenever automatic tuning is desired. This undesirable characteristic of the semi-automatic connection can be eliminated by modifying the switching mechanism so it will disconnect both sections of the gang tuning condenser from the receiver circuit whenever automatic tuning is used. Fig. *12A* illustrates one way in which this can be accomplished, and Fig. *12B* shows how the MANUAL button could provide the required double-pole, double-throw switch action.

Oftentimes it is undesirable to have long leads running from the receiver chassis to the push-button tuning mechanism (because of the inductance of these leads); for this reason

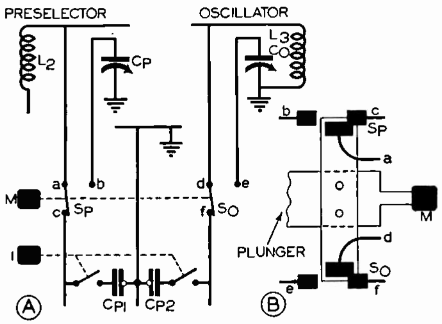


FIG. 12. At *A* is a simplified circuit showing a full-automatic connection of an electrical automatic tuning unit to a superheterodyne receiver having two tuned stages. Pressing button *M* restores the gang tuning condenser connections and breaks the two connections to the tuning unit; pressing any other button releases *M*, disconnecting the gang tuning condenser sections, and inserts a set of trimmers in the tuned circuits. The sketch at *B* shows how this switching could be accomplished with a plunger like that in Fig. 9.

the manual-tuning switch is sometimes incorporated in the band-changing switch. In this case one setting of the switch might be labeled BROADCAST MANUAL and another setting labeled BROADCAST AUTOMATIC. In one receiver the change-over from manual to automatic operation is accomplished by pushing the wave band switch knob in or out; this particular switch also operates dial lights which illuminate the words *automatic* or *manual* to indicate which particular tuning system is being used.

Tuning by Coil Substitution. Just as with mechanical automatic tuning systems, the oscillator tuned circuit can be the cause of frequency drift in an electrical automatic tuning system. To secure better frequency stability, some manufacturers are using a push-button switching system to substitute adjustable coils instead of trimmer condensers in the oscillator tuned circuit. Special coils employing pulverized iron cores which can be moved by means of an adjusting screw to change the inductance of the coil are used for this purpose. A fixed condenser, usually of the temperature-compensating type, provides the necessary capacity for the oscillator circuit. Because of the higher cost of variable-permeability iron core coils, they are usually used only in the oscillator circuit. A slight change in trimmer condenser capacity will have *far more de-tuning effect in the oscillator tuned circuit* than in a preselector tuned circuit.

Initial Adjustments. It is neither advisable nor necessary to make each adjustable part in an electrical automatic tuning system cover the entire 540 to 1500 kc. broadcast band. A more economical and stable construction is secured by limiting the tuning range of each adjustable coil or trimmer condenser to a definite section of the broadcast band; for example, one set of adjustable parts may be designed to tune from 540 to 900 kc., another set may cover the range from 700 to 1300 kc., and the third and final set might cover the range from 1000 to 1500 kc. Notice that there is enough overlapping between these three groups so that a station near the limit of one group may also be tuned in by another group.

Receivers employing electrical automatic tuning are usually adjusted by the servicemen as a part of the installation job, rather than by the listener. First of all, it is wise to prepare a list of the stations which have been selected by the listener for automatic reception. Assign one push-button to each of these stations, making sure that each button is in the proper frequency group, as specified in the instruction manual supplied with the set. The station call letter tabs, also supplied by the manufacturer, can now be affixed to the buttons or the escutcheon. The receiver should be turned on during this preliminary work, so it can warm up for twenty to thirty minutes and reach its stable operating temperature. If you suspect that the I.F. amplifier may be out of alignment, be sure to check this and realign if necessary before making any preselector and oscillator adjustments.

To set up a button for a station, tune in the station manually and note the nature of its program at that time. Now push in the button assigned to that station (if a semi-automatic connection is used, be sure to turn the tuning condenser to its minimum-capacity position before adjusting any trimmer condensers); locate the oscillator trimmer condenser or variable inductance controlled by that button, and adjust until the desired station is heard with maximum audio output. For best results do not depend upon your ears, but use an output indicator or the tuning indicator in the receiver (if available). With this done, locate the preselector trimmer condenser which is controlled by this button and adjust for maximum output in the same manner; you will note that this adjustment is quite broad, whereas the setting of the oscillator trimmer was quite critical. Repeat this procedure for each other push-button.

Radiotricians sometimes prefer to use a signal generator which is set to the station frequency and fed into the receiver input as a guide for initial adjustments of the trimmer condensers; if the signal generator is quite accurately calibrated, only slight additional adjustments of the trimmers will be needed after the signal generator is removed.

Oftentimes the initial adjustments will change slightly during the first

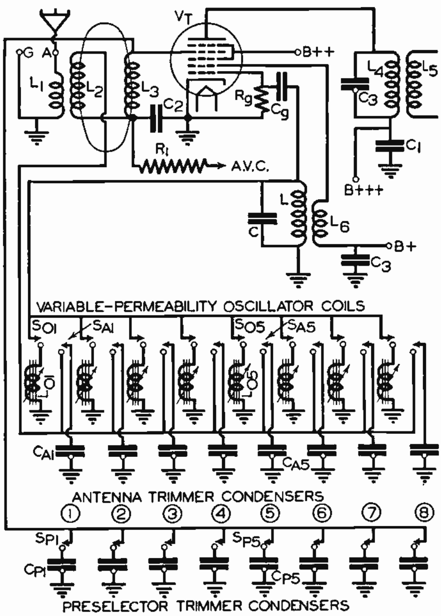


FIG. 13. Circuit diagram of the tuned sections of the RCA-Victor model HF-1 high-fidelity broadcast band superheterodyne receiver, designed for automatic reception of eight different local stations. Eight push-buttons control the electrical automatic tuning system; there is no tuning dial or knob.

few days after they have been made. When the receiver does not have A.F.C., it is a good idea to return in about a week and make final adjustments which will correct for any changes which may have occurred.

RCA-VICTOR Model HF-1. This is an excellent example of a receiver employing a push-button switching mechanism for substituting a pre-adjusted variable inductance in the oscillator tuned circuit and substituting a pre-adjusted trimmer condenser in each of the two preselector tuned circuits. No manual tuning control is provided. The circuit diagram for the tuned sections of this receiver is given in Fig. *13;* vacuum tube *VT* is a conventional pentagrid converter tube, with the first two grids acting as the oscillator grid and plate respectively. The oscillator tuned circuit is made up of condenser *C*, fixed inductance *L*, and one of the adjustable-core oscillator coils shown just below in the diagram. Coil *L* acting alone with condenser *C* resonates below the correct frequency, and the pre-adjusted coil which is shunted across *L* by the switching mechanism lowers the net inductance in the circuit exactly the correct amount for a particular station. Coil L_6 serves as the oscillator feed-back coil.

Two tuned circuits in the preselector make up a band pass tuner. In one of these circuits is fixed inductance L_2 and one of the pre-adjusted antenna trimmer condensers which is controlled by the push-button switching mechanism; the other preselector tuned circuit is made up of coil L_3 and one of the trimmer condensers. All three input circuit coils, L_1, L_2 and L_3, are mutually coupled inductively.

Provisions are made for automatic tuning of eight different stations. The switching action is as follows: Pressing button *1* closes switch S_{O1}, shunting L_{O1} across oscillator coil *L*, and simultaneously closes switches S_{A1} and S_{P1}, inserting pre-adjusted trimmer condensers C_{A1} and C_{P1} in their respective preselector tuned circuits. Pushing in button *5* would first release all switches controlled by button *1*, then close switches S_{O5}, S_{A5} and S_{P5}, which would place parts L_{O5}, C_{A5} and C_{P5} in the tuned circuit.

Electro-Mechanical Automatic Tuning Systems

Electro-mechanical automatic tuning systems can be divided into two general types according to the method of operation involved: 1, *the non-homing system;* 2, *the self-homing system.* Each type will generally include the following sections:

1. A small electric motor which drives the gang tuning condenser through speed-reducing gears and which can be reversed by means of a switch.

2. A switching mechanism which can be adjusted to stop the driving motor at predetermined positions which correspond to the gang tuning condenser settings for desired stations.

3. A group of push-button-controlled switches, each of which starts the motor and connects into the motor circuit the proper switch mechanism for stopping the motor at the correct point (these may be located at any reasonable distance away from the receiver, making remote control tuning possible).

4. A means for silencing the audio system of the receiver during the interval when the motor is driving the tuning condenser, *in order to prevent annoying blasts of sound as the receiver is tuned past strong undesired stations;* a means for releasing temporarily the A.F.C. system while the tuning motor is in motion or just after it stops, *in order to allow the desired station to "take hold" of the A.F.C. system.*

In the non-homing system the motor always drives the variable condenser in the same direction in which it was rotated by the previous automatic tuning action. If this direction is toward the desired station, the motor stops when it has driven the tuning condenser to its correct setting. If the direction is away from the desired station, the motor is automatically reversed when the tuning condenser reaches the limit of its rotation, and the condenser is then driven past its original setting to the desired new setting. In this non-homing system it is important that the motor stop instantly when its circuit is opened by the switching mechanism, for otherwise it might coast long enough while power is off to drive the tuning condenser beyond the correct setting. This is called a non-homing system because the motor does not always "go home" to the correct new setting immediately.

In the self-homing system, the electric motor always travels in the correct direction to bring the tuning condenser to the desired new setting in the quickest possible time; if the motor overruns the proper stopping position because of inertia after power has been cut off, it will instantly reverse and correct its error automatically.

In both the self-homing and non-homing systems the variable tuning condenser cannot swing through more than 180° (one-half of a complete revolution), because the rotor plates of the tuning condensers used in modern receivers are given added rigidity by a metal strip at one end. Variable condensers can be made which will rotate through a full revolution, but it then becomes difficult and costly to make the rotor plates sufficiently rigid.

Non-Homing Electro-Mechanical Tuning Systems. The essential features of a non-homing system are illustrated in Fig. *14*. First of all, observe that a small reversible electric motor drives the shaft of the main tuning condenser through a chain of speed-reducing gears. These gears are necessary because the midget motors used in these systems rotate at a speed higher than one thousand revolutions per minute, a speed which is far too great for tuning purposes.

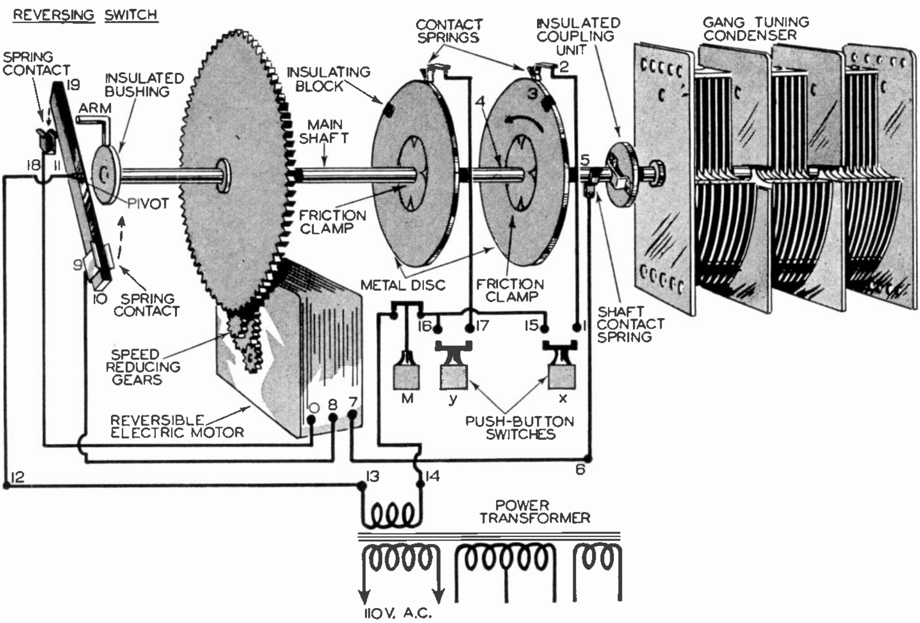


FIG. 14. **Essential features of a non-homing electro-mechanical automatic tuning system.**

For simplicity we will consider a system having only two station-selecting buttons, designed as x and y in Fig. *14*. For each button there is one metal disc on the extended tuning condenser shaft, held rigidly in place by a friction clamp. A small block of insulating material is set into the circumference of each disc, as indicated. Above each disc is a contact spring which normally makes contact with the disc but which is insulated from the disc whenever the insulating block is directly under the spring. Each contact spring is connected to the switch controlled by its push-button; the push-button switching mechanism is the same as that used in electrical automatic tuning systems, with a latch bar serving to release a previously pushed button before holding in the button for a desired station.

Now let us see what happens in this non-homing electro-mechanical system when button x is pushed in. We see immediately that the switch controlled by this button shorts together points *1* and *15*, so let us start at point *1* and trace the circuit through the motor to point *15* again. Follow through from point *1* to point *2*, then through the contact spring to point *3* and the metal disc provided for this button. From the disc we trace through the tuning condenser shaft from point *4* to point *5* and then through a shaft contact spring to points *6* and *7*. From point *7* we know that current must flow through the motor and come out either at point *O* or point *8*. Tracing from point *O*, we find an open circuit at point *18* and know that current cannot flow over this path at this time. We therefore trace from point *8* to point *9* and then to point *10*, the other terminal of the reversing switch. From *10* we go through the metal arm of the reversing switch to point *11*, to point *12*, to point *13*, through a secondary winding on the power transformer (which provides the required voltage for the motor) to point *14*, through manual tuning switch M, and finally we are back at points *15* and *1* again.

With this complete circuit for the motor between its terminals and the source of power, the motor begins to rotate, and the direction will be such that the tuning condenser shaft and the metal disc will rotate in a counter-clockwise direction (as indicated by the arrow on the metal disc) until the insulating block in this disc comes directly under the contact spring. This breaks the circuit between points 2 and 3, opening the motor circuit and stopping the motor. If the position of this metal disc on the condenser shaft is properly chosen, the tuning condenser setting will now be exactly correct for receiving the station assigned to button x.

Now suppose that we desire to receive the station assigned to button y. We push in this button, and the latch bar lifts just enough to release button x and open the circuit between points *1* and *15*. The latch bar then holds in button y, and the corresponding switch shorts points *16* and *17*. Since the arm at the left end of the condenser shaft has not yet touched the reversing switch, contacts *9* and *10* are still together and the circuit traces from point *17* through the left-hand metal disc, through the shaft, through the shaft contact spring to point 7, through the motor to point *8*, through contacts *9* and *10* and the reversing switch to point *11*, and then through the power transformer winding and switch M to points *16* and *17*. The motor rotates in the same direction as it did for button x, and the insulating block on this metal disc moves away from its contact spring. The motor continues rotating in this counter-clockwise direction until the arm at the end of the shaft flips the reversing switch over to a position which opens the circuit between points *9* and *10* and closes the circuit between points *18* and *19*. Now the circuit through the motor is from point

7 to point O and the internal connections of the motor are such that this reverses the direction of rotation, making the tuning condenser rotate in a clockwise direction. This continues until the insulating block has moved under the contact spring and opened the motor circuit.

The speed of the motor is so high that this tuning action takes place in a few seconds. During the tuning process, the station-selecting knob on the panel of the receiver is rotating and the dial pointer is moving, since both are driven by the tuning condensershaft. (For simplicity, the manual tuning mechanism has been omitted from the diagram in Fig. *14*.)

Self-Homing Electro-Mechanical Automatic Tuning Systems. The basic features of a self-homing system are shown in Fig. *15*. First of all, we note that there is no separate reversing switch for the motor; an ingenious switching mechanism automatically starts the motor in the correct direction, eliminating the need for reversing the motor during the tuning process.

In this mechanism, a single circular disc of insulating material is permanently and rigidly mounted on the tuning condenser shaft. To the edges of this disc are fastened two semi-circular metal segments, with their ends separated by insulating segments *J* and *K* so there is no electrical circuit between them. The lead marked *6* connects metal segment *v* to one metal slip ring which is mounted on but insulated from the tuning condenser shaft, and the lead marked *9* connects the other metal segment (*w*) to the other metal slip ring. Surrounding and resting upon the two semi-circular metal segments are a number of sliding contacts or brushes, one for each push-button, which can be set at any required position along the circumference of this disc.

Now let us push in button *x* and trace through the motor circuit to see what will happen. The switch controlled by button *x* has only two terminals, *11* and *1*, which are shorted together when the button is held in by the latch bar. Starting at terminal *1*, we trace to point *2* and through the manual tuning switch *M*, through power transformer winding S_M and then to terminal *3* on the motor. If terminal *4* is the other motor terminal in the circuit, we get a clockwise rotation of the tuning condenser shaft, and if terminal *O* is in the circuit we

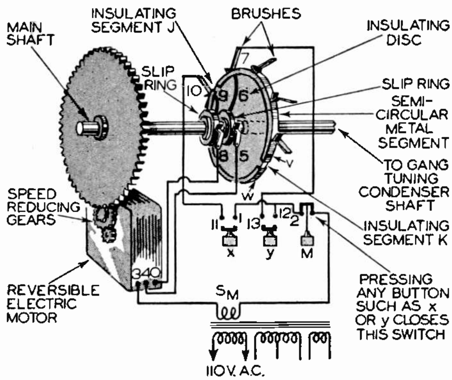


FIG. 15. Essential features of a self-homing electro-mechanical automatic tuning system.

get a counter-clockwise rotation of the shaft. Let us trace from point *4* first; we go to slip ring contact *5*, then through the slip ring and through connecting lead *6* to metal segment *v* on the disc. None of the brushes which are resting on this disc provides a closed circuit to point *1* again, so we know that motor current does not take this path.

Returning to the motor, we trace from point *O* to slip ring contact *8* and through this slip ring and connecting lead *9* to metal segment *w*. Brush *10*, resting on this metal segment, connects directly to point *11*, which is shorted to point *1* by the switch, and hence we have a closed circuit for the motor. The motor rotates the shaft in a counter-clockwise direction until brush *10* is directly over insulating segment *J*. This breaks the circuit, and the motor stops. If the motor coasts far enough after the circuit is broken so that brush *10* touches metal segment *v*, the motor circuit is instantly closed through its other path (*4, 5, 6, 10,* and *11* to *1*) and the motor starts up in the reverse direction rotating the shaft in a clockwise direction. This quickly returns brush *10* to its position above the insulating segment, and since the motor has not had a chance to build up speed, it stops instantly. If brush *10* is properly located, a station will now be tuned in correctly.

Now suppose we wanted to receive the station assigned to button *y*. We press in this button, releasing button *x* and shorting points *12* and *13*. Current now flows over the path *12-2-3-4-5-6-7-13-12,* and the motor turns the tuning condenser shaft in a clockwise direction until brush *7* is directly over insulating segment *J*. If the motor "over-runs" the insulating segment, brush *7* will contact segment *w* and the motor will be reversed just long enough to correct the error. In this way a self-homing or self-correcting automatic tuning action is obtained.

Although only two station-selecting buttons have been shown in Figs. *14* and *15,* as many additional buttons can be used in both these systems as are desired. In each case, one additional manual tuning button *M* must be pressed to open the main motor supply lead when manual tuning is desired. Since the common latch bar acts upon all buttons, the mere act of pressing a station button releases the manual tuning button, closing its switch and restoring automatic tuning.

With non-homing systems, one metal disc with its insulating block is required for each station which is to be automatically tuned; with self-homing systems only one large disc is required, with one brush resting on the metal segments of this disc for each station which is to be automatically tuned. The metal segments may be made wide enough so that two brushes can rest side by side or very close together on it, permitting automatic tuning of stations which are only 10 kc. apart.

Audio-Silencing and A.F.C.-Releasing Switches for Electro-Mechanical Systems

There are five methods in general use for silencing the audio system, of which the first is the most common:

1. **Grounding the grid of an audio tube.**
2. **Shorting the terminals of the loud-speaker voice coil or shorting the primary winding of the output transformer.**
3. **Shorting the diode load resistor in the second detector circuit.**
4. **Applying a large negative C bias to an audio tube in order to block the tube.**
5. **Applying a large negative C bias to the tubes in the frequency converter and the I.F. stages of a superheterodyne in order to reduce the sensitivity of the R.F. system.**

Two methods are in general use for removing A.F.C. action while the tuning mechanism is in operation or for temporarily releasing the A.F.C. system when tuning is completed:

1. **Shorting the output of the A.F.C. discriminator sections.**
2. **Applying a large negative C bias to the tubes in the frequency converter and I.F. stages. (Reducing the input voltage to the A.F.C. system in this manner prevents the system from holding a station which is even a small amount off resonance.) This method also provides audio silencing.**

Regardless of which method is used for silencing the audio system and releasing A.F.C. action, the switches used must be interlocked with the automatic tuning mechanism. The switches can be actuated either by mechanical movement of some part of the tuning system or by the flow of current through the motor circuit.

Switch Control by Motor Shaft Movement. An electric motor consists essentially of a rotating part, called the armature or rotor, and a stationary part called the stator. The interaction of the magnetic fields produced by these two parts causes rotation. For greatest rotating force, the rotor must be exactly in the center of the stator; if the rotor is off center to one end or the other, it will be magnetically pulled into the center whenever voltage is applied to the motor. This endwise movement of the rotor is used in some electromechanical automatic tuning systems to actuate the audio silencing and A.F.C. releasing switches.

The arrangements of parts for a switch control action of this type is shown in Fig. *16A*. A spring on the rotor shaft, pressing between the rotor and the frame of the motor, serves to push the rotor off center when the motor is stopped. Under this condition the contacts of the switches are open, permitting normal receiver operation and A.F.C. action.

When voltage is applied to the motor, the rotor instantly centers itself by moving to the right, as indicated in Fig. *16B*. This causes a collar on the shaft of the motor to press against a lever arm which actuates a multi-contact spring switch, shorting all contacts to ground and thus grounding the audio grid and shorting the discriminator output resistor. When current through the motor is interrupted, the rotor-centering force disappears and the spring again pushes the rotor to the position shown in Fig. *16A*, opening the audio and A.F.C. circuits.

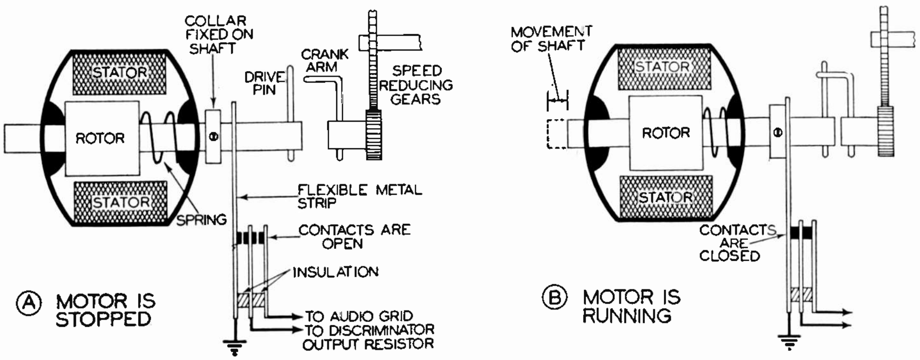


FIG. 16. Details of audio-silencing and A.F.C.-releasing switches which are actuated by thrust (end-wise movement) of the motor shaft when voltage is applied to the motor of an electro-mechanical automatic tuning system.

The end movement of the rotor shaft is also used to engage the motor with the speed-reducing gears which drive the gang tuning condenser shaft. The movement of the rotor shaft to the right when voltage is first applied causes a drive pin on the motor shaft to engage with a crank arm on the shaft of the smaller gear, as indicated in Fig. *16B*. When current to the motor is interrupted by the station-selecting system, the drive pin moves away from the crank arm, allowing the motor to coast to a stop without causing undesirable rotation of the gang tuning condenser. The friction load on the gang tuning condenser itself is sufficient to make it stop instantly when the driving force is removed. The switches shown in Fig. *16* may, of course, be used for any of the other audio silencing and

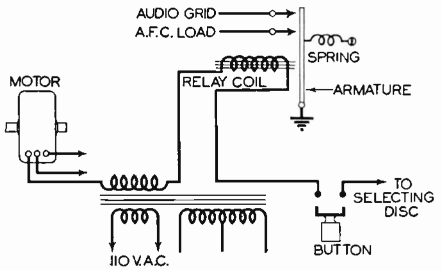


FIG. 17. Method of using a relay in the motor circuit to actuate audio-silencing and A.F.C.-releasing switches in an electro-mechanical automatic tuning system.

A.F.C. releasing methods which are employed by receiver designers.

Switch Control with Electro-Magnetic Relays. The flow of current in the main lead to the motor of an electro-mechanical automatic tuning system can be used to actuate an ordinary A.C. relay having contacts which are connected to silence the audio system and release the A.F.C. system, since this motor current flows only during the tuning operation. The circuit arrangement is quite simple and is shown in Fig. *17;* the pressing of any station-selecting button sends current through the relay coil as well as the motor. The relay armature is attracted to the relay core by the magnetic flux created by the relay coil, and this movement of the armature causes the audio grid and A.F.C. load contacts to be grounded. When the station-selecting mechanism interrupts the current to the motor, the current flow through the relay likewise stops, allowing the spring to move the armature away from the core and open the audio and A.F.C. circuits.

Electrical Circuit (without Switches) for Audio Silencing and A.F.C. Releasing. In this circuit, the A.C. voltage for the A.C. motor is also applied to a twin rectifier stage, and the resulting D.C. voltages are made to increase the negative C bias on an audio amplifier tube enough to silence the audio system, and to increase the negative C bias on the

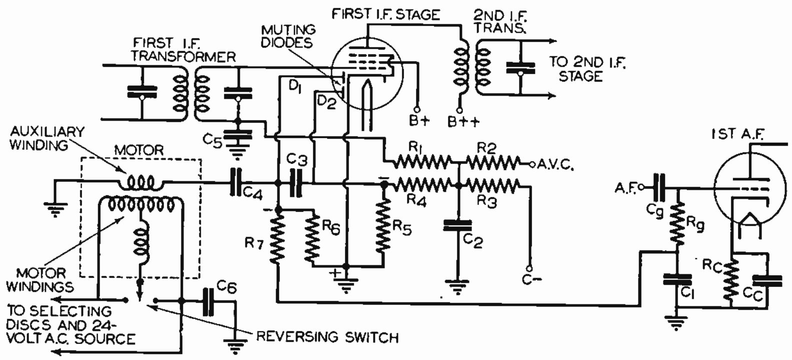


FIG. 18. Circuit diagram showing connections for an electrical system which silences the audio amplifier and releases the A.F.C. system during the operation of the electro-mechanical automatic tuning system. This scheme is used in some Motorola receivers. The use of a duo-diode-pentode in the first I.F. stage eliminates the need for an extra muting tube.

I.F. stages in order to prevent the A.F.C. system from acting during the tuning operation.

A typical circuit arrangement is shown in Fig. *18*; the A.C. voltage developed by an auxiliary winding on the motor core is applied to the two diode plates of the first I.F. tube through D.C. blocking condensers C_4 and C_3, the return path being from the grounded cathode to the grounded end of the auxiliary winding. On alternate half cycles the diode sections act as shorts across resistors R_5 and R_6, and the current pulses flowing through these resistors on the remaining half cycles produce rectified voltage drops across them.

The D.C. voltage across R_6 acts in series with the normal C bias on the first A.F. tube, driving this tube sufficiently negative to prevent audio amplification. Condenser C_1 and resistor R_7 make up a filter which smooths out ripples in the rectified D.C. voltage across R_6.

The D.C. voltage developed across R_5 when the motor is operating acts upon the grid of the I.F. tube through resistors R_4 and R_1, and drives this grid sufficiently negative to reduce the strength of the I.F. carrier signal and thus release the A.F.C. system. Note that this A.F.C releasing voltage acts in shunt with the AV.C. voltage and the normal C bias voltage for the I.F. tube. Condensers C_2 and C_5 are filter condensers, while resistors R_2, R_3 and R_4 serve to isolate the various negative voltage sources acting upon the I.F. tube grids. Condenser C_6 places the motor circuit at R.F. ground potential.

RCA Electro-Mechanical Automatic Tuning System. This electromechanical system is of the non-homing type, and consequently the motor will sometimes drive the gang tuning condenser away from a desired setting until the limit of condenser rotation is reached and a reversing switch is tripped. A top view of the tuning mechanism is shown in Fig *19A*; the motor, the speed-reducing gears, the A.F.C. and A.F. shorting switches, and the pin and crank arm drive are all essentially the same as for the system shown in Fig. *16*, while the reversing switch is like that shown in Fig. *14*.

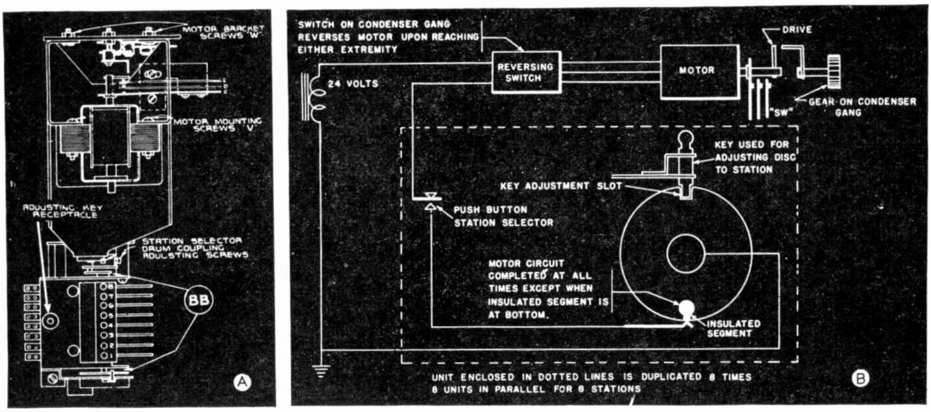


FIG. 19. RCA electro-mechanical automatic tuning system of the non-homing type. Shaft coupling units are designated as *BB*.

The simplified diagram in Fig. *19B* shows how this system operates. The metal disc with an insulated segment and a slot on opposite sides is one of eight discs which are mounted on a common shaft and held in position by friction; beneath each disc is a spring contact. During manual tuning the metal discs turn with the gang tuning condenser but the electric motor remains motionless since the pin on its shaft is not engaged with the crank arm on the speed-reducing gear.

To make the preliminary station-setting adjustment for this RCA mechanism, one of the buttons is pressed, and after the motor has stopped, an adjusting key (provided with the unit, and kept in a special adjusting key receptable when not in use) is inserted in the adjusting hole corresponding to this button; this places the key in the slot on the metal disc, exactly as shown in Fig. *19B*. The A.F.C. system is turned off by means of a switch on the receiver panel, and the receiver is now tuned manually to the station desired for that button. Removal of the adjusting key completes the adjustment for this station; the process is then repeated for each other button. It is not necessary to lock the metal discs in position, since there is sufficient friction to prevent them from slipping during normal receiver operation.

The operation of this automatic tuning system is as follow: The pressing of the push-button station selector in Fig. *19B* closes the circuit to the motor through the reversing switch and through the contact spring and metal disc; the motor starts up in the direction of its previous rotation, with its rotor automatically centering in the stator so that the drive pin engages with the crank arm on the gear and the A.F.C. and A.F. shorting switches are closed. The motor stops when the metal disc has turned to the position where the contact spring is over the insulated segment; if the gang tuning condenser reaches the limit of its travel before this occurs, the reversing switch changes the direction of motor rotation.

General Electric Electro-Mechanical Automatic Tuning System. Diagrams for this non-homing system are given in Fig. *20*. As you can see, no metal station-selecting discs are used; instead, a metal arm with a knife-edge spring contact is mounted on the tuning condenser shaft, and swings over a number of metal contact buttons which are set into slots in an insulating panel. The tuning motor drives the tuning condenser shaft through reducing gears; when the limit of rotation is reached, a reversing switch changes the motor direction and starts the contact arm moving back over the contacts again. All this is shown in Fig. *20A*.

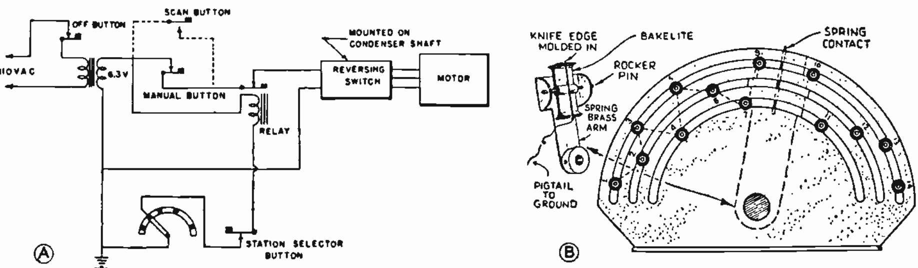


FIG. 20. General Electric non-homing electro-mechanical automatic tuning system.

The circuit connections for one contact button are indicated in Fig. *20B*; here is how the system works. When the *MANUAL BUTTON* is pressed, it opens the motor supply circuit and raises the latch bar enough to release all other push buttons. The latch bar also releases the *OFF BUTTON* at this time, thus closing the primary circuit of the power transformer.

Under this condition neither the relay nor the motor gets power (because all station selector button switches as well as the manual button switch are open), and the receiver can be tuned manually.

When the *STATION SELECTOR BUTTON* is pressed, the latch bar releases the *MANUAL BUTTON*, closing its circuit. Power is thus applied to the motor, and it rotates the gang tuning condenser and the rotating contact arm until this arm is directly over the contact button corresponding to the station selector button which has been pressed. This closes the relay circuit, and its armature pulls in, opening the motor circuit and stopping the motor. The relay remains closed until the pressing of another station selector button switch opens its circuit. The A.F. system is silenced and the A.F.C. system is temporarily released by means of a conventional switching arrangement operated by the end-thrust action of the motor (this is not shown in Fig. *20*).

Another interesting feature of this General Electric system is the non-latching *SCAN BUTTON*. When manual tuning is in use, pushing of the scan button will close the motor circuit, and it will continue to rotate the gang tuning condenser back and forth through its entire 180° of rotation as long as the button is pressed. In this way stations can be tuned in roughly without the trouble of turning a manual tuning knob, and when a desired station is heard the scan button can be released. Accurate final tuning can then be done manually if necessary, but usually the A.F.C. system will be able to take hold instantly and tune in the desired station when the scan button is released.

To set up any station selector button, the desired station is tuned in manually while the manual button is depressed. A contact button near the contact arm is now loosened and moved directly under this arm. Labeling the station selector button with the call letters of the station tuned in completes the setting up process; this is repeated for each other button.

Tuning Motors

Despite their small size, tuning motors require careful design and construction. They must operate

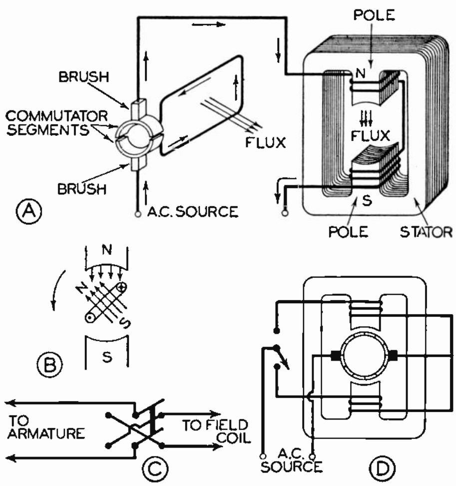


FIG. 21. **Details of a series-wound tuning motor. Short arrows indicate direction of *current* flow for one half of cycle. Plus sign in wire indicates current flow *into paper;* dot in wire indicates current flow *out of paper.***

with as little noise as possible, must operate with little or no oiling, must not heat up excessively while in use, and must operate from an A.C. source. Usually they are designed for 6.3 volt operation, in which case they can be connected in shunt with the filament supply of the receiver; some motors are designed for higher voltages, however, and for these an extra secondary winding must be provided on the power transformer.

There are two types of small A.C. motors in general use in automatic tuning systems: 1, series motors; 2, induction motors. The fundamental operating principles of each will be discussed.

Series Motors. In Fig. *21* is a simplified diagram illustrating the operating principles of a series motor. For convenience, the armature is shown as a single loop of wire whose ends are connected to two semi-circular commutator segments; in an actual motor, there will be many loops of wire and many more commutator segments, and the entire armature will be mounted in the center of the stator, between the pole pieces. Two fixed brushes make contact with the commutator segments as indicated. The armature loop and the field coils are connected *in series* across the A.C. source, as you can easily see by tracing the current from one source terminal through the circuit as indicated by arrows to the other source terminal; all motors having the armature and field coils connected in series in this way are known as *series motors*. In an actual series motor the wire loop is wound around a cylindrical soft iron core whose shaft is free to revolve in bearings at each end. The stator (the stationary part of the motor) is usually made from sheet metal laminations to reduce eddy current losses. Field coils are wound over the poles of the stator, and are connected together in such a way that both will produce flux in the same direction at any instant. When current flows through this motor in the direction indicated by arrows, the loop of wire on the armature will set up a magnetic flux in the direction indicated, and the field coils will likewise set up a magnetic flux which makes one pole north and the other pole south in polarity, as indicated.

Naturally the magnetic fields produced by the armature and stator will interact with each other when the armature is inside the stator. For the armature position and direction of current flow shown in Fig. *21B*, the armature will act as a pivoted magnet having the indicated polarity. The armature *N* pole will be repelled by the stator *N* pole and attracted by the stator *S* pole, and likewise the armature *S* pole will be repelled by the stator *S* pole and attracted by the stator *N* pole, causing counterclockwise rotation. Since the like poles are closest together now in Fig. *21B*, the repelling action will be strongest; when the armature has rotated a bit farther, the unlike poles will be closer together and the attractive force will be the strongest, reaching a maximum when the armature *N* pole is next to the stator *S* pole. At this time the current through the armature loop is reversed in direction by the commutator, and the entire process of repulsion and attraction repeats itself, causing the armature to continue rotating in the same direction until it is again horizontal and current flow is again reversed by the commutator.

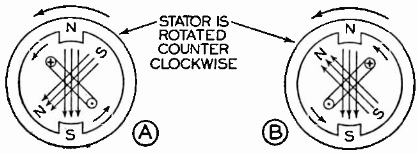


FIG. 22. **Simplified diagram showing the operating principles of an induction motor.**

Reversing a Series Motor. With a given connection of armature and field coils, as indicated in Fig. *21A*, the armature will revolve in a certain direction; to reverse this direction of rotation it is necessary to reverse the direction of current flow through *either* the field coil *or* the armature (*but not through both*). This can be done by inserting a double-pole, double-throw switch in the circuit as shown in Fig. *21C*. If, however, a center-tap field coil arrangement like that shown in Fig. *21D* is used, a single-pole, double-throw switch will serve for reversing purposes. Note that with this arrangement only one field coil is carrying current and producing magnetic flux at any one time.

A series motor operates on either an A.C. or D.C. source, since the reversal of current flow through both the field coils and the armature does not change the direction or magnitude of the forces acting on the armature.

Induction Motors. All induction motors operate on the principle that when a closed or shorted loop of wire is pivoted in the center of a rotating magnetic field, the loop will rotate in the same direction as the field. Let us see why this statement is true.

Suppose we have a magnetic field like that shown in Fig. *22A,* made up of an *N* pole and an *S* pole, which is being rotated by some mechanical means in the counter-clockwise direction indicated. Between these two poles is a shorted copper loop or ring which is pivoted at its center and is therefore free to turn. If the initial positions of the loop and magnetic field are as shown in Fig. *22A,* a certain amount of magnetic flux will pass through the loop. When the magnetic field begins to rotate counter-clockwise, however, the amount of flux through the ring will be reduced and consequently the flux linkage in this coil or loop will be reduced. From Lenz's law we know that whenever there is a change in flux linkage in a coil, a voltage is induced in the coil in such a direction as to *oppose the original change in flux linkage.* This means that the loop in Fig. *22A* will set up a flux to aid the original flux, and the coil will act as a small magnet having the polarity indicated. Since like magnetic poles repel and unlike poles attract, we can readily see that the coil will rotate in the same direction as the magnetic field, as indicated by the arrows.

The shorted loop cannot rotate at exactly the same speed as the magnetic field, for then there would be no change in flux through the loop. The loop is continually slipping or lagging behind the magnetic field, but even when it slips past the pole pieces it is still forced in the same direction of rotation. Suppose that the relative positions of the coil and magnetic field

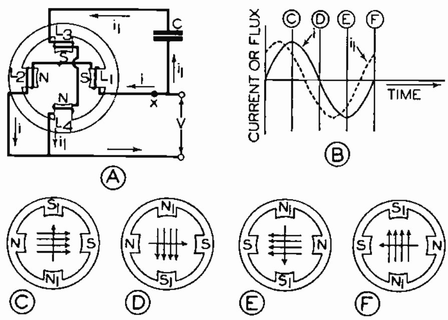


FIG. 23. These diagrams show how a condenser can be made to produce a clockwise-rotating magnetic field for a split-phase induction motor. Short arrows indicate *current* flow.

are as indicated in Fig. *22B* at one instant, with the field traveling faster than the loop. The number of flux linkages in the loop will now be increasing, and consequently the loop will set up a flux to oppose the original flux, in an attempt to maintain a constant number of flux linkages. The polarity of the loop will be as indicated, and since like poles repel we still have the loop rotating in the direction of the magnetic field. In a practical induction motor there are a large number of shorted loops mounted on the armature, each contributing a rotational force.

Electric motor design engineers

have devised a number of simple ways for producing a rotating magnetic field by electrical means in a single-phase A.C. induction motor (the induction motors used for radio tuning purposes will operate on a two-wire, single-phase, A.C. power line, and hence are often called single-phase motors).

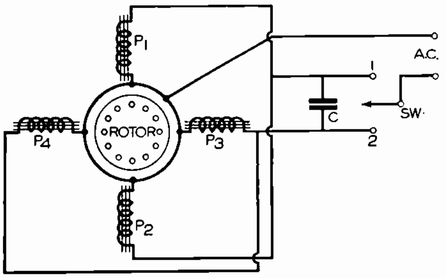


FIG. 24. Circuit of General Electric condenser split-phase induction motor as used in a number of automatic tuning systems. When switch *SW* is set at contact *1*, current to poles P_3 and P_4 (which are connected together in parallel rather than in series) must flow through *C;* when *SW* is at *2*, current to P_1 and P_2 flows through *C*, reversing the direction of the rotating magnetic field and thus reversing the direction of motor rotation.

Capacitor Split-Phase Induction Motor. In Fig. *23* is shown a method of producing a rotating magnetic field by means of a four-pole stator, with a coil wound on each pole and a condenser connected in series with two opposite coils to make them draw a current which is approximately 90° out of phase with the current through the other coils.

A.C. voltage *V*, applied to the motor terminals, sends a current *i* through field coils L_1 and L_2, and the flux produced by this current is *in phase* with the current. The current which voltage source *V* sends through field coils L_3 and L_4 must pass through high-capacity condenser *C* and the capacitive reactance of this condenser is so high with respect to the inductive reactance of these coils that current i_1 leads the A.C. voltage *V* by almost 90°. The curves in Fig. *23B* give the phase relationship of the two currents, *i* and i_1, and show that i_1 leads *i* by almost 90°; since a flux is always in phase with the current which produces it, these curves can also represent the flux produced by each pair of poles.

You can readily see that sine wave alternating current *i*, flowing through the horizontal pair of poles, will cause the flux to reach a maximum in one direction (Fig. *23C*), drop almost to zero (Fig. *23D*), reach a maximum in the opposite direction (Fig. *23E*), and again drop almost to zero (Fig. *23F*). The vertical pair of poles is going through this same complete cycle of changes in flux, but the flux is here 90° ahead of that for the horizontal poles. At each instant, the fluxes produced by the two pairs of poles combine, and it is the resultant flux which acts upon the shorted loops of wire on the armature. Referring to Figs. *23C, D, E,* and *F*, you can see that the weaker flux in each case (shown by a single arrow line), will have little effect upon the stronger flux. Furthermore, the position of the stronger flux at each quarter-cycle is such that we have the same effect as was produced by the rotating magnetic field in Fig. *22*,

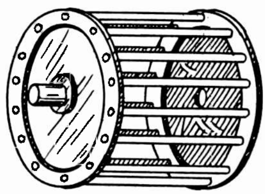


FIG. 25. Typical rotor of an induction motor, made up of copper rods which are riveted and soldered at each end to circular copper discs mounted on the rotor shaft. Before assembly, laminated sheet steel discs having slots for the copper rods are placed on the shaft inside this "squirrel-cage"; this steel core serves to reduce the reluctance of the path for the rotating magnetic flux and for the fluxes set up by the many shorted loops in the rotor.

with our magnetic field rotating in a clockwise direction in this particular case.

A counter-clockwise rotation of the magnetic field could be secured in

Fig. *23* simply by inserting the condenser in series with the other pair of coils, such as at point x. Since in tuning motors it is usually necessary to have a reversing switch, this particular type of induction motor will usually be found connected as shown in Fig. *24*, with a single-pole, double-throw switch arranged to change the condenser from one circuit to the other. The condenser could just as well be replaced by a high-inductance coil, making current i_1 in Fig. *23A* lag rather than lead current i, for it is the difference in phase which creates the rotating magnetic field. The rotors used in this and all other types of induction motors are much the same in construction and appearance, resembling that shown in Fig. *25*.

Shaded-Pole Induction Motor. Another method of producing a revolving magnetic field is shown in Fig. *26A*. Alternating current is fed through coil L_1, which is wound on one of the poles of the motor, with the result that an alternating flux θ_1 is produced at the pole face. A short-circuited coil L_2 is wound around one portion of the pole; when flux θ_1 is increasing, that portion of

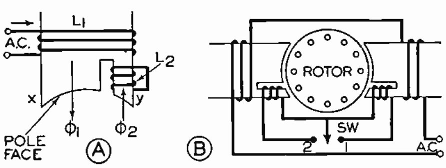
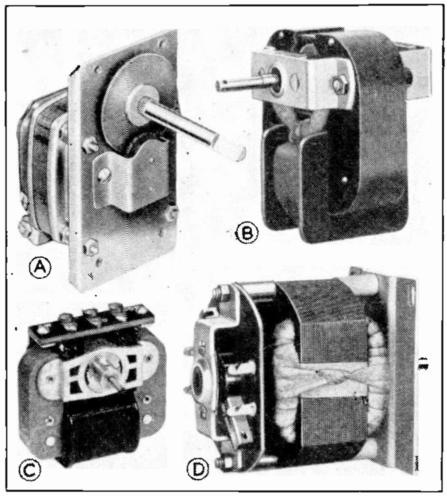


FIG. 26. Diagrams showing principles of a shaded-pole type induction motor.

θ_1 which passes through coil L_2 will likewise be increasing. The result is that a voltage will be induced in L_2, and this will set up a flux θ_2 which tends to oppose any change in the flux through this coil. In other words, when θ_1 is increasing, θ_2 will oppose the main flux θ_1 and the flux near point y on the pole face will be quite weak. When θ_1 is decreasing, θ_2 will attempt to prevent this decrease by aiding the main flux, and under this condition there will be a stronger flux at point y than at point x. During one-half of a cycle the region of



Typical examples of motors used in electro-mechanical automatic tuning systems.

Courtesy Alliance Mfg. Co.
***A*—Alliance Model R shaded-pole induction motor. The shading coils are connected according to the diagram in Fig. *26B*, and motor is therefore reversible. Note the speed-reducing gear assembly mounted directly on the motor.**

Courtesy Delco Appliance Div., General Motors Sales Corp.
***B*—Delco split-phase (reversible) induction motor; this unit employs the auxiliary high-inductance winding shown in Fig. *27* to produce the out-of-phase flux required for a rotating magnetic field. These motors are made for 5, 20 or 115 volt A.C. operation.**

Courtesy Barber-Colman Co.
***C*—Reversible single-phase, shaded-pole Barcol induction motor designed for 110-volt A.C. operation. A single main coil serves for both poles; separate shading coils are wound around a portion of each pole and connected as in Fig. *26B* to permit reversal of the motor.**

Courtesy Delco Appliance Division
***D*—Delco reversible series motor. Two brushes resting on the commutator feed current to the armature windings in the correct direction. Field coil connections are as shown in Fig. *21D*, permitting reversal of the motor with a simple single-pole, double-throw switch.**

maximum flux travels from x to y; during the next half cycle this process repeats itself, with the point of maximum flux again moving from point x to point y. We thus have a maximum flux rotating always in the same direction across this pole face, *from the main pole toward the shorted coil,* which is known as a *shading coil.* The rotor will follow this rotating flux, and consequently *the rotor of an induction motor will always rotate toward a shading coil.*

The direction of rotation can be reversed by placing a shading coil on each pole of the motor, with the various coils connected together in the manner shown in Fig. *26B.* When switch *SW* is at contact *1,* only the right-hand shading coil will be shorted and effective, and the rotor will rotate in a clockwise direction, toward this shading coil. When switch *SW* is at contact *2,* the left-hand shading coil will be shorted and the direction of rotation will be counter-clockwise.

Instead of short-circuiting the shading coils, as was done in Fig. *26B,* they may be connected together and to the main voltage supply. Since their reactances will be different from the reactances of the main field coils, the shading coils will produce fluxes which are out of phase with the main fluxes, thus giving a rotating magnetic field.

Split-Phase Induction Motor with Reactive Winding. Another way of producing a rotating magnetic field is that shown in Fig. *27,* which involves using an extra pole on which is wound a coil (L_3) having a high inductive reactance. The A.C. line current flowing through the regular field coils L_1 and L_2 produces a pulsating A.C. magnetic flux, which alone is not sufficient to cause rotation. When switch *SW* is set at contact *2,* placing L_3 across L_2, the current through high-inductance coil L_3 will lag the current through low-inductance coil L_2 by almost 90°, and consequently the flux produced by L_3 will lag the flux from L_2 by almost 90°. This phase relationship will be maintained as each flux increases and decreases in a sine wave manner, with the result that we have the required rotating magnetic field. When switch *SW* is set at contact *1,* shunting L_3 across L_1, we secure this same phase relationship between the fluxes but now the resultant or combined flux will rotate in the opposite direction, causing reversed rotation of the rotor.

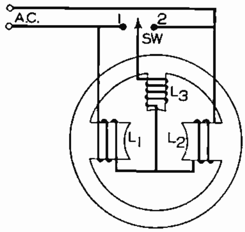


FIG. 27. Simplified diagram of a split-phase induction motor employing an auxiliary pole with high-inductance winding L_3 for producing the required rotating magnetic field.

Speed. The maximum speed at which an induction motor can operate is of course the rotational speed of the rotating magnetic field. The motor can approach this speed only under no load conditions, and will slow down (due to increased slippage) as a load is applied. The maximum speed can easily be computed; the speed in revolutions per second is equal to the frequency of the alternating current in cycles per second divided by the *number of pairs of poles.*

The tuning motors used in radio receivers ordinarily have two poles, forming a single pair, since this construction has been found efficient as well as economical in cost. For 60-cycle current, then, the speed will be 60 divided by 1, or 60 revolutions per second. To obtain the speed in revolutions per minute (r.p.m.) we multiply by 60, getting 3600 r.p.m. as the maximum speed of an induction tuning motor. If a gang tuning condenser were driven directly by such a motor, the required half-revolution would take only a little more than

1/200 of a second; obviously this is far too fast. Speed-reducing gears must therefore be used with induction motors; ordinarily they are designed to give a reduction in speed of at least 100 to 1, which means that the longest time required for a motor to tune in a station will be only a few seconds.

TEST QUESTIONS

Be sure to number your Answer Sheet 35FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Into what three groups (each having a different operating principle) can automatic tuning systems be divided?
2. What is the chief cause of oscillator frequency drift in an ordinary superheterodyne receiver?
3. Into what two general groups can mechanical automatic tuning systems be divided according to the manner in which they are operated by the listener?
4. Where will a slight change in trimmer condenser capacity have more detuning effect—in a preselector tuned circuit or in the oscillator tuned circuit?
5. Name the two general types of electro-mechanical automatic tuning systems.
6. In an electro-mechanical automatic tuning system, why is the A.F.C. system released temporarily while the tuning motor is in motion or just after it stops?
7. What method of removing A.F.C. action during a tuning operation also provides audio silencing?
8. What two types of small A.C. motors are in general use in automatic tuning systems?
9. How can the direction of rotation be reversed in a series motor?
10. In what direction will the rotor of a shaded-pole induction motor rotate?

HOW DETECTORS WORK IN SOUND AND TELEVISION RADIO RECEIVERS

17FR-2

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How Detectors Work in Sound and Television Radio Receivers

THE IMPORTANCE OF DETECTORS

THE radio signals which are picked up by the antenna of a sound or television radio receiver are modulated radio frequency signals; these were produced at the transmitter by making the amplitude of an R.F. carrier vary in accordance with a sound, picture or code intelligence signal. The separation of the intelligence signal from the R.F. carrier by a process which is known as *demodulation* or *detection* is one of the actions required before the intelligence can again be made audible or visible. In effect, the process of demodulation serves to detach the modulation envelope of the incoming signal from its carrier wave.

At least one detector stage is necessary in every radio receiver for the purpose of demodulating the incoming signal. We will consider this type of detector first, then take up detectors used for other purposes.

Demodulation or detection of a modulated R.F. signal is accomplished in two distinct steps. First the incoming signal current is *rectified,* so that practically half of each R.F. cycle is removed. The resulting pulsating current, which consists of R.F. current pulses whose amplitudes vary in accordance with the wave form of the intelligence signal, is then passed through a circuit which in effect *separates* the desired intelligence signal from the undesired R.F. current. Keep these two steps (*1, rectification; 2, signal separation*) in mind as you study the various types of detector circuits.

Modulation clearly plays an important part in the transmission of any intelligence by means of R.F. carrier waves, particularly in the process of detection. We shall therefore review a few essential facts in connection with modulation and give some attention to what happens to the intelligence signal in a transmitter before taking up our detailed study of how detectors work.

CARRIER LEVEL AND MODULATION PERCENTAGE

When the broadcast station to which a receiver is tuned becomes silent for a few seconds, such as just after the station announcement, the R.F. *carrier* voltage which reaches the detector input will be unmodulated, and the wave form of this unmodulated carrier will appear as at A in Fig. *1*. The peak value of voltage (N) is constant here and is a measure of the *intensity level* of the carrier.

If a chime is struck or some other pure sine wave sound is picked up by the microphone after the silent period, the carrier will be modulated with this sine wave signal and the resulting wave form will be like that at B in Fig. *1*. M represents the peak value of the sine wave modulation signal; the ratio of M to N is a measure of the amount of modulation. To be more exact, the peak modulation signal voltage M divided by the peak carrier voltage N and then multiplied by 100 gives the *percentage of modulation*. For example, if the peak carrier voltage level N in Fig. *2B* is 10 volts and the peak modulation signal voltage M is 4 volts, the percentage of modulation will be $(4 \div 10) \times 100$, or 40%.

A line drawn through the peaks of the R.F. carrier cycles (such as the dotted lines in Figs. *1B, 1C* and *1D*) is called a *modulation envelope*. It is the current having a wave form like that of the modulation envelope which must be separated from the R.F. carrier by the process of detection.

When the carrier level at the transmitter is held constant and the modulation signal increased, percentage modulation increases and the wave form appears as at C in Fig. *1*. When the two voltages, M and N, are exactly equal you have 100% modulation, and the wave form will be like that at D. The greater the percentage modulation of a transmitter for a given carrier level, the greater will be the signal intensity and the

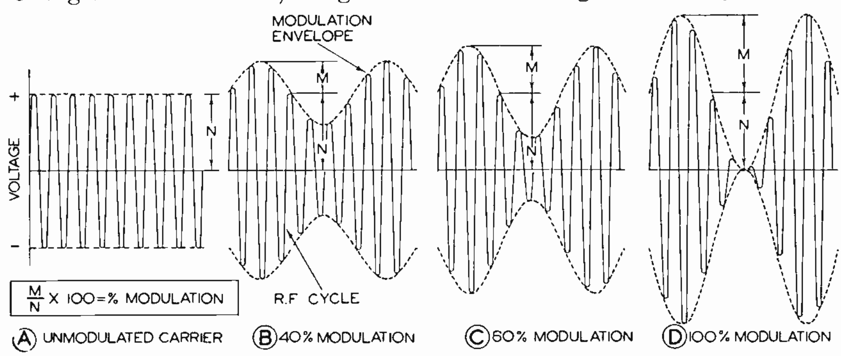

FIG. 1. The unmodulated R.F. carrier at A takes on the wave forms at B, C and D when modulated with a sine wave signal at various modulation percentages. These waves can represent currents as well as voltages.

demodulated output of the detector in a receiver, but distortion occurs when modulation goes over 100%. Modulation percentages greater than 100% are therefore prevented at the transmitter whenever possible.

An actual modulated carrier will have many different shapes of modulation envelopes as the sound or picture signal changes; one possible envelope is shown at A in Fig. *2*. If a signal with this wave form is fed into an R.F. amplifier stage having an over-all amplification of 3, the signal which enters the detector will be like that at Fig. *2B*, with three times as much amplitude but exactly the same wave form as the input signal at A. Both carrier and modulation are amplified equally, hence the percentage modulation remains unchanged after amplification.

In the study of detectors, just as in the study of other radio circuits, it is much simpler to consider only sine wave modulation signals and sine wave carrier signals. If the detector will handle a sine wave modulated signal without distortion at a particular percentage of modulation, and if no frequency distortion occurs when the frequency of the sine wave modulation signal is varied from the lowest to the highest value which is to be handled, then the detector will handle all components of a complex wave equally as well.

DETECTOR CHARACTERISTICS

There can be quite a bit of difference between the signals which a detector must handle; the R.F. carrier signal fed into the detector by an R.F. amplifier (or by the antenna circuit when there is no pre-amplifier) may have a high, low or in-between voltage and may have any percentage of modulation from 0 to 100%. Furthermore, detectors themselves vary greatly in characteristics, making it desirable to have some means for comparing the performance characteristics of different detectors. Before going on to a study of different detectors, then, let us consider briefly the three important performance characteristics of detectors, which are *sensitivity, fidelity* and *voltage-handling ability.*

Sensitivity. Radio men are always interested in how much of the modulation frequency voltage they can obtain from a detector when feeding in a certain modulated R.F. voltage at a definite carrier level and percentage of modulation. The sensitivity rating of a detector gives this information, for it is *the ratio of the demodulated output voltage to the R.F. input voltage.* The more sensitive a detector is, the higher will be its demodulated output voltage for a given input carrier signal voltage and given modulation percentage. This sensitivity rating includes any amplification contributed by the detector.

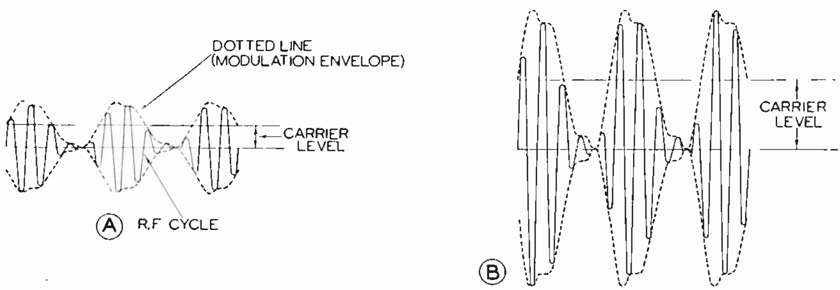

FIG. 2. One of the many possible wave forms of an R.F. carrier modulated with an actual sound signal (middle C as produced by a piano) is shown here before and after amplification.

Fidelity. A transmitter is considered to have high fidelity when the envelope of the modulated carrier current is a true reproduction of the intelligence signal. The function of the detector in a receiver is the production of a demodulated signal current corresponding in wave form to the envelope of the carrier; the more nearly these two wave forms correspond, the better is the *fidelity* of the detector. Furthermore, there should be no wave form (amplitude) distortion at any modulation frequency. Freedom from amplitude and frequency distortion is obviously highly desirable in a detector.

Voltage Operating Range. The range of input carrier signal voltages over which a detector will operate with satisfactory fidelity is by no means unlimited. Some detectors can handle only weak carrier signals without distortion, while others will distort on weak carriers yet work perfectly well on strong carriers. Furthermore, the percentage of modulation of the incoming signal also limits the operating range of a detector; some circuits work well at high percentages of modulation, while others do not.

LINEAR AND SQUARE LAW DETECTION

I have already pointed out that detection consists of two distinct steps: *1*, rectification; *2*, signal separation. Rectification is the more important of the two, for signal separation can generally be attained with little difficulty. A crystal, diode tube, triode tube or pentode tube used as a detecting device may either give complete rectification (cutting off completely one-half of each R.F. input cycle) or incomplete rectification (where more current flows on one half of an R.F. cycle than on the other half). Each form of rectification can be utilized satisfactorily for detection if the proper operating point or bias voltage on the input voltage-output current characteristic curve is chosen.

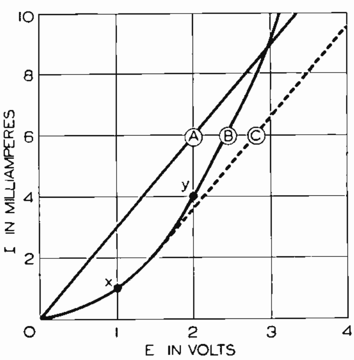

FIG. 3. A detecting device may have either a linear (*A*), square law (*B*), or combination linear-square law input-output characteristic (*C*). These curves apply for direct current values only, and hence are often called *static* detector characteristic curves.

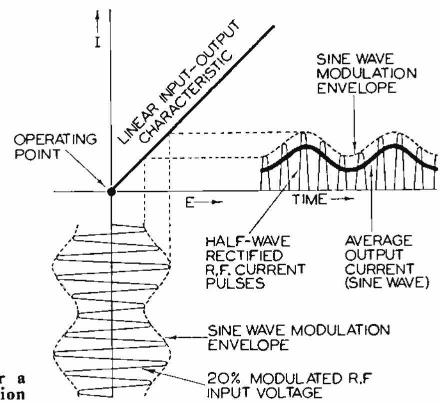

FIG. 4A. Action of a linear detector when the R.F. carrier input voltage is 20% modulated.

If the D.C. input voltage-D.C. output current characteristic curve of a detector is a straight line and the output current is zero when input voltage is zero (or is made such by inserting a D.C. bias voltage in series with the input voltage), we have *linear* detection. Under this condition a sine wave R.F. input voltage will undergo complete half-wave rectification and the average value of the output current will be directly proportional to the R.F. input voltage. Thus, if the input voltage is doubled, the output current will also be doubled; if the input voltage is tripled, the output current will be tripled.

If the D.C. input voltage-D.C. output current characteristic curve bends upward according to a square law relation and the inserted D.C. bias voltage is such that an output current flows when the input R.F. voltage is zero, there is incomplete rectification, with current increases being greater than current decreases. The difference between the increases and decreases constitutes the detector output current, and since this output current is at all times proportional *to the square of* the input R.F. voltage, we have the condition for *square law detection.* Thus, if the R.F. input voltage is doubled, the average value of rectified output current will be increased four times, and if the input voltage is tripled, the average value of rectified output current will be increased nine times.

Curve *A* in Fig. *3* is an example of a perfect linear input voltage-output current characteristic curve for a detector, while curve *B* is an example of a perfect square law curve. Remember that these are ideal curves; in actual tubes you will more often encounter something like curve *C*, which is a combination of linear and square law curves.

Linear Detection. The demodulating action of a linear detector is shown graphically in Fig. *4A* for the case where the R.F. input voltage has 20% modulation. The D.C. bias voltage applied in series with the R.F. input is so chosen that when the R.F. voltage is zero, the output current will be zero. (Crystal detectors and diode vacuum tube detectors generally do not require this D.C. bias.) When the modulated

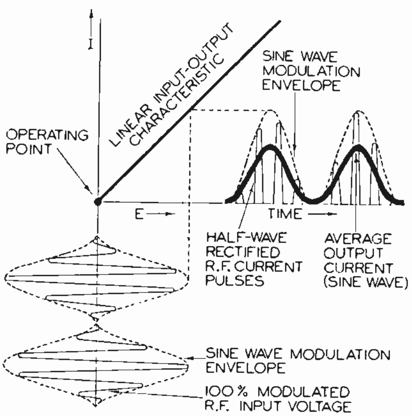

Fig. 4B. Action of a linear detector at 100% modulation.

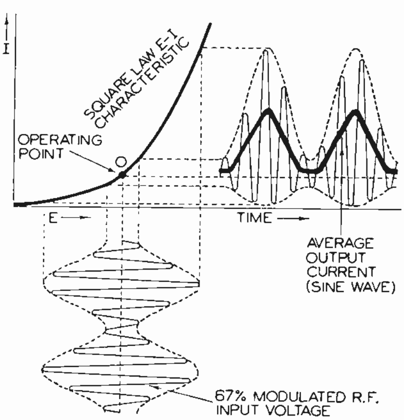

Fig. 5. Action of a square law detector.

R.F. input voltage wave shown in Fig. *4A* is applied to this linear detector, exactly half of each R.F. cycle will be cut off, giving half-wave rectification, and the resulting output current will consist of many pulses whose peaks vary in accordance with the modulation envelope, as shown at the right in Fig. *4A*. These pulses of direct current are allowed to flow through a resistor or other load device, and the resulting *average* output current will have the wave form represented by the heavy line curve in Fig. *4A*. This current develops across the load a voltage of similar wave form, exactly like the modulation envelope of the R.F. input if the detector is working properly. A condenser connected across the load not only provides signal separation by providing a path around the load for the R.F. components of the output current, but also acts as a filter condenser (like the input condenser in a power pack filter system) which raises the average current through the load resistor because of its charge and discharge action on each R.F. cycle. This shunting condenser is often effective enough to make the average load resistor current almost correspond to the peaks of modulation.

Either a mathematical or a graphical analysis will show that with linear detection the amplitude of the variations in output current depends upon the percentage modulation as well as the amplitude of the R.F. carrier. R.F. amplifiers in a receiver will increase the amplitude, thus boosting the amplitude of the detector output current, but nothing in a receiver can change the percentage modulation of a signal. It is therefore desirable to use the highest permissible modulation percentage at the transmitter. Figure *4B* shows clearly that increasing the percentage modulation to 100% (without changing the carrier level) increases the amplitude of the average sine wave output current, thus increasing the volume of the sounds produced by the loudspeaker or increasing the brightness of the picture formed on the cathode ray tube screen. Thus, when a receiver is tuned to a certain station and the operator at that transmitter *increases* the percentage modulation while holding the carrier level constant, *the demodulated output of the detector will increase* regardless of the type of detector used.

Square Law Detection. When an *unmodulated* R.F. carrier is fed into a detector tube which has a *square law* input voltage-output current characteristic, considerably more current will flow on positive swings of the input R.F. voltage than on negative swings, provided that the input voltage does not swing beyond the square law region of the curve. Picture this condition for curve *B* of Fig. *3*. Assume that the operating point has been placed at x by adding a D.C. bias of one volt in series with the R.F. input voltage. A current of 1 ma. will then flow when the R.F. voltage is zero. If an unmodulated R.F. carrier having a peak voltage of 1 volt is applied, the current will increase to 4 ma. on the positive half-cycle and decrease to 0 ma. on the negative half-cycle. The 3 ma. increase of current on the positive half-cycle is thus off set by a 1 ma. decrease on the negative half-cycle, giving a resultant increase of 2 ma.

We will get this same resultant current increase at any other operating point on the square law curve. For example, a one-volt positive swing from operating point y will produce a 5 ma. current increase ($9 - 4 = 5$) and the corresponding negative voltage swing will cause a 3 ma. decrease in current; the resultant current increase is $5 - 3$, or 2 ma., as before.

Now let us consider the action of a square law detector when the R.F. carrier is modulated with a sine wave signal. The graph in Fig. *5* shows you exactly what happens when a modulated carrier is fed into a square law detecting device having operating point *O*. Clearly the curve for average output current is not a true sine wave; the distortion is far beyond acceptable limits. (For 100% modulation, the distortion would be 25%). Although a square law detector *always distorts the demodulated signal,* satisfactory results (negligible distortion) are secured when the modulation is below about 20% or when a special push-pull circuit (to be described later) is used to cancel out some of the effects of the distortion. In ordinary detector circuits, *linear detection gives the least distortion of strong signals.*

Combination Linear-Square Law Detection. As has already been pointed out, many detectors have part-linear, part-square law curves.

By choosing the proper operating conditions, one of these detectors can be made to operate as a square law detector at low carrier voltages and as a linear detector at high carrier levels. Curve *C* in Fig. *3* represents this condition when the operating voltage *E* corresponds to point *x*; large positive swings of R.F. voltage give essentially linear increases in current, while large negative swings of R.F. voltage give decreases in current which are so small that they can be neglected.

All linear detectors in actual receivers have both square law and linear action to some extent, with the linear characteristic predominating for strong signals and the square law characteristic for weak signals. A detector with both characteristics has better sensitivity when operating as a square law detector (on weak signals) than as a linear detector (on strong signals).

With combination linear-square law detection, the detector circuit is adjusted so the operating point will be at the *point of greatest curvature* on the input voltage-output current characteristic curve of the detector. For curve *C* in Fig. *3*, this will be point *x*, at the bend of the curve.

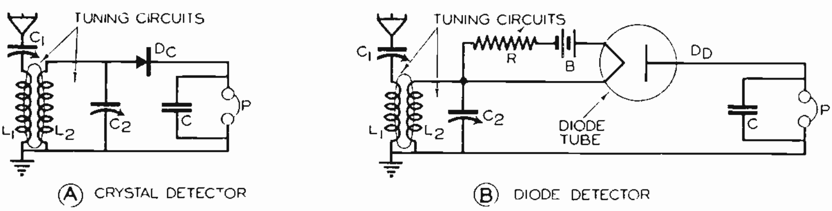

Fig. 6. Two early detector circuits.

Up to this point we have discussed the general behavior of detectors from the standpoint of their input voltage-output current characteristics. Now we will take up the various detector circuits individually and analyze their behavior in detail, starting with two of the earlier detectors.

THE CRYSTAL DETECTOR

Before the days of vacuum tubes, practically every radio receiver contained a crystal detector; even today you can purchase "crystal sets" in many radio stores, for they give acceptable reception of local broadcasts with ample volume for headphone use.

A crystal detector circuit which has been widely used is shown in Fig. *6A*; parts C_1 and L_1, mutually coupled inductively to L_2 and C_2, are tuning circuits. Condenser *C* provides a path for R.F. currents around the phones; the entire modulated R.F. voltage is thus applied to crystal detector D_C, which acts as a rectifier in cutting off one-half of each R.F. cycle. No. D.C. bias is required to get zero output current when the input voltage is zero. The R.F. components in the pulsating current are smoothed out or by-passed by condenser *C*, so that only intelligence signal currents flow through the headphones. The diaphragms in the headphones respond to these currents and reproduce the original intelligence signal. Thus rectification takes place at the crystal, and signal separation occurs at the load (at the headphones). There is no amplification in a crystal detector.

Many variations in the R.F. tuning circuits were used, some giving greater R.F. output and others better selectivity; a dry cell was often placed in series with certain types of crystals to place the operating point at the point of maximum curvature on the detector characteristic curve, thus improving detection. The crystals used were either of galena, iron pyrites, silicon, carborundum or combinations of these minerals. A fine phosphor bronze wire, often called a "cat's-whisker" because it was about as thin and springy as the whisker of a cat, was filed to a point at one end and used to make contact with a sensitive spot on the crystal.

Any one who uses a crystal detector soon realizes that it is in general a delicate device; strong signals tend to burn the crystal at the point of contact, and the slightest jar necessitates resetting of the "cat's-whisker." Fixed crystal detectors, made by mounting a piece of carborundum permanently against a soft metal disc, do not require adjustment but are considerably less sensitive (give poorer rectification).

In certain foreign countries where radio receivers are taxed according to the number of tubes which they contain, copper-oxide rectifiers having elements about the size of a pinhead are used as detectors. Early commercial receivers generally utilized two or even more crystals, with switches to change from one to another, thus making reception more dependable.

EARLY DIODE DETECTORS

The first vacuum tube to be developed by Dr. Fleming for radio purposes was a diode containing simply a filament and a plate; this half-wave rectifier tube, when connected in place of the crystal detector to form the diode detector circuit shown in Fig. *6B*, gave greatly improved results; a battery connected in series with the tube, so that the plate was biased positively with respect to the cathode, improved detection even more at low carrier intensities by making the tube operate at the point of maximum curvature on its characteristic curve. Diodes had none of the faults of crystals; a diode tube was able to handle large R.F. voltages, and did not require continual adjustment. These early tubes were less sensitive than a crystal detector, and were also costly and difficult to obtain, so the early diode detector circuit had a rather limited use. The operating principles of the diode detector are exactly the same as those of the crystal detector, hence rectification takes place at the diode tube and signal separation is obtained at the load.

GRID LEAK-CONDENSER DETECTORS

Dr. Lee De Forest, who introduced into the vacuum tube a third element or grid, found that his triode tube gave phenomenal results in the circuit shown in Fig. *7A*. Actually he had a diode detector with resistor R_g as its load and the grid current of the tube as its output current, plus one stage of audio amplification. This was the origin of the *grid leak-condenser detector* which proved so popular for a time as a detector of weak carrier currents. The grid leak-condenser detector is an excellent example of a circuit which gives square law detection on weak signals and linear detection on strong signals. Although grid detection can be secured with triodes, tetrodes or pentodes, we will for simplicity consider only the more widely used triode circuits.

How a Grid Leak-Condenser Detector Works. The action of a grid leak-condenser detector is exactly the same for both linear and square law detection. A typical circuit is shown in Fig. *7A*; when no R.F. signal is present in the input, the grid is at a small negative potential, even though there appears to be no fixed bias voltage. This condition occurs because some of the electrons which flow from filament to plate under the influence of the plate voltage will hit the grid, then flow through grid

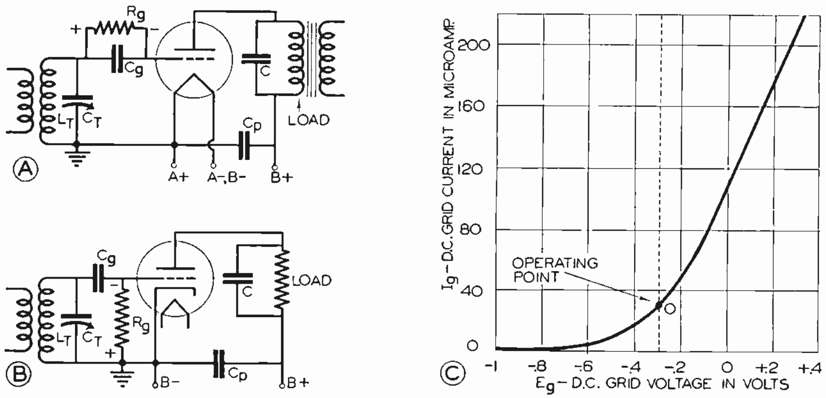

FIG. 7. Circuits and characteristic curve illustrating the operating principles of a grid leak-condenser detector. Although the grid voltage-grid current curve shown here is for a type 27 triode tube, it is representative of all triode tubes.

resistor R_g to ground. This grid current flow will give to the terminals of R_g the polarity indicated, and thus the grid will have a negative bias which is equal in value to the voltage drop in R_g.

The action of a grid leak-condenser detector is best illustrated by means of a grid voltage-grid current curve like that shown in Fig. *7C*. This curve was obtained by applying various positive and negative D.C. voltages to the grid of a detector tube (in a special measuring circuit) while plate voltage was constant at normal operating value, measuring the grid current flow with a D.C. microammeter, and plotting the values obtained. The operating grid voltage for a particular grid leak-condenser detector circuit such as that in Fig. *7A* can be approximately determined by measuring the grid current when there is no R.F. signal input, and multiplying its value in amperes by the ohmic value of R_g.

The incoming modulated R.F. carrier voltage (developed across tuning circuit L_T-C_T in Fig. *7A*) is applied directly to the grid-cathode terminals of the tube, since grid condenser C_g has a negligibly low reactance at radio frequencies. In the case of square law detection, which is used only for weak signals, this carrier will have peak values of about

.5 volt or less, and will swing the grid alternately positive and negative about the operating point (about point O in Fig. *7C*).

The grid current increases considerably more on a positive R.F. voltage swing than it decreases on a negative swing (because of the bend in the E_g-I_g curve in the region of the operating point), with the result that rectification of the R.F. input signal takes place in the grid circuit. Since the rectified grid current depends upon the input voltage, the voltage drop which this rectified current produces across the grid leak-condenser combination will vary in accordance with the modulation envelope of the input signal.

The desired demodulated signal voltage developed in the grid circuit is applied directly to the grid and cathode of the tube, producing corresponding variations in plate current. The incoming modulated voltage is also acting on the grid, and consequently there are both modulated R.F. signals and intelligence signals in the plate circuit. By-pass condenser C (ordinarily about .002 mfd.) separates these R.F. currents from the desired demodulated current, and by-pass condenser C_p provides a path for the R.F. currents to ground. Thus we have rectification and signal separation *in the grid circuit,* amplification by the tube, and a second separation of signals in the plate circuit.

For satisfactory detection of weak signals (lower than .25 volt), grid resistor R_g should have a value somewhere between 2 and 10 megohms, and grid condenser C_g should be about .00025 mfd. This places the operating point in the vicinity of point O on Fig. *7C*, insuring that the R.F. input signal will not swing beyond the square law portion of the curve.

For satisfactory detection of strong signals (as high as 5 volts), the grid resistor should be between .25 and .5 megohm, with about a .0001 mfd. grid condenser. The operating point is still in the vicinity of point O, but the high input voltage swings the grid so far up along the linear part of the curve in Fig. *7C* that the effects of the curved region in the curve are negligible and detection is essentially linear. No appreciable grid current flows on negative swings of the R.F. input voltage, and hence there is practically perfect rectification of the input signal.

Distortion in Grid Leak-Condenser Detectors. Frequency distortion (unequal response to different audio frequencies) in receivers employing grid leak-condenser detectors can often be traced to incorrect values of C_g, R_g, or the load by-pass condenser C. Incorrect load impedance values can also cause amplitude distortion (introduction of undesired harmonics during amplification).

With a grid leak-condenser circuit adjusted for detection of weak signals, distortion becomes severe as soon as signals exceed a certain value (because rectified grid current is then not proportional to the applied grid voltage). Likewise, when a grid leak-condenser detector is adjusted for satisfactory detection of strong signals by using a grid resistor of low ohmic value, it will not be sensitive on weak signals.

A grid leak-condenser detector circuit may also be in the form shown in Fig. *7B*, where the grid resistor R_g is connected directly between grid and ground. The operation of this circuit is exactly the same as was given for the circuit in Fig. *7A*. Condenser C_g is a low-reactance path for the R.F. input currents, and serves to filter out any R.F. components in the rectified grid current which flows through R_g.

THE REGENERATIVE DETECTOR

The output of a simple weak-signal grid leak-condenser detector circuit such as has just been described is rather low; some years ago Major Armstrong made use of regeneration in the detector circuit in order to increase detector sensitivity. The modulated R.F. plate current *in the plate circuit* of the detector was fed back into the grid input circuit in order to reinforce the incoming modulated R.F. carrier voltage. Naturally a means of controlling the amount of feed-back was necessary, for ex-

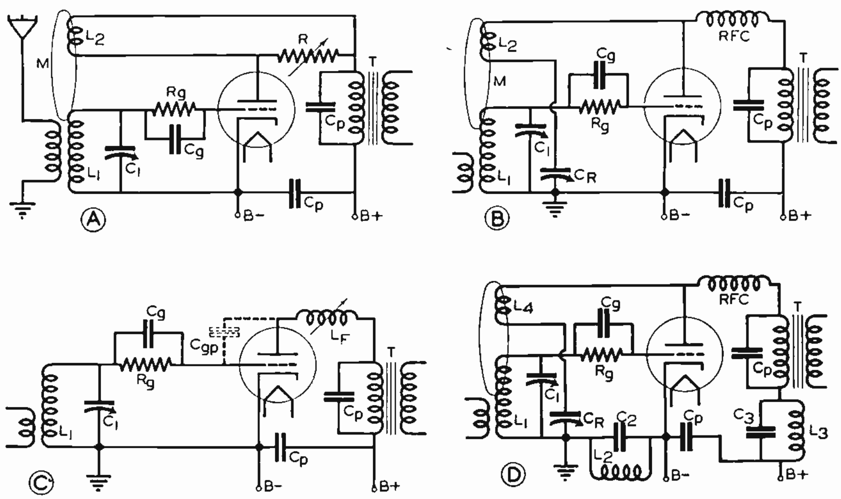

FIG. 8. Examples of regenerative and super-regenerative detector circuits.

cessive feed-back resulted in oscillation and complete destruction of the modulation envelope of the carrier.

One form of regenerative grid leak-condenser detector circuit is shown in Fig. *8A*. The grid circuit of the tube is exactly the same as that of the grid leak-condenser detector, but tickler coil L_2 feeds the modulated R.F. plate current back to the grid circuit, where it induces in the grid tank circuit, through mutual inductance M, the desired amount of R.F. voltage. Variable resistor R, connected across the tickler coil, controls the amount of feed-back. Some receiver builders vary the mutual inductance between coils instead of varying R in order to control feed-back voltage.

Another form of regenerative detector is shown in Fig. *8B*. Variable condenser C_R is here in series with tickler coil L_2 between plate and ground. Varying the setting of C_R controls the amount of R.F. current flowing from the plate circuit to ground and hence controls the regeneration; increasing the capacity of C_R increases regeneration. (The exact amount of feed-back voltage here depends upon the mutual inductance M, the frequency of the R.F. current, and the amount of R.F. current flowing through coil L_2.)

It is a well known fact that when the plate circuit of a triode tube is made inductive, any R.F. voltage in the plate circuit will feed back through the grid-to-plate capacity C_{gp} to the grid circuit and reenforce the grid input voltage. Figure *8C* is an example of a circuit using this type of feed-back. Coil L_F makes the plate circuit inductive; varying its inductance controls the amount of feed-back.

Disadvantages of Regenerative Detection. Regeneration reduces the effective resistance of the grid tank circuit L_1-C_1, making this resonant circuit very selective *for the desired signal*, but this is accompanied by attenuation of side-band frequencies and severe frequency distortion (for code reception and reception of ordinary speech, this frequency distortion is not at all objectionable, hence regenerative detectors may still be found in certain commercial receivers). When a regenerative detector having a simple tuned input circuit is used in a location where there are a number of high-power broadcasting stations, regeneration is effective only in improving selectivity for the particular signal being tuned in. All other signals enter the receiver circuits without undergoing regeneration, and consequently some may be strong enough to interfere with the desired program. In this case regeneration is of little or no value, for the over-all selectivity of the detector is poor and fidelity is reduced.

Furthermore, a regenerative circuit goes into oscillation quite easily, especially when condenser C_1 is adjusted from a low to a high frequency. The resulting oscillations are radiated by the receiving antenna just as if the receiver were a small transmitter, and interference is created in neighboring receivers. In addition, an annoying squeal is usually heard from the receiver itself, for the frequency of oscillation generally differs only slightly from the frequency of the desired incoming signal, and the resulting beat frequency is in the audio frequency range.

When interrupted continuous wave code signals are being received, a regenerative or oscillating detector produces a desirable tone; the accompanying radiation of interference can be eliminated by placing a stage of tuned R.F. amplification ahead of the regenerative detector.

SUPER-REGENERATIVE DETECTORS

A regenerative detector is "super-sensitive" or has its greatest sensitivity when just on the verge of going into oscillation. The one great practical difficulty encountered when this adjustment is made is that small increases in carrier input will set the circuit into oscillation, and once this occurs, decreases in carrier intensity will not stop the oscillation.

Major Armstrong eliminated these difficulties with the super-regenerative detector, a circuit based upon the principle that it takes a certain amount of time for a detector to go into oscillation. If the feed-back can be reduced quickly enough during this interval of time, oscillation can be prevented. This feed-back can be reduced temporarily either by increasing the negative C bias in the grid circuit or by decreasing the plate voltage; either can be accomplished by introducing into the regenerative detector circuit *a varying voltage,* which may be sinusoidal in wave form, and which is known as the *quenching signal.* The quenching frequency must be somewhat higher than the intelligence signal frequency, for otherwise it would create interference; for code and speech reception a quenching frequency of between 10 and 20 kc. is quite satisfactory.

A super-regenerative detector circuit, in which the tube acts both as a regenerative detector and as an oscillator for producing the quenching frequency, is shown in Fig. *8D*. Resonant circuit C_2-L_2 in the grid circuit and C_3-L_3 in the plate circuit act in conjunction with the tube as an oscillator, with feed-back being provided either by the grid-to-plate capacity of the tube or by mutual induction between coils L_4 and L_T. A separate oscillator may, of course, be used to produce the quenching frequency; this is often done in order to secure independent control of the quenching signal.

C BIAS DETECTORS

With the development of high-gain R.F. amplifiers, the need for a sensitive or super-sensitive detector became less important. Detectors which were free from amplitude and frequency distortion and which were able to handle large R.F. input voltages were required. An ordinary vacuum tube amplifier operated with a C bias almost large enough to cut off plate current met these requirements and became known as a C bias detector. Automatic C bias, secured from a resistor in the cathode lead, is almost universally used in C bias detectors to provide the C bias voltage. The C bias vacuum tube detector simultaneously amplifies and rectifies the incoming modulated R.F. carrier, and since it is the bend or curvature in the *plate current-grid voltage* characteristic curve which produces rectification, C bias detection is often called *plate bend detection* or simply *plate detection.* A.C. bias detector is also known as an *infinite impedance* detector.

The E_g-I_p characteristic curve of a C bias detector may be either linear or square law in form beyond the bend. The square law C bias detector is used comparatively little today in radio receivers. The linear C bias detector, on the other hand, is today one of the most popular detector circuits for applications where the detector must provide amplification. A linear C bias detector is capable of handling large input voltages with relatively little amplitude distortion.

THE SQUARE LAW C BIAS DETECTOR. This type of detector is sometimes used as a first detector in superheterodyne receivers. In addition, its rectifying action has a special use in certain measuring circuits, as well as in circuits which serve as primary standard sources of unmodulated R.F. voltage (sources whose voltages can be determined with great accuracy and used in calibrating other instruments).

The process of rectification of an R.F. voltage always involves the production of even harmonics of this R.F. input voltage, the second harmonic being of course the strongest; these even harmonic currents flow in the plate circuit. The square law C bias detector has one outstanding characteristic; the peak value of the second harmonic current in the plate circuit is always equal to the increase which occurs in D.C. plate current when the R.F. input voltage is applied; this characteristic is utilized in the so-called *microvolter* circuit, an arrangement for securing R.F. voltages of known value which can be measured accurately with an ordinary D.C. meter.

It will be of interest to look over the microvolter circuit shown in Fig. *9A* at this time, in order to see how square law C bias detection is utilized in a practical circuit. The R. F. input voltage is fed into the primary winding of transformer *T*. The secondary winding feeds directly into the control grids of the two tubes, with the center tap of the winding connected to the common cathode lead through a C bias battery; the grid excitation voltages for the two tubes are thus 180 degrees out of phase. The operating point is on the

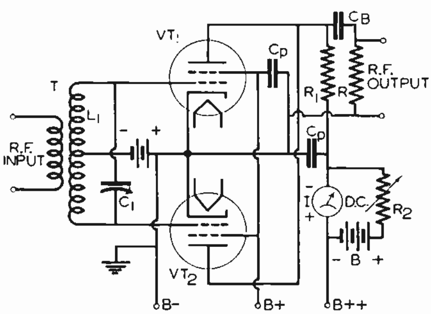

Fig. 9A. Microvolter circuit in which square law detection is used to provide an R.F. output voltage which can be accurately measured with an ordinary D.C. meter. The output frequency is twice the input frequency, for this circuit eliminates the fundamental and all odd harmonics.

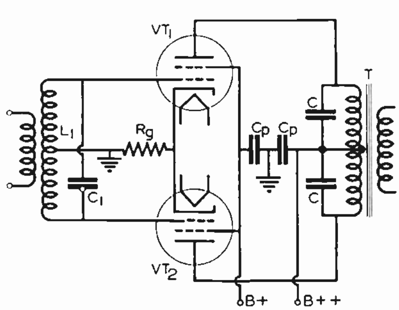

Fig. 9B. Square law detector circuit using a push-pull arrangement. This circuit eliminates even harmonics produced in the process of detection.

bend of the characteristic curve for each tube, just as for square law detection, and hence there is partial rectification and the production of even harmonics at each tube. The plates of the two tubes are connected together and feed into a load made up of R_1, C_B and R. Under these conditions there is *complete cancellation of the fundamental input frequency and reenforcement of its even harmonics*. Clearly, then, no fundamental frequency current reaches the load; furthermore, the second harmonic current in the load is so strong that all other even harmonics can be neglected. The frequency of the R.F. output voltage across load resistor R will therefore be twice the input frequency.

When there is no R.F. excitation on the grids, the D.C. plate current assumes its operating value. The application of R.F. sends second harmonic current through load resistor R, causing the D.C. plate current to increase. (Since R_1 is at least 100 times greater in ohmic value than R, little second harmonic current flows through R_1.) Variable resistor R_2 and battery B are adjusted to make the meter read zero when there is no R. F. excitation; the meter thus reads only D.C. current increase and this increase is exactly equal to the peak value of the second harmonic current. The peak value of the second harmonic R.F. voltage across R is obtained by multiplying the ohmic value of R by the increase in D.C. current in amperes as measured by D. C. microammeter I.

Square law detectors arranged in a push-pull circuit as shown in Fig. *9B* will suppress rather than reenforce all even harmonics resulting from rectification. As you can see, the input R.F. carrier voltage is divided into two equal but out-of-phase components by the mid-tap of coil L_1. The square law-rectified R.F. current outputs of each tube are fed to the primary of audio transformer *T*. Condensers *C* by-pass through C_p to ground all R.F. currents, and the even harmonics of the demodulated signal are cancelled out by the output transformer just as in a regular push-pull circuit. Thus only the fundamental demodulated signal and possibly a few very weak odd harmonics pass through the output transformer. The only disadvantage of this circuit is, of course, the fact that two tubes are required; occasionally, however, push-pull C bias detectors of either the linear or combination square law and linear type are used to give high-fidelity detection in broadcast receivers.

THE LINEAR C BIAS DETECTOR. The linear C bias detector is really a vacuum tube amplifier stage which is operated at a high enough plate voltage and with a high enough plate load resistance (for intelligence signal frequencies) to make the dynamic E_g-I_p curve of the tube practically straight or linear. The automatic C bias is adjusted to

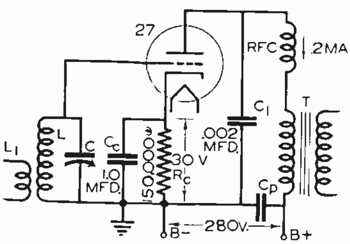

FIG. 10A. Linear C bias detector circuit using a triode tube. The voltages and parts values required for linear detection are indicated.

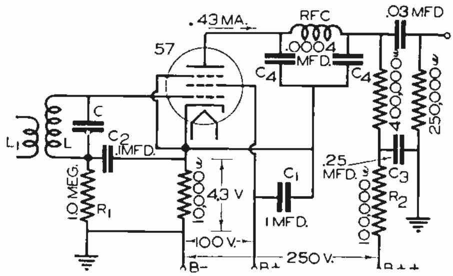

FIG. 10B. Linear C bias detector circuit using a pentode tube, with voltages and parts values indicated. Choke *RFC* and condensers C_4 together have a resemblance on this diagram to the Greek letter π (pi), and hence are known as a pi filter.

place the operating point at or near the plate current cut-off point, so one-half of each R.F. cycle is removed in this process of detection, exactly as shown in Figs. *4A* and *4B*.

Triode Circuit. A typical linear C bias detector circuit using a triode tube is shown in Fig. *10A*. Cathode resistor R_c provides an automatic C bias which is high enough to reduce plate current almost to zero when there is no R.F. input signal. When a modulated R.F. signal is applied to the detector input, a voltage of similar wave form is induced in coil *L*. Since *L* and *C* form a series resonant circuit which is tuned to the R.F. input signal, the voltage induced in *L* undergoes resonant step-up before being applied to the grid of the tube for simultaneous rectification and amplification. The resulting plate current is a series of R.F. pulses whose amplitudes and average values vary according to the modulation signal. Condenser C_1 and choke *RFC* serve to keep R.F. out of output transformer *T* and smooth the pulses, with the result that only the desired intelligence signal is transferred through *T* to the detector load.

Pentode Circuit. Another linear C bias detector circuit, using a type 57 pentode tube which gives relatively high output voltages even for weak input signals, is shown in Fig. *10B*. The operating point is near cut-off, as before. Condensers C_4 and choke *RFC* form a special filter system which is called a *pi filter* and which serves to keep any unrectified R.F. plate current out of the load. This filter, if properly designed, has little effect upon the load resistance at any modulation frequency.

Variations in the current flowing through the cathode resistor are kept out of the grid circuit by filter R_1-C_2. (These variations have the same wave form as the input signal but are out of phase with it, so if allowed to get back into the grid circuit they would cause a reduction in input signal voltage, which is degeneration.) A.F. currents in the plate circuit are by-passed to ground through C_3, and reach the cathode through the cathode resistor. Any ripple in the power supply is filtered out by R_2-C_3. Condenser C_1 is an R.F. by-pass path to cathode for the screen grid.

DETERMINING DETECTOR EFFECTIVENESS

You have undoubtedly observed that the exact values for each important part are specified in the circuits of Figs. *10A* and *10B*. It will be interesting to see how these values are determined, and learn what parts they play insofar as detector effectiveness is concerned. Ordinary input voltage-output current characteristic curves are unsuited for a practical analysis such as this; instead, we must deal with input R.F. voltage-demodulated output voltage characteristics, which tell us immediately how much the output intelligence signal voltage will be for a given input R.F. carrier level and given percentage modulation. Although these input-output voltage curves apply to all detectors, we shall consider only that for a typical linear C bias detector; it will serve to show how the effectiveness of any detector can be determined. Let us first see how such a curve is obtained, then investigate its uses.

Securing a Detector Input-Output Curve. When there is no R.F. input to a linear C bias detector which is biased nearly to cut-off, the plate current will be very low, and the D.C. voltage drop across the plate load will likewise be low. If an unmodulated R.F. signal is applied to the input, the D.C. output voltage will increase. When we measure this output D.C. voltage for various values of input carrier voltages, and plot the results on a graph, we will obtain the *input-output voltage curve* shown in Fig. *11*.

The application of a modulation signal to a carrier changes the carrier level from instant to instant, as you already know. In our linear C bias detector, each change in carrier level results in a corresponding change in D.C. output voltage, so if the detector is essentially linear in its action, the changes in this output voltage will correspond exactly to the desired demodulated intelligence signal. All this is shown in Fig. *11;* by projecting points on the modulation envelope of the input signal up to the input-output curve and then over to the right, we get the A.F. output voltage curve.

An input-output voltage curve also tells when distortion will occur. A study of Fig. *11* will reveal that as long as the modulation envelope swings over a linear part of the input-output curve, any curvature near the operating point on the curve will not affect the wave form of the output voltage. Signals with low carrier levels or high modulation percentage (near 100%) consequently undergo distortion in a linear C bias detector having the characteristic shown in Fig. *11*.

Checking for Amplitude Distortion. The values of operating voltages and circuit parts for a detector can be so chosen that distortion will not occur over the operating range. Usually it is necessary to set up an actual detector circuit such as that in Fig. *10A* or *10B*. To check for amplitude distortion, an unmodulated R.F. carrier is fed into the circuit at various levels, the output D.C. voltage is measured for each level, and the results are plotted in the form of an input-output curve. If this curve is straight over the range of carrier levels which the detector is to handle, and is straight for a sufficient distance outside this range so the grid cannot swing beyond the linear portion at the maxi-

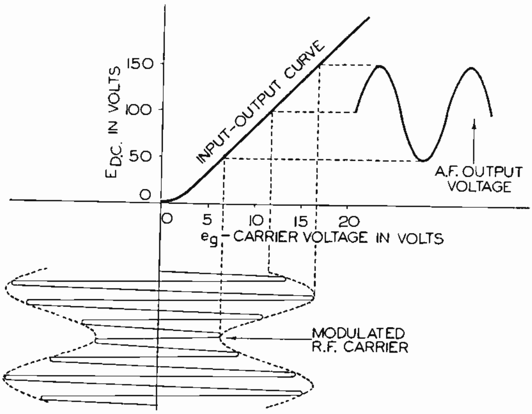

Fig. 11. Operation of a linear C bias detector is here shown by an input-output curve, in which A.C. input voltage (peak or r.m.s.) is plotted against resultant rectified output D.C. voltage, peak A.C. values being shown in this case. Variations in the level of the input signal due to modulation cause corresponding variations in the D.C. output voltage, with the result that we get the desired A.F. output voltage out of our detector. An input-output curve like this for a detector is also known as a dynamic detector characteristic curve.

mum percentage modulation to be encountered, you know there will be no amplitude distortion.

Checking for Frequency Distortion. This must likewise be done experimentally. A modulated R.F. carrier is fed into the detector, and the frequency of modulation is varied over the entire audio or video range while keeping the carrier level and modulation percentage constant. If the output modulation voltage remains constant throughout this test, all modulation frequencies are being amplified equally well and there is no frequency distortion.

These experimental procedures for determining whether distortion exists in a linear C bias detector can also be used for other types of detectors. If distortion is present, the operating voltages and parts values are varied until satisfactory operation is obtained. Only designers of detector circuits ordinarily go through this procedure, but a knowledge of it is valuable when trouble develops due to failure of some part or voltage.

In general, when any resistor in a detector circuit requires replacement and the original value is not known, the electrical value of the replacement part should be adjusted until rated D.C. plate current flows when no signal is applied to the grid, after making sure that all other electrode voltages are normal. This is the usual procedure followed by radio servicemen.

Distortion in C Bias Detectors. Radio servicemen give altogether too little attention to the subject of detectors, for they fail to realize that a defect in a detector or a change in electrode voltages can cause plenty of distortion. Once the reasons for distortion in detectors are understood and the effects of distortion on the reproduced signal are recognized, changes can be made in electrode voltages and circuit parts of the detector stage to correct the undesirable condition.

Specific reasons for distortion in C bias detectors will now be considered, primarily to show the importance of having the correct electrical values for the various parts in the circuit. The importance of the R.F. by-pass condenser or pi filter which is connected across the plate load requires special emphasis; with a condenser alone, its capacity must be low enough to prevent frequency distortion in the plate circuit. The correct value for this capacity is especially important in the case of second detectors in superheterodyne receivers which are fed by a low I.F. value, for too large an R.F. by-pass condenser across the plate load of a C bias detector would by-pass the higher audio frequencies, causing frequency distortion. The problem is even more serious in the detector of a television receiver, where the I.F. carrier may be about 15 megacycles and the highest modulation frequency about 3 megacycles; carefully designed pi filters are required in this case.

When all electrode voltages are correct in a C bias detector circuit yet distortion occurs, the grid may be swinging positive and cutting off the peaks of modulation. If a D.C. microammeter inserted in the grid return circuit indicates a flow of grid current, you have proved that this is the trouble. Reducing the level of the R.F. carrier input is a positive cure.

When weak carrier signals are not detected and strong carrier signals are heard but considerably distorted, measure the D. C. plate current when no carrier is applied. If this current is unusually low, it is safe to assume that the C bias voltage is too high; reduce the ohmic value of the bias resistor after making sure that no undesirable currents are flowing through it and raising the bias. If the D.C. plate current is high under this same condition of no carrier input, the C bias value is too low and you will have to increase the ohmic value of the bias resistor. Thus you can see the importance of checking the D.C. plate current when working with a detector stage.*

The presence of gas in a detector tube makes any test misleading, so it is always best to check the tube before looking for trouble elsewhere. The presence of gas will usually cause a high plate current when there is no carrier input, even though electrode voltages are correct.

If a by-pass condenser opens and the plate load is inductive, regeneration or oscillation may occur when the receiver is tuned. Whenever regeneration, degeneration or oscillation is traced to the detector stage, check each of the by-pass condensers in turn for an open circuit or loss of capacity by placing across

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*The manner in which average D.C. plate current varies with the level of the R.F. input signal is a clue to the type of detector used in a particular circuit. With grid leak-condenser detectors, increases in input signal level cause *decreases* in average D.C. plate current, while in all other types of detectors, increases in input level produce *increases* in average D. C. plate current.

it a new condenser; if an improvement is noticed in any case, the old condenser is defective and should be replaced.

The foregoing analysis refers to abnormal amounts of distortion. Some distortion is always present in any detector stage, and its amount can be determined only by actual distortion tests with laboratory equipment. This is a job for the designer rather than the radio serviceman.

THE LINEAR DIODE DETECTOR

The need for a detector which contributes a certain amount of gain in addition to demodulating the signals is less important today than high quality demodulation, since high gain R.F. amplifiers are now easily built. Radio engineers have therefore returned to the diode detector, a modern version of the first Fleming two-electrode tube which was so outstanding in the very early days of radio.

A diode detector is really a grid leak-condenser detector without its associated audio amplifier. It is simple and inexpensive to build, and

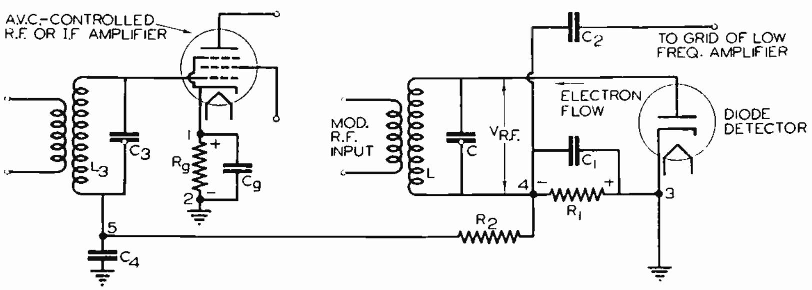


FIG. 12. The linear diode detector at the right serves the dual purpose of demodulating the incoming modulated R. F. carrier and supplying to the amplifier stage at the left (as well as other amplifier stages) a negative bias voltage whose value increases with carrier level and can therefore be used for automatic volume control (AVC).

will deliver a D.C. voltage which is about 1.4 times the effective value of the input carrier voltage; when the input carrier is modulated, the detector output voltage will vary with the modulation envelope. Another advantage of the diode detector is that it can deliver a D.C. voltage which is negative with respect to ground and which increases with increases in carrier level; this voltage can be employed for *automatic volume control,* commonly referred to as AVC. Other types of detectors do not deliver any suitable negative D.C. voltage such as this, making necessary the use of an additional tube if AVC action is desired.

The fundamental circuit of a diode detector, together with its preceding amplifier stage, is shown in Fig. *12.* An analysis of this circuit will show you how detection is secured and how the bias voltage required for AVC action is provided. We shall return to the conventional input D.C. voltage-output D.C. current characteristic curve for this, in order to make our analysis as simple as possible. Only when we want to know how well a detector performs is it necessary to study a D.C. input-D.C. output voltage characteristic curve.

Resonant circuit L-C, the last tuned circuit in the R.F. or I.F. amplifier, as the case may be, furnishes a modulated R.F. carrier voltage V_{RF} to the diode detector through condenser C_1. The diode acts as a half-wave rectifier, cutting off one-half of each R.F. cycle in exactly the same manner as is illustrated in Figs. *4A* and *4B*. Electron flow in diode detector Fig. *12*, is from the cathode to the plate, then through coil L, through diode load resistor R_1 to ground and cathode. This pulsating D.C. electron flow gives to R_1 the polarity indicated. Condenser C_1 serves to prevent the voltage across R_1 from dropping to zero during those R.F. half-cycles when there is no current flow through the tube. Because of this action of the condenser, the voltage across R_1 follows the R.F. peaks, as illustrated in Fig. *13A;* the larger the capacity of C_1 the more nearly will the voltage drop across R_1 follow the wave form of the modulation envelope. The capacity of C_1 cannot be so large, however, that frequency distortion occurs at the high modulation frequencies. The audio or video intelligence signal voltage is thus produced across resistor R_1; this voltage is fed to the first low frequency amplifier tube by connecting its grid to the negative terminal of R_1 through coupling condenser C_2.

The curves in Figs. *13B* and *13C* represent the voltage across R_1 for both low and high level carriers. As you can see, increasing the level of the carrier increases the average D.C. voltage drop across R_1. Let us see how this is utilized for automatic C bias on the preceding R.F. or I.F. amplifier tube.

Resistor R_g and condenser C_g in the amplifier stage in Fig. *12* together produce a negative C bias which is made the correct value for maximum R.F. amplification of the *weakest* input signal. When stronger carriers come in, the R.F. amplifier does not have to produce as much gain; in fact, its gain should be reduced to prevent distortion.

You already know that with variable mu or super-pentode R.F. tubes used as R.F. amplifiers, increasing the negative C bias reduces the gain. We can increase this bias by adding to it the negative voltage which is developed across resistor R_1 in the diode detector circuit. Instead of connecting the grid of the R.F. amplifier stage directly to ground it is connected through resistor R_2 to the minus terminal of R_1; the voltage drop between points *3* and *4* then adds to the drop between points *1* and *2* and increases the negative C bias on the amplifier tube when strong signals come through.

Resistor R_2 and condenser C_4 serve a very important purpose in connection with AVC action. Remember that the voltage across R_1 is made up of two components, a D.C. voltage whose value varies with carrier level, and a low frequency A.C. voltage corresponding to the intelligence signal; Fig. *13B* shows all this. Clearly we cannot use the A.C. component for C bias purposes, as it would modulate the R.F. amplifier.

R_2 and C_4 have no effect upon the D.C. component of the voltage across R_1, for no direct current is drawn through R_2 by the grids of AVC-controlled tubes, but they do serve to filter out the A.C. component of this voltage. R_2 may have a value of several megohms and hence offers considerable opposition to the flow of A.C. Whatever low frequency current gets through R_2 goes directly to ground through C_4 without affecting the grids of the AVC-controlled tubes, for C_4 has a negligibly low reactance to A.C.

If the time constant of this R_2-C_4 filter circuit is less than the time duration of one cycle of the lowest modulation frequency, the voltage between point *5* and ground will be practically pure D.C. at any given input carrier level.

The values of the various parts in the circuit are such that AVC action varies the C bias voltages on the controlled tubes just enough to keep the carrier level practically constant at the detector input. Thus an increase in input carrier level would increase the D.C. component of voltage across R_1, and a short time later would make the D.C. voltage between *5* and ground more negative, driving the grids of the controlled tubes more negative and reducing the gain enough to counteract the increase in input carrier level.

The time constant of R_2-C_4 must be short enough so that any rapid fading of the carrier signal will be compensated for immediately. If the time constant is too long, AVC action will be slow and amplification will be excessive when tuning quickly from a weak to a strong signal; the result is blasting or unpleasantly loud volume for a few moments, until C_4 adjusts itself to the new condition. A time constant of one-tenth second is commonly used. Condenser C_4 also serves as a low reactance path to ground for R.F. signals in the grid tank circuit of the amplifier.

Although AVC action is taken up more thoroughly elsewhere in the Course, it is introduced here to show you why the diode detector is preferred to the linear C bias detector in most radio receivers today.

A diode tube acts as a very high resistance when its plate is negative with respect to the cathode, and as a relatively low resistance when its plate is made positive by the R.F. carrier. This lower value of resistance varies with the carrier level, but if the diode load resistor R_1 is made large, the effect of this variation in resistance will be negligible.

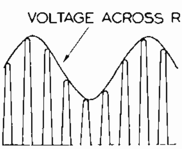


FIG. 13A. Action of condenser in building up the voltage between peaks in a diode detector circuit.

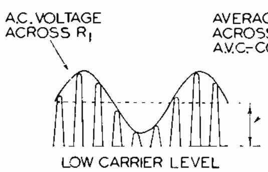


FIG. 13B. Wave form of voltage across a diode detector load resistor (R_1) at a low carrier level.

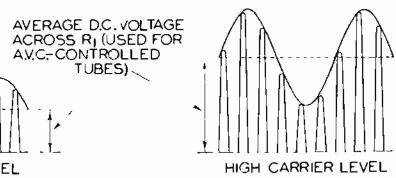


FIG. 13C. Wave form of voltage across a diode detector load resistor at a high carrier level.

The larger the ohmic value of the diode load resistor, the greater will be the rectified voltage developed across it. As was pointed out before, the maximum obtainable voltage is the peak voltage of the input carrier and hence is 1.4 times the effective voltage of this carrier; this maximum voltage can be obtained only when the load resistance is of high ohmic value. Under this condition the diode detector has a practically linear characteristic, which is highly desirable.

When designing a diode detector circuit, it is necessary to make some compromise between the values for R_1 and C_1; if R_1 is made too large, C_1 may have to be reduced in order to prevent frequency distortion. This increases the reactance of C_1, greatly reducing the R.F. voltage which is applied to the diode tube. A value somewhere between .25 and .5 megohm is usually chosen for R_1. The value of C_1 will depend upon the carrier frequency; for the 500 to 1500 kc. range, C_1 can be between 50 and 150 mmfd.; for the 260 to 500 kc. range, C_1 can be between 150 and 300 mmfd.; for the 175 to 260 kc. range, C_1 can be somewhere between 300 and 450 mmfd.

By employing the full-wave rectifier arrangement shown in Fig. *14A* as a detector, the value of C_1 can be reduced considerably. The action of the two diode sections of the tube is such that a full-wave rectified current flows through resistor R_1. Thus there are twice as many current pulses, and the average current is considerably higher than the value which would be obtained with half-wave rectification. This doubling of the resistor current makes it possible to reduce the resistance of R_1 and the capacity of C_1 while still securing the same rectified voltage as with a single diode detector.

Lowering of the values R_1 and C_1 decreases the time constant of the R_1-C_1 combination. Because of this decreased time constant, higher modulation frequencies will appear across R_1; a full-wave diode detector can thus be designed to give high fidelity performance. The nature of the output current for this full-wave detector circuit is shown in Fig. *14B*.

When the diode detector is used in a television receiver, it is often necessary to reduce the diode load resistor to a value of below 100,000 ohms. In addition, condenser C_1 is eliminated, R. F. filtering being provided by the inter-electrode capacity of the tube and by the shielded lead going to the grid of the first picture amplifier tube. This is necessary to prevent the attenuation of high modulation frequencies. The output voltage drops considerably, but this can be offset to a certain extent by using two diode tubes in parallel, as shown in Fig. *15*, which

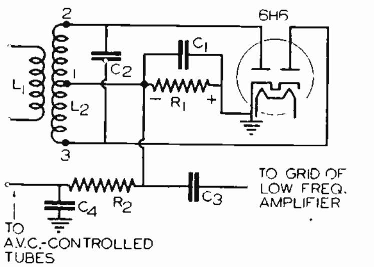


FIG. 14A. Full-wave diode detector circuit.

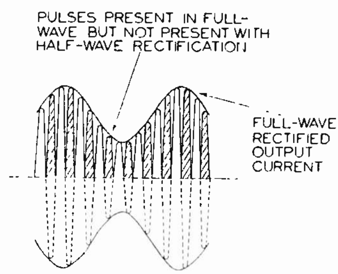


FIG. 14B. Output current wave for full-wave diode detector circuit.

represents a typical television picture signal demodulator circuit. Point *1* is shown grounded, but point *2* could just as well be grounded and the picture signal amplifier connected to point *1*.

Multi-Function Tubes. Tubes with twin diode sections and a triode or pentode section, all using a common cathode connection, are often employed in radio receivers in order to secure detection, AVC voltage and amplification from a single tube. There are many possible ways of using a three-in-one tube such as this; for example, a twin diode pentode could be used as an I.F. amplifier, a single diode detector, and a diode rectifier for independent AVC voltage production. In another case this tube might be connected as a full-wave diode detector followed by an audio amplifier stage.

The circuit in Fig. *16* shows how a triple-section tube can be used as an independent diode detector, a diode rectifier for AVC, and an audio amplifier stage. Diodes D_1 and D_2 are fed from resonant circuit L_1-C_1, with diode D_1 coupled to this resonant circuit through condenser C. The AVC voltage is developed across resistor R_3, while R_1 and C_4 now serve as the AVC filter. The demodulated signal voltage is developed across resistors R_2 and R_4, any R.F. in this voltage being filtered out by R_4 and condensers C_2 and C_3. The demodulated signal is impressed across volume control VC, and then fed to the grid of the pentode amplifier section. The C bias for the amplifier is obtained from another circuit. Thus a single tube serves three separate functions.

LINEAR POWER DETECTORS

Any linear detector which is capable of handling very large R.F. voltage (from about 5 to 50 volts) without distortion can be considered as a power detector. In superheterodyne receivers, where as many as five or six high-gain stages may precede the second detector, power detection is almost universally employed for the second detector. Power detection always involves *linear* detection, for square law detection gives severe distortion on strong signals having high modulation percentages.

Bear in mind that linear power detectors are simply ordinary detector circuits which are adjusted to handle large R.F. voltages without excessive distortion. A linear power detector may therefore be either a linear grid leak-condenser detector, a linear C bias detector or a linear diode

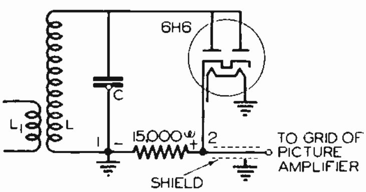
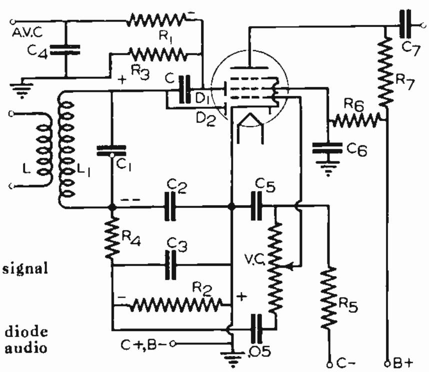


FIG. 15 (above). Typical television picture signal detector circuit.

FIG. 16 (at right). Triple-section tube used as diode detector, diode rectifier for AVC voltage and audio amplifier.



detector. Diode detectors are very widely used as linear power detectors for separating intelligence signals from their carriers, especially in sound and television superheterodyne receivers, where they serve as second detectors.

HETERODYNE OR BEAT DETECTORS

When two signals of different frequencies are mixed together and then fed into a detector, the resulting rectified current will include a current whose frequency is equal to the difference between the two original frequencies. This difference frequency is commonly known as a *beat frequency* or a *heterodyne frequency,* and the method by which it is produced is known as *heterodyne action.*

Uses for Heterodyne Detectors. Heterodyne action is used in every superheterodyne receiver, where the incoming R.F. carrier is mixed with the R.F. signal output of a local oscillator in the so-called mixer-first detector tube, producing the intermediate frequency signal.

Heterodyne detectors are also widely used for receiving continuous wave code transmissions. A local oscillator differing from the incoming carrier frequency by an audio frequency is fed into the beat detector along with the desired carrier, and the resulting difference frequency is an audio tone which is interrupted according to the code signals being sent.

A heterodyne or beat detector is often used to locate the carrier of a desired station when that station is so weak that it might ordinarily be passed over while tuning; this tuning aid is of great advantage in short-wave reception.

Two R.F. signals are mixed together and then fed into a heterodyne detector in order to obtain a desired audio frequency signal in the widely used test instrument known as an audio beat frequency oscillator.

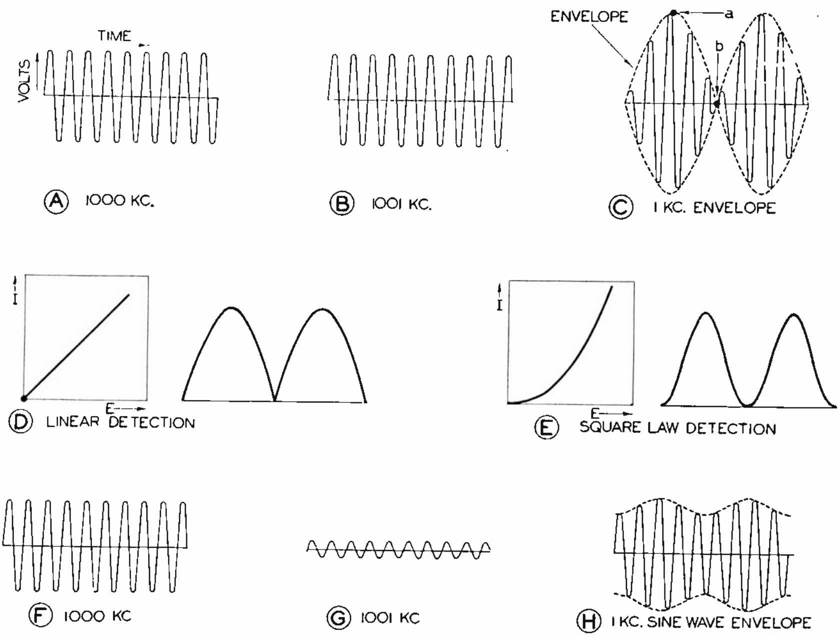


Fig. 17. Action of a heterodyne detector.

These uses for the heterodyne detector have been brought up simply to show its importance in radio today.

How a Heterodyne Detector Works. The action of a heterodyne detector can be best understood by a study of the wave form curves in Fig. *17*. When two R.F. signals which differ in frequency by an audio frequency value, such as the signals in Figs. *17A* and *17B*, are mixed together, the result is the complex wave shown in Fig. *17C*. Notice that peak *a* is rounded, while the trough at *b* is sharp. Clearly the envelope is not of a sine wave shape.

If a voltage having the wave form shown in Fig. *17C* is sent through a linear detector, as shown in Fig. *17D*, the resulting demodulated current is hardly sine wave in form. On the other hand, when the wave of Fig. *17C* is sent through the square law detector, as shown in Fig. *17E*, the sharp troughs of the demodulated signal are rounded out by the detector characteristic, resulting in a sinusoidal output wave form.

So far we have assumed that the two input signals were of equal amplitude, the condition for maximum output when square law detection is employed. When one signal is about ten times as large as the other, however, as is the case for the waves in Figs. *17F* and *17G*, a complex wave form like that at Fig. *17H* is secured; if one signal is about ten times as great as the other, the envelope of this complex wave is a practically pure sine wave. Linear detection may now be used, giving a sine wave beat frequency output signal. It is common practice to make one input signal at least ten times as strong as the other, regardless of whether linear or square law detection is employed. If the desired result is an audio beat signal, any unrectified R.F. component must be by-passed or filtered out in the usual manner; if an R.F. beat signal is desired, the load should be a resonant circuit which will accept the desired beat frequencies.

The pentagrid converter so widely used in superheterodyne receivers is a heterodyne detector. The tube has five grids, one of which acts in conjunction with the cathode and plate as an ordinary linear or square law C bias detector, giving plate detection. Either grid leak-condenser or C bias detector circuits can be used in heterodyne detectors, with the choice of linear or square law operation depending upon the relative magnitudes of the incoming and locally produced R.F. signals.

Reviewing Methods of Providing C Bias for All Types of Circuits

THE different ways of providing the negative operating C bias required in A.F. and R.F. amplifiers, detectors, demodulators, oscillators—in fact, in any vacuum tube circuit, will now be considered; some of these methods you are already familiar with, since they were pointed out in connection with the study of other radio circuits in this and in previous lessons, but we will review them briefly here in order to secure a complete picture. The various circuits are given in Fig. *18*; although triode tubes have been shown for simplicity in each case but one, the circuits apply to any other tubes which have a control grid requiring a negative C bias. (It is common practice among radio men to say *C bias* when *C bias voltage* is meant.)

A simple battery-operated amplifier circuit is shown in Fig. *18A;* the voltage drop in filament resistor R_F makes the grid negative with respect to the minus terminal of the filament. Actually the bias should be computed with respect to the center of the filament; for example, if a 5-volt tube and a 6-volt filament supply source are used, the C bias becomes minus 3.5 volts (R_F drops the voltage 1 volt; this added to half the filament voltage [5 ÷ 2, or 2.5 volts] gives 3.5 volts). Resistor R_g is the grid return path,* and is of no importance insofar as the C bias is concerned as long as the grid is never driven positive (with respect to the cathode) by the input signal. (A flow of grid current through R_g would

*In all of the circuits shown in Fig. 18, resistor R_g may be replaced with a choke coil, a tuned circuit or the secondary of a transformer, regardless of whether R.F. or A. F. signals are being handled. These alternative parts offer practically no opposition to direct currents, and therefore do not interfere with the application of a C bias voltage, as long as the grid does not draw current.

make the C bias *more negative*.) By placing resistor R_F in the positive lead of the filament and connecting R_g to the plus terminal of the filament battery, a positive C bias can be applied to the grid for special purposes; reversing connections to the filament source is another way of making the grid positive.

In Fig. *18B* an external D.C. source, consisting either of a battery, a generator (as is often used in transmitters) or a separate diode rectifier tube with a filter circuit is connected between the *C*— and *C*+ terminals to provide the negative C bias; when used in this way, these D.C. sources are called C batteries, C bias generators and C bias rectifiers. For the connection shown, one-half of the filament voltage should be added to the external C bias voltage in order to determine the exact C bias on the tube.

A part of the plate supply voltage may be used to give automatic C bias, as shown in Fig. *18C*. The plate current (also the screen grid current in the case of a tetrode, and both screen and suppressor grid currents in the case of a pentode), flowing through resistor R_c, produces a voltage drop across R_c, with the grounded end of the resistor negative with respect to cathode. Changes in supply voltage automatically change the value of the C bias in the proper manner. Resistor R_g serves to connect the grounded end of R_c to the grid. Since resistor R_c is common to both grid and plate circuits, there is a possibility of degeneration; this is avoided by shunting the resistor with condenser C_c, which lowers the A.C. reactance of the B minus-to-cathode path for A.C. voltage and at the same time filters out any changes caused by fluctuating plate currents through R_c. A steady D.C. voltage drop is thus produced across R_c, and serves as a C bias.

The circuit in Fig. *18D* is identical with that of *18C* except that a heater type tube is used. Heater-type tubes are used almost exclusively at the inputs of high-gain amplifiers, to lessen the possibility of hum pick-up.

When the filaments of filament-type tubes in an amplifier are fed directly from an A.C. source, special center-tapped resistors or center-tapped filament transformer secondaries like those shown in Figs. *18E* and *18F* are used to prevent any A.C. voltage from entering the grid circuit. The filaments of filament-type tubes may be fed from an A.C. source provided that all electrode voltages have correct values with respect to the center of the filament. In the circuit of Fig. *18E*, resistor R provides the equivalent of a center tap filament connection. The circuit is a push-pull arrangement with the plate currents of both tubes flowing through grid bias resistor R_c; no shunt condenser is required across R_c because push-pull action makes the current through R_c a pure direct current.

In the circuit of Fig. *18F* the center tap of the filament transformer secondary serves as filament center tap; this is equally as good as the method shown in Fig. *18E*, and in addition eliminates one radio part, the center-tapped resistor. For this reason, filament transformers with center-tapped secondary windings are very widely used. The circuit in Fig. *18F* requires no further explanation, since it is quite similar to that in Fig. *18D*.

In circuits where the grid draws current when an R.F. grid voltage is applied, such as oscillator and detector circuits in receivers and power R.F. amplifier circuits in transmitters, the rectified grid current is often used to produce automatically the required C bias; an example of this method is shown in Fig. *18G*. The rectified grid current flowing through resistor R_{c2} or through R_{c1} (an optional connection) produces a pulsating voltage drop which makes the grid of the tube negative; condenser C_c filters out the pulsations, so a practically pure D.C. operating bias is secured when the input signal is unmodulated. Condenser C_c also acts as a low reactance path for the R.F. currents.

It is possible to obtain a C bias directly from the power pack. With the arrangement shown in Fig. *18H*, this C bias will be practically independent of the plate current drawn by the tube. This method is particularly recommended for push-push stages and for balanced class AB amplifier operation, where the tubes require a fixed C bias (a *fixed* C bias is one which remains constant regardless of other changes in circuit conditions). A combination bleeder re-

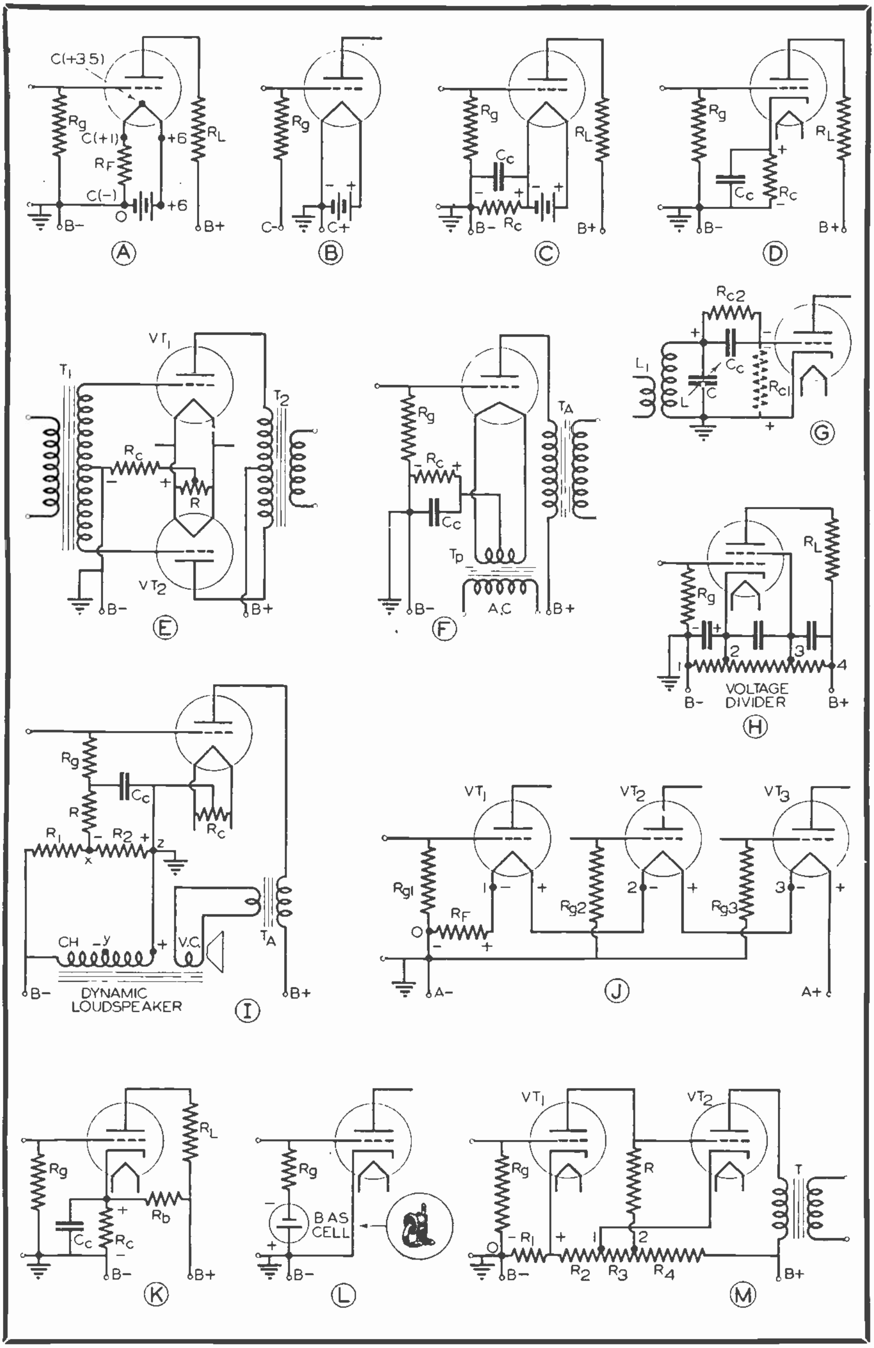


Fig. 18. Thirteen ways of providing C bias voltages for vacuum tube circuits are shown in these circuits.

sistor and voltage divider is connected across the power pack terminals. When the cathode of the tube is connected to point *2* on this voltage divider, point *1* will be negative with respect to the cathode and points *3* and *4* will be positive with respect to cathode. By-pass condensers keep the signal currents out of the voltage divider and power pack. In a push-push circuit, R_g would be replaced by one-half of the secondary winding of the input transformer.

Another very practical and widely used method of securing an essentially fixed operating C bias is shown in Fig. *18I*. Coil *CH* may be either a separate choke or the field coil of the dynamic loudspeaker, as indicated in this circuit. It is so connected into the power supply circuit that all of the direct current required by the receiver passes through the coil. With the C bias produced by the total receiver current in this way, any normal variations in the current drawn by the power stage are unimportant. A voltage divider made up of R_1 and R_2 is connected across the field coil, and point *x* on it is connected to grid resistor R_g through an additional resistor *R* which with condenser C_c insures proper filtering of the C bias voltage. Any ripple in the voltage supply is thus kept out of the signal circuits. *R* and C_c together force the signal currents to travel through C_c to the cathode. Since the cathodes of all tubes are grounded, the grounding of point *z* makes all electrode currents pass through field coil *CH* and the voltage divider which is across it. If it is feasible to provide a tap at the proper point on the choke coil, resistors R_1 and R_2 can be omitted and resistor *R* connected directly to this tap (point *y*).

In some of the older models of receivers designed for operation from D.C. power lines, the filaments of all tubes were connected in series. This made it necessary, when filament type tubes were used, to secure the correct value of C bias by connecting the grid to the correct point in the filament supply circuit. Figure *18J* shows such an arrangement; here tube VT_1 gets a C bias whose value is determined by the voltage drop in resistor R_F plus half of the filament voltage of tube VT_1. The C bias on tube VT_2 in this case is equal to the drop across R_F plus the filament voltage of the first tube plus half the filament voltage of the second tube, while tube VT_3 has a C bias which is equal to the drop between points *0* and *3* plus half of the filament voltage of the tube. Note that the grid resistors are all connected to point *0*; when connected to other points in the filament circuit, other C bias values are obtained. For example, R_{g3} will, when connected to point *2*, supply tube VT_3 with a C bias equal to the filament voltage of tube VT_2 plus one-half of the filament voltage of VT_3.

The circuit in Fig. *18K* is much like that in Fig. *18D* except that an extra resistor R_b, known as a bleeder resistor because it "bleeds" or draws extra current from the supply at all times, is used to provide a larger negative C bias and allow use of a lower ohmic value for R_c. The use of a bleeder resistor also makes the C bias less dependent upon the plate current of the tube, thus providing a C bias which is practically fixed. In this circuit, as well as in the circuits of Figs. *18C*, *18D* and *18F*, condenser C_c must have a high capacity if frequency distortion is to be low at low audio and picture frequencies. This is especially true when high μ tubes are used, because degeneration is bound to occur if the reactance of this condenser path is too high.

Separate batteries can be used, of course, to provide an operating C bias voltage, but these are obviously not desirable because of the need for frequent replacement. There is on the market today, however, a small C bias cell, about the size of an acorn, which actually is a storage cell having a voltage output of about one volt. One of these cells, when connected into an amplifier circuit in the manner shown in Fig. *18L*, will provide a C bias of about one volt; additional cells can be used in series to increase the bias to any desired value. Occasional high signal voltages will cause the grid of the amplifier tube to draw current, and this current will serve to charge the C bias cell. The cell must not be used in a circuit where grid current is drawn continually, however. Since the cell is entirely in the grid circuit, it cannot cause any regeneration or degeneration effects because of common coupling to the plate circuit. Although these cells cannot be tested directly with an ordinary voltmeter, you can check their effects by measuring the plate current of an amplifier with first the old cells and then new cells (or dry batteries of equivalent voltage) in the circuit; if new cells cause an appreciable decrease in plate current, the old cells need replacement.

Finally, there is the direct resistance-coupled amplifier shown in Fig. *18M*, where one voltage divider serves for two stages and the correct C bias voltages are secured by making connections to points *1* and *2* as indicated. The C bias for the second tube is equal to the difference between the voltage drop produced by plate current flowing through resistor *R* and the voltage drop between points *1* and *2*; the voltage drop across *R* is the larger of the two, and consequently a negative C bias is applied to VT_2.

TEST QUESTIONS

Be sure to number your Answer Sheet 17FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What are the two distinct steps involved in the demodulation or detection of a modulated R.F. signal?
2. Name the three important performance characteristics of detectors.
3. When the percentage modulation of a transmitter is increased, will the demodulated output of the detector (any type) increase in a receiver which is tuned to that transmitter?
4. Which type of detection (linear or square law) gives the least distortion of strong signals in ordinary detector circuits?
5. When combination linear-square law detection is used, to what operating point on the input voltage-output current characteristic curve is the detector circuit adjusted?
6. In a grid leak-condenser detector, where does rectification take place?
7. In a regenerative grid leak-condenser detector, what current is inductively fed back to the grid circuit to reinforce the incoming modulated R.F. carrier?
8. What would happen to the higher audio frequencies in a C bias detector if too large a by-pass condenser were used across the plate load?
9. What important use can be made of the negative D.C. voltage, varying with carrier level, which is produced by the diode detector?
10. What is a power detector?

HOW PRACTICAL REQUIREMENTS CHANGED RECEIVER CIRCUITS
(Crystals To Supers)

18FR-2

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EST. 1914
WASHINGTON, D.C.

THE STORY OF RADIO RECEIVERS

A bird's-eye view of the rapid growth of Radio from the crystal set of three decades ago to the highly complicated television superheterodyne receiver of today is presented in this book. Stirring history-making events like the sending of the first wireless signals across the Atlantic and the life-saving role of Radio at the Titantic disaster are interwoven with achievements of men like Marconi, De Forest, Armstrong, Hertz and hundreds of others. Naturally we cannot hope to explain, in a single book like this, the details of each individual development. Indeed, it is not the purpose of this book to do this; rather, we are giving you a story of just one phase of this industry, the radio receiver. You will learn how each new receiver evolved logically from the preceding and how practical requirements of the listening public resulted in one improvement after another.

Transmitter progress went hand in hand with receiver progress throughout the growth of Radio, hence you will encounter frequent mention of new transmitter developments in this story. Careful allocation and constant checking of transmitter frequencies by the Federal Communications Commission has reduced interference between stations to a minimum, even though there are today more stations on the air than ever before.

I am placing this book in its present position in your Course for a very definite reason; a knowledge of the technical problems which have been solved by the pioneers in Radio will be of great help to you in understanding and mastering the ingenious and highly perfected circuits which exist today. Many of these older receivers are still in use; the information given will be of real practical value when they require servicing, and will tell you what to expect from these older sets in the way of performance.

You are already familiar with a great many of the circuits and parts described in this lesson, but naturally there will be a few unfamiliar terms; if you will read this book again a few months from now, after you have progressed further with the Course, it will mean a lot more to you.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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How Practical Requirements Changed Receiver Circuits (Crystals to Supers)

INTRODUCTION

RADIO receiver design is today an art as well as a science. Radio engineers now have at their command the equipment, knowledge and experience required to produce practically any type of radio receiver demanded by the public. These engineers can produce receivers which will operate entirely from one or more batteries, or from A.C. or D.C. power outlets of any voltage and frequency; they can make receivers compact enough to slip into an overcoat pocket, or as large as any other piece of furniture in a home. They can also produce cabinets having any desired finish, color scheme and design, to harmonize with furniture in any style ranging from antique to ultra-modern, but we are primarily interested in the technical aspect, the evolution of radio receiver circuits.

The circuit chosen for any particular receiver depends upon seven important technical requirements set up by the public for that type of receiver: *1, selectivity; 2, sensitivity; 3, fidelity; 4, power output; 5, signal-to-noise ratio; 6, interference reduction; 7, ease of operation.* Today the radio engineer can produce receivers which meet the requirements of the public, but it took a long time to reach this stage. Radio receivers have a humble origin, for the early circuits were of decidedly limited ability.

After the first novelty of owning a radio receiver wore out, back in the days when the Radio industry was just getting started, owners of sets began to take note of the many shortcomings. They required and wanted something better; receiver designers learned of these requirements and undertook research with a view to improving the receivers. New discoveries resulted and were quickly adopted; innovation followed innovation as consumers kept demanding better receivers.

In order that you can better appreciate the technical perfection of the present day radio receiver, as well as realize why various receiver models today differ so greatly from each other, we shall trace the development of radio receivers from the days prior to the crystal detector to the all-wave high fidelity superheterodyne receivers of today. A knowledge of the receivers of the past will be of value to any one who plans to do radio servicing work, for a great many of these receivers are still in use and occasionally in need of servicing and adjustment.

COHERERS TO CRYSTAL DETECTORS

About 1856 James Clerk Maxwell, one of the great British scientists, predicted by means of complicated mathematics that an oscillating current would radiate electromagnetic waves which are identical with light waves except for frequency . He prophesied that these waves would travel at the speed of light (186,000 miles per second), would be reflected from conducting surfaces and would travel through dielectrics.

The electromagnetic wave theory advanced by Maxwell aroused considerable scientific argument. For twenty years Heinrich Hertz, a German scientist, attempted to prove that Maxwell's assumptions were wrong and that these electromagnetic waves could not exist. The results of these experiments quite surprised Hertz, finally converting him to the Maxwell theory. As a result, Hertz published in 1887 and 1889 the famous papers which brought him fame and gave to the world experimental proof that radio waves were entirely possible. Even today radio waves are designated by many people as *Hertzian waves*.

In 1890 Sir Oliver Lodge, another brilliant British scientist, actually set up an oscillating circuit (a charged condenser shunted by a heavy wire loop in series with a spark gap), and proved that another oscillatory circuit would pick up by induction the energy from the first circuit, if properly tuned.

The next important development before the actual sending of messages through the air was that of the coherer, a device which is based upon the fact that the enormous resistance offered to the passage of electric current by loose metal filings is greatly reduced under the influence of alternating current.

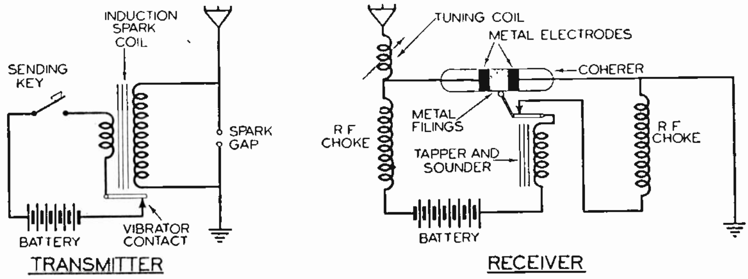


FIG. 1. Early Marconi wireless transmitting and receiving circuits. The vibrator at the transmitter operated as long as the sending key was pressed, interrupting the primary current of the induction coil and inducing in the secondary a high enough voltage to produce sparks across the gap. The oscillations resulting from the sparks were radiated into space by the transmitting antenna. These electro-magnetic radiations induced R.F. currents in the receiving antenna, making the coherer conducting, and battery current passed through to operate the combination tapper and sounder. The buzzing sound of the tapper (an ordinary buzzer) was thus heard whenever the sending key was pressed.

In one very popular form, a coherer consisted of a two or three-inch long glass tube, inside which were metal plugs spaced perhaps a quarter inch apart, with the space between the plugs filled with metallic filings. Various metals were used for the plugs or electrodes and for the filings. The passage of radio frequency current through the filings caused them to "cohere" or stick together, forming a conducting path for the direct current which actuated a telegraph sounder (an electromagnet which makes an audible click each time it operates). The great problem was to break up this path again after the R.F. current has ceased flowing; some experimenters mounted the coherer on a vibrating table, but the most popular arrangement was that used by Popoff of Russia and by Branly, in which a tapper attached to the telegraph sounder was used to jar the glass tube after the arrival of each signal.

Scores of scientific men began experimenting with the newly-discovered Hertzian waves, each contributing additional data on the behavior of these waves, but it remained for Marconi in 1896 to combine the results of all these scientists and produce one simple and workable radio system. His early apparatus was capable of transmitting messages for only short distances, but on December 12, 1901 he used the transmitter and receiver shown in Fig. *1* to transmit three dots (the letter S) over and over again from Poldhu, England to St. Johns, Newfoundland. To Marconi rightfully belongs the title "father of wireless," for he co-ordinated the work of others and put wireless on a practical working basis. Before the advent of broadcasting, *radio* was known as *wireless*.

In order to secure long-distance transmission in those days, it was necessary to use tremendously large power oscillatory circuits together with antennas much longer than those in common use today. In some of the high-powered transmitters used for trans-Atlantic communication, the extremely large currents jumping across the spark gap each time the key was pressed produced crashes of thunder-like noise in the transmitter room. This great power was necessary primarily because of the low sensitivity of the coherer in the receiver.

Having increased the power of transmitters to the practical limits of the time, scientists now turned their attention to improvements in receivers. The electrolytic detector, a fine platinum wire immersed in sulphuric acid, came into the picture around 1903. It was about this time also that the headphone unit used in telephone systems was brought into play to replace the telegraph sounder used for wireless, with the result that a fairly sensitive receiver became available.

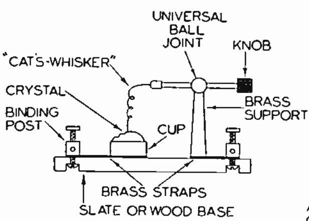


FIG. 2A. Cross-section of typical crystal detector.

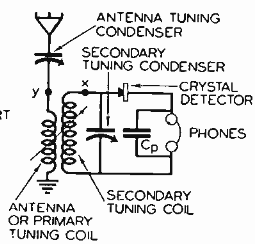


FIG. 2B. Typical crystal detector circuit.

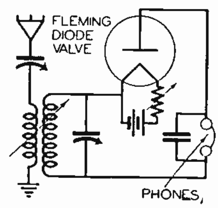


FIG. 3. Early diode detector circuit.

In 1904 Dr. Fleming invented the diode vacuum tube, then known as the *Fleming valve*. This contained a wire filament heated by direct current, and a metal plate or anode mounted a short distance away, both electrodes being enclosed in an evacuated glass envelope.

At about this same time the crystal came into widespread use as a more convenient and more sensitive detector. Way back in 1874, Braun had discovered that two crystals making point-to-point contact with each other had a high resistance to the flow of current in one direction and a low resistance to current flow in the opposite direction. Single crystals in contact with a sharpened length of fine wire were found to give equally good rectifying action; materials such as galena, iron pyrites, fused silicon, carborundum, molybdenite, and other minerals came into use. A typical crystal detector is shown in Fig. *2A*; this has the necessary mechanical adjustment which permits setting the cat's-whisker at a spot on the crystal which gives good rectification. These crystals were generally mounted in a brass cup, being held in place by a metal having a low melting point. One form of crystal detector circuit is shown in Fig. *2B*.

One or more extra crystal detectors were often employed, with a switching arrangement to permit instant changeover in case the crystal in use lost its adjustment. Stations were on the air only intermittently, hence a buzzer was loosely coupled to the antenna to produce a signal which served as a guide for adjusting crystals in between reception of messages.

With the development of more sensitive crystal and diode detectors, together with sensitive headphones, long-distance reception became possible and more and more transmitters went on the air. These were all code or telegraph transmitters, of course, and were operating on wavelengths longer than 600 meters (lower than 500 kc.). Congestion of the airways became severe, and steps were taken to make transmitters use narrower bands of frequencies and to make receivers more selective.

One of the earliest schemes for improving the selectivity (station-separating ability) of a receiver, the use of variable coupling between the antenna coil and the secondary coil, is illustrated in Fig. *2B*. Additional coils, known as *loading coils*, were sometimes inserted in the tuning circuits at points x and y to give reception on the longer wavelengths.

A typical Fleming valve detector circuit is shown in Fig. *3*. The same tuning controls are used here as in the crystal detector circuit of Fig. *2B* to secure the required selectivity. Actually the two circuits are identical except for the type of detector used.

The art of radio receiver design remained at this single-tube stage for many years, while transmitter progress went ahead with a view to radiating more and more kilowatts of dot-and-dash power into space, with less radiation in side bands in order to give more selective reception.

DE FOREST INTRODUCES TRIODE TUBES

The introduction of the grid in the Fleming diode tube by Lee De Forest in 1909 was an outstanding contribution to the Radio art, and revolutionized the entire Radio industry. The De Forest triode tube was first used only in detector circuits, where it provided a considerable amount of signal amplification in addition to demodulation.

A typical triode detector circuit is shown in Fig. *4*. The output of tuned circuit L_T-C_T was fed to the grid and filament of the triode tube through series condenser C_g. The headphones, in series with a high voltage battery (22½ to 45 volts) were connected between the plate and filament of the tube. It was found that a leaky condenser gave best results for C_g (the reason for this was not at first apparent, but is now fully understood—the intelligence signal voltage was developed across this leaky condenser (its resistance) and then amplified by the triode tube). Thus the filament and grid of the tube together acted as a diode rectifier, while the entire tube acted as a low frequency amplifier; this circuit is still used to a certain extent even today, being known as the grid leak-condenser detector.

Early triode tubes gave even better detector action than present day triodes, because tubes at that time were rather poorly evacuated and therefore contained a certain amount of gas. This gas made possible a larger plate current than would exist in a pure vacuum. These gas tubes were commonly known as soft tubes; difficult to adjust properly as detectors and their useful life was very short. Improving the vacuum in the tube (giving a so-called "hard tube") gave better stability and longer life, but somewhat poorer sensitivity.

The loss in sensitivity through the use of a hard tube was more than overcome by the invention of regeneration by De Forest in 1912 and by Armstrong in 1914. A simplified form of this regenerative circuit is shown in Fig. *5*; here the modulated R.F. current which exists in the plate circuit is fed back to the input circuit to reinforce the incoming signal. In the hands of an expert the regenerative detector gave amazing results, setting up new and more consistent long-distance receiving records.

By this time condenser manufacturers had improved their products by reducing leakage (of current), and now it became necessary to place a separate resistor in shunt with the grid condenser to secure accurate control of rectification. This grid resistor generally had an ohmic value of somewhere between 2 and 10 megohoms. Although this resistor (R_g) is connected between grid and filament in Fig. *5*, it could be and often was connected directly across the grid condenser C_g.

AUDIO AMPLIFICATION

Attempts to bring up the volume of very weak code signals by increasing the feed-back of a regenerative detector were decidedly unsatisfactory, for the circuit became unstable and often went into oscillation, producing very annoying squeals. Practical requirements demanded amplification of weak but clearly demodulated signals—audio amplification.

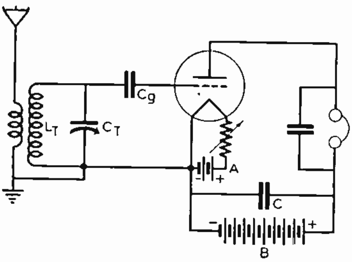


FIG. 4. Early triode detector circuit.

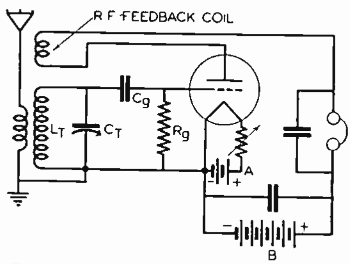


FIG. 5. Regenerative detector circuit.

Engineers soon learned that they could use the soft triode tube for amplifying purposes if the vacuum in it could be improved. Considerable development work was therefore carried out on vacuum pumps and other means of getting rid of gas, with the result that "hard" tubes, having a more perfect vacuum, were produced. We hear very little about hard and soft tubes today, for all tubes are now thoroughly evacuated during manufacture. Even tubes which are intentionally filled with a certain amount of gas, such as neon, argon, or mercury vapor, are first completely evacuated to remove undesired gases.

The next step in receiver development was quite logical; one or more stages of audio amplification were added to the regenerative detector to increase the volume of weak code signals. Plug-in jacks were provided for each stage, as in the typical circuit shown in Fig. *6*, so that headphones could be inserted either in the detector stage, the first audio stage or the second audio stage. This was a crude but effective means of controlling volume. Although this was a great improvement over any other receiver available at the time, manufacturers of radio apparatus were not yet ready to scrap the elaborate tuners which were then widely used with crystal detectors; they simply manufactured a separate two-stage audio amplifier which could be connected to the output of any crystal detector.

In 1920 a typical commercial receiver consisted of two resonant circuits with variable inductive coupling, independently tuned antenna and secondary coils, means for loading each circuit, a regenerative detector using a soft triode tube, an auxiliary crystal detector for emergency use, and two stages of audio amplification. In the hands of an expert wireless operator, this receiving arrangement gave reliable reception and was widely used on board ship.

RADIO BROADCASTING IS BORN

With code wireless an established fact, engineers turned their attention to the transmission of voice and music through the air. The old spark coil transmitter, with its highly damped oscillations, was clearly inadequate for the transmission of voice signals. In 1903 Poulsen had perfected a generator of high frequency current which utilized an electric arc; he showed experimentally that telephonic communication through

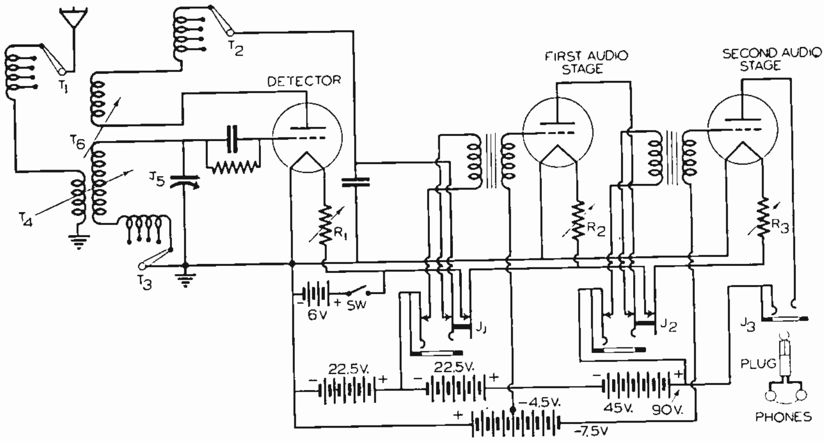


FIG. 6. A regenerative receiver of 1920 vintage, with two A.F. stages. There were six tuning controls: T_1, T_2, T_3, T_4, T_5 and T_6. R_1, R_2 and R_3 were filament rheostat controls. Headphones could be plugged into jack J_1 when receiving strong signals, disconnecting the filaments of the A.F. tubes and prolonging battery as well as tube life; with the phones plugged into jack J_2, only one A.F. stage was in use, while full amplification for weak signals was obtained with the phones in jack J_3. *SW* was the main OFF-ON switch. Thus a three-tube receiver required thirteen controls.

space over very short distances was entirely possible with his transmitter if a microphone were used to modulate the radio waves. The Poulsen arc transmitter was used extensively for code transmission, but did not prove entirely satisfactory for voice signals.

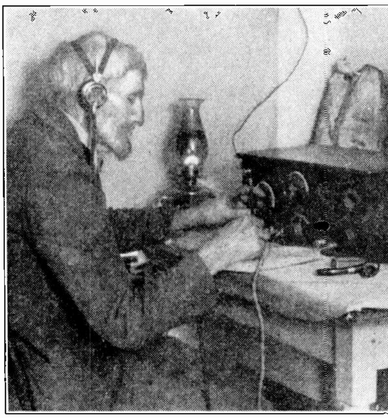
A high frequency dynamo electric generator was designed and constructed by Fessenden in 1906 for the production of continuous waves; with it he was able to transmit telephone messages for 15 miles.

De Forest in 1907 was the first to use wireless for the broadcasting of phonograph records; he placed his musical program on the air without preliminary announcement, completely surprising the wireless code operators on duty at this time.

The invention of the triode vacuum tube and its development as an oscillator for the generation of high frequency current resulted in the world-famous demonstration on December 30, 1915, when the government radio station at Arlington, Virginia succeeded in sending telephone messages through the air to Honolulu, Hawaii and Paris, France.

During the World War (1914–1918) the large electrical manufacturers in this country had developed elaborate wireless research and manufacturing departments for the production of radio apparatus for the government. The close of the war marked the collapse of the market for their products, and naturally these manufacturers tried to find new ways of stimulating wireless activities and creating new markets. The Westinghouse Electric and Manufacturing Company, believing that the future of radio was in the direction of voice and music broadcasting delegated Frank Conrad to carry out research work along this line. Fortified with a vast amount of wireless experience, the latest scientific aids and practically unlimited manufacturing facilities, Conrad developed the first broadcasting station. For months radio amateurs in the vicinity of Pittsburgh listened with interest to experiments in broadcasting, and then, on November 2, 1920, Westinghouse radio station KDKA astonished the world by broadcasting the results of the presidential election.

Wireless gradually came to be known as radio, and every one wanted to listen in on the broadcasts. Shortly after this epoch making broadcast, Westinghouse opened radio station WJZ in New York City, the



Early one-tube regenerative receiver, with batteries inside the cabinet. This set was particularly popular in farm homes, and undoubtedly a few are still in use today.

This early T.R.F. receiver, with three vernier tuning dials and a separate loudspeaker cabinet, was for a time quite the rage among radio fans. Jacks were provided for headphone reception.

first commercial broadcasting station. Station after station sprang into existence—broadcasting swept the country, expanding into a vast industry and proving correct the early prophesies of Westinghouse.

The nuisance of having to wear headphones whenever listening to radio broadcasts had long been recognized as a distinct drawback to the universal popularity of radio. In 1921 a megaphone was attached to an electromagnetic headphone unit, giving the first practical loudspeaker. The vibrating diaphragm of the phone unit, acting in conjunction with the outward flaring curve of the megaphone, served to excite the surrounding air waves so that all the persons in a room could listen to a single program. The immediate acceptance of the horn unit called for further research and resulted in the development of the balanced armature unit which gave greater diaphragm movement and consequently greater sound output.

During the period between 1922 and 1924, the receiver circuit shown in Fig. *6*, used with batteries and a horn-type loudspeaker, was the accepted standard. The tapped loading coils, shown as T_1 and T_2, were not used, for 360 meters was the accepted wavelength for broadcasting. At this stage in the development of radio, people wanted plenty of "gadgets" on their receivers; the more controls a receiver had, the better it was received by the public.

SUPER-REGENERATIVE RECEIVERS

Realizing that most reliable reception was obtained when the detector of a receiver was fed with a strong carrier signal, engineers used extremely long antennas in the days of regenerative receivers. These antennas of course resulted in very poor selectivity, and when more and more stations came on the air, practical requirements demanded means for *separating* these R.F. carrier signals. Armstrong, who had been experimenting constantly all through this period, developed one solution which we cannot overlook, for it is occasionally encountered even today. This involved the use of a highly directional tuned loop antenna* which had the desired selective characteristics but low output, and a special super-

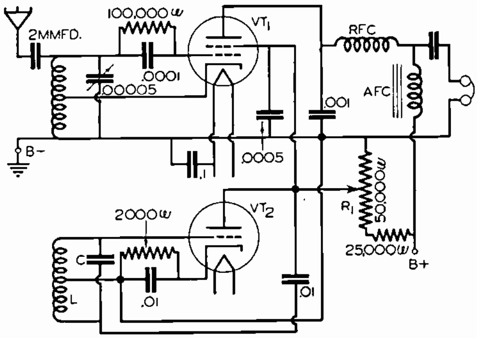


Fig. 7. Circuit of a typical modern five-meter super-regenerative receiver. A separate quench oscillator tube (VT_2) operates at a frequency determined by the values of L and C, usually about 50,000 cycles. Potentiometer R_1 serves as volume control for the receiver.

regenerative detector to boost the gain tremendously. The Armstrong super-regenerative circuit is really an ordinary regenerative detector with special provisions for operating it just below the point of oscillation where it is most sensitive.

The circuit diagram of a modern super-regenerative 5-meter receiver is shown in Fig. 7; the same operating principles apply to this circuit as to the original Armstrong circuit. Referring to Fig. 7, tube VT_1 is in a modified regenerative detector circuit, which will go into oscillation when the screen grid voltage is increased sufficiently. Tube VT_2 is in a Hartley oscillator circuit which operates continually and produces a low radio frequency output (generally above 20,000 cycles) which is fed to the screen grid electrode of VT_1. Potentiometer R_1 is adjusted until the detector stage gives maximum sensitivity. Under this condition any tendency for VT_1 to go into oscillation is "quenched" by the local oscillator voltage on the screen grid (this local signal reduces the screen grid voltage below the oscillation point once per cycle; the frequency of the local signal is made high enough that there will not be sufficient time for regeneration to build up to the point of oscillation between cycles of the quenching voltage). Tube VT_1 is thus on the threshold of oscillation, where it is most sensitive, yet is prevented from oscillating.

* A loop antenna is a coil from 6 to 24 inches in diameter, wound on a very short circular or rectangular coil form; it receives signals at right angles to the axis of the coil.

The super-regenerative circuit, although highly sensitive, is entirely *too broad* for use in congested wavebands (has very poor selectivity). It is therefore used only where adjacent station selectivity is relatively unimportant and where the stability of the R.F. oscillator in the transmitter is poor, such as in the 5-meter band now assigned to police, amateur and experimental radio stations.

TUNED RADIO FREQUENCY RECEIVERS

Regenerative receivers had one very serious fault; they would feed energy back into the receiving antenna, and this would be radiated, interfering with reception of signals by other receivers in the immediate neighborhood. Owners of radio receivers did not enjoy listening to ear-splitting squeals each time their neighbors decided to tune in a new station, and thus the public created a demand for the next improvement.

Around 1925 engineers seriously began to consider the problem of adding R.F. amplification ahead of a non-regenerative detector. The big problem here was that of making the then available vacuum tubes

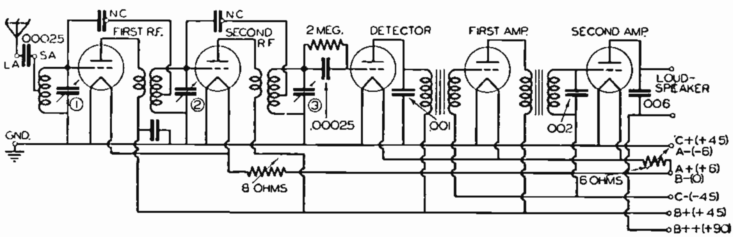


Fig. 8. Circuit diagram of a typical five-tube neutrodyne receiver, the model NR-5 Freed-Eiseman set which appeared in 1925. R.F. feed-back was cancelled out by adjusting neutralizing condensers *N.C.* Batteries were connected by means of a cable.

amplify R.F. signals without causing feed-back which would result in shrill squeals accompanying the desired program. The neutrodyne circuit, as developed by Hazeltine, effectively prevented R.F. feed-back and proved the solution to this problem.

A typical neutrodyne circuit, as used in receivers of this period, is shown in Fig. *8*. There were three tuning dials, one for each resonant circuit tuning condenser in the two stages of R.F. amplification. Other controls included a rheostat for varying the filament current to the detector and the two A.F. amplifier tubes, and another rheostat to control the filament current to the R.F. amplifier tubes. Plug-in jacks (omitted for simplicity in the diagram) were inserted in each audio stage to allow the listener to use headphones instead of the less-sensitive loudspeaker on weak distant stations. People still insisted upon being able to stay up into the wee hours of the morning, with headphones "glued" to their ears, trying for coast-to-coast reception. The neutrodyne receiver of 1925 was heralded as the marvel of its day.

This "squeal-less" radio receiver captivated the attention of the radio public. Many manufacturers turned over their entire facilities to the production of these receivers under the Hazeltine patent, in order to meet the rapidly growing demand. Other manufacturers developed their own R.F. feed-back cancellation systems, all attempting to balance out the plate-to-grid circuit feed-back voltage with an equal and opposite voltage.

The 5-tube receiver was the standard of this period, although some set makers secured added sales appeal by using three resistance-capacitance coupled A.F. stages to give a 6-tube receiver. Others used two power-tubes in parallel, to secure the extra sales appeal of a 6-tube set.

Although only licensed manufacturers were legally permitted to make neutrodyne receivers, many ignored the legality of the Hazeltine patent. The entire radio patent situation was in chaos at this time, with large as well as small manufacturers refusing to pay tribute to the various holders of important radio patents, for fear that other claimants to these patents would demand additional royalties.

Some manufacturers attempted to get around the neutrodyne patent by developing tuned radio frequency circuits which had enough loss in each R.F. stage to absorb the feed-back energy and prevent squeals. This "losser" method proved fairly successful.

Grid suppressors also came into use, as cures for feed-back and negative resistance troubles in some of the earlier T.R.F. receivers.

Other circuit improvements inaugurated at about this period included a variable resistor connected across the primary of the second tuned R.F. transformer for the purpose of controlling regeneration and volume. Fixed resistors and ballast resistors (such as the Amperite) in the fila-

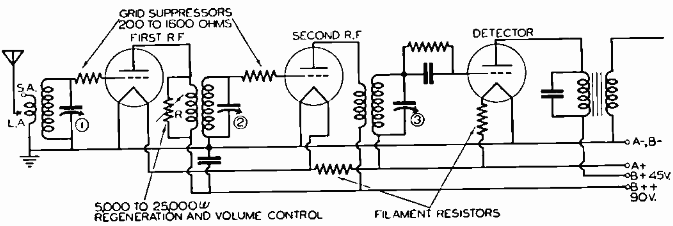


FIG. 9. **T.R.F. amplifier and detector section of a receiver which was popular about 1926. The grid leak-condenser detector was usually followed by two stages of A.F. amplification.**

ment circuits made it unnecessary to adjust filament current. Three tuning controls and a volume control now constituted all the adjustments used for a standard receiver.

The schematic circuit diagram of a tuned radio frequency amplifier using a grid leak-condenser detector is shown in Fig. *9*. Receivers of this type were designed to regenerate slightly when resistor *R* was set at its highest ohmic value, thus giving perfect control and high R.F. gain.

HOME-MADE RECEIVERS

From the very first stage of wireless, the building of radio receivers in homes was a popular hobby. When radio broadcasting began, many more thousands joined the ranks of receiving set builders. Circuit diagrams of all types of regenerative receivers were available to these experimenters under many fancy sales names, but finally all regenerative sets were "nick-named" "blooperdynes" because of their squealing characteristics.

Some of the more skilled experimenters built super-regenerative receivers. When the neutrodyne circuit was introduced, complete kits of parts for this were made available. In those days just as many radio receivers were home-made as were produced by manufacturers. Gradually, however, as manufacturing technique was placed on a production basis, the economy and superiority of commercial sets became evident, and the popularity of home-made receivers began to fade. Experimenters no longer had a market for their home-made products, but they continued building sets for their own use. Parts manufacturers brought out special circuits and kits to keep alive the set-building habit and promote the sale of their radio parts.

Receivers at this time were judged principally on the basis of long-distance or DX reception. Parts manufacturers built up their sales appeal around circuits with high sensitivity, capable of picking up far distant stations, while set manufacturers were gradually beginning to feature simplicity of operation and quietness of reception, as well as fidelity of reception.

Out of this chaotic period of home-made receivers there stands out one receiver which gave exceptionally good performance and which is still being used today, in slightly modified form, by many short-wave radio amateurs. This receiver contained a neutralized T.R.F. amplifier ahead of a regenerative detector, and was commonly known to the old-timers as the Browning-Drake receiver, after its inventors. The circuit diagram for this receiver is given in Fig. *10*; one stage of audio amplification is shown here, but ordinarily a power stage was also used to provide loudspeaker operation.

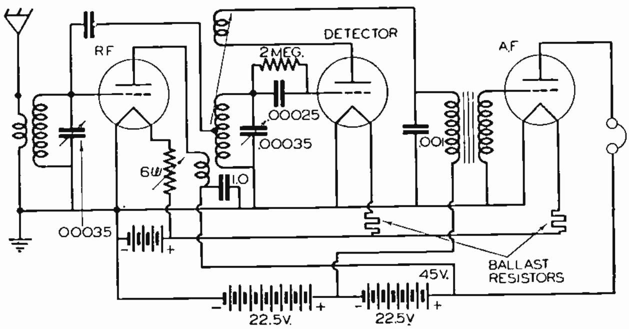


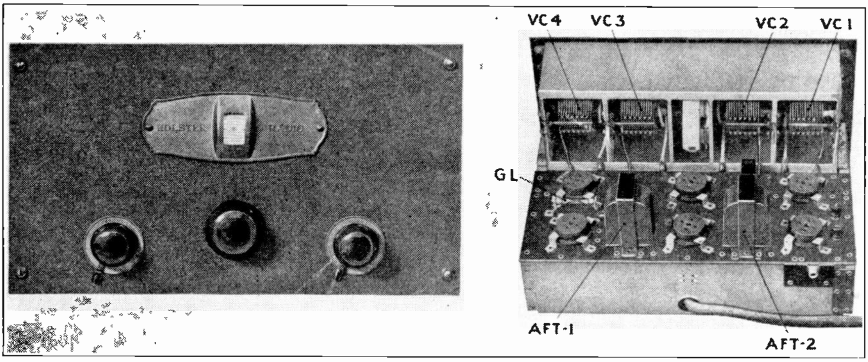
Fig. 10. One form of the famous Browning-Drake receiver circuit, the hit of the 1925-1927 period of home-made receivers. This circuit is still popular among radio amateurs.

Home set-building died a natural death soon after the introduction of the superheterodyne, primarily because of the increasing complexity of receiver circuits and the necessity of having special instruments for aligning the superheterodyne. Today, people who build their own receivers usually buy complete kits of parts, but the number of these experimenters is relatively small because little or no money can be saved. Modern radio factories, buying parts in very large quantities and using the latest mass production technique can, in many a case, assemble complete receivers for less than the price which an experimenter would have to pay for the parts alone.

SIMPLIFIED TUNING

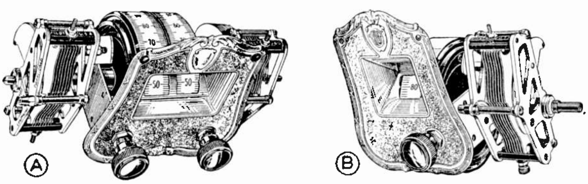
The advent of T.R.F. receivers of the neutrodyne and grid suppressor types changed radio from a fad to an established industry, but prior to 1926 it was still looked upon as a fall-winter-spring affair. The radio industry struggled and worried through the summer months, wondering if their business would return again in the fall. It did come back, bigger and better than ever each fall; with confidence established, business men began to invest great sums of money in radio. These investors could see no real reason for the summer slump, and demanded an organized effort to bridge the gap. Broadcasting stations boosted their power during the summer months, better and better programs were put on the air and reasons for the summer slump in radio popularity were studied.

It was found that many people objected to three dial receivers on the basis that they had only two hands with which to tune. It was found



Front and rear views of the Kolster Six receiver for which the circuit diagram is given in Fig. 13. It is a tuned radio frequency circuit with single-dial control and four tuned circuits controlled by variable condensers *VC1, VC2, VC3 and VC4,* followed by a grid leak-condenser detector (*GL*) and two audio amplifier stages coupled together by audio transformers *AFT-1* and *AFT-2.*

that two of the three tuning circuits could be made to operate exactly alike; referring to Figs. *8* and *9*, where the tuning circuits are marked *1*, *2* and *3*, manufacturers designed circuits *2* and *3* to tune exactly alike, permiting control of the two tuning condensers with a single dial. The input tuning circuit was still the trouble maker, for here the effects of the antenna were quite marked. With the input circuit designed for a



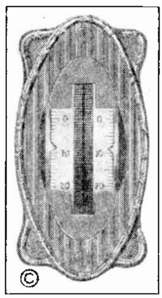


FIG. 11. Types of tuning dials in common use during the period when radio was passing from the multi-dial to the single-dial control stage.

short antenna (*S.A.*), then the connection of a long antenna (*L.A.*) would make the dial reading for tuning condensers *2* and *3* differ as much as ten divisions from that for tuning condenser *1*. The difference in the characteristics of long and short antennas was overcome by providing two antenna posts, one for a long antenna and one for a short antenna; with the antena connected to the proper post, and condensers *2* and *3* ganged together, a two-dial receiver was obtained. One form of two-dial control is illustrated in Fig. *11A*; the third condenser was attached to the shaft of one of the two condensers shown.

The next step in the simplification of tuning was the introduction of drum dials, which permitted adjusting the two tuning controls either separately or together. The face of one of these two-drum controls is shown in Fig. *11C;* one drum controlled the condensers for tuning circuits *2* and *3*, and the other controlled the single antenna tuning condenser. Some receivers used three separate drum dials, one for each condenser, while others had all three condensers controlled by a single dial, like that shown in Fig. *11B*, for rough tuning to a station, and had some means for making fine (vernier) adjustments of each condenser when more accurate tuning was desired.

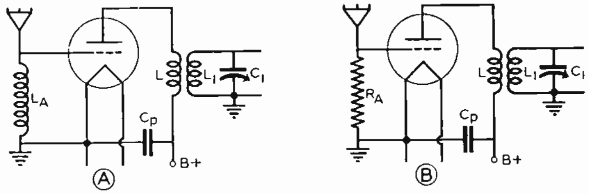


FIG. 12. Two forms of untuned antenna circuits as used with T.R.F. receivers.

The ideal single dial receiver was still sought by radio designers and by the public, for with it even a child would be able to tune in radio broadcasts correctly and easily. It was fully realized that the antenna circuit was the trouble maker. Untuned antenna circuits like those shown in Figs. *12A* and *12B*, followed by two stages of tuned R.F. amplification (three variable condenser circuits) were tried but found unsatisfactory. The trouble was that in the vicinity of powerful local stations, the strong R.F. input signal reaching the first R.F. amplifier tube would make that tube work as a detector, and the strong incoming local signal

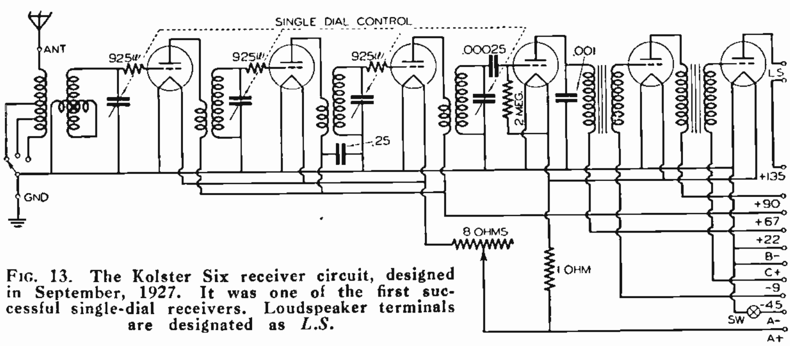


FIG. 13. The Kolster Six receiver circuit, designed in September, 1927. It was one of the first successful single-dial receivers. Loudspeaker terminals are designated as *L.S.*

would mix with or modulate whatever other incoming signal was being tuned in. This so-called *cross-modulation interference* effect was so objectionable that the idea of an untuned antenna system was dropped completely. Incidentally, cross-modulation is still a problem in radio receiver design, although by no means as serious as it was more than a decade ago.

Engineers reasoned that if the R.F. section could be designed with plenty of gain, exact tuning in the antenna circuit would not be necessary and single dial controls could be used. Tests proved this reasoning to be correct as far as local and near distant stations were concerned, and the single-dial receiver became a reality.

The circuit of one of the first popular single-dial receivers is shown in Fig. *13*. Notice that it contains a three-stage R.F. amplifier (four ganged variable condensers), a grid leak-condenser detector and two transformer-coupled audio amplifier stages. The variable inductance, then known as a *variometer*, was coupled to the antenna coil; this variometer could be adjusted to tune the antenna exactly to resonance when a weak distant station was being received, but ordinarily was not needed or used when tuning in local stations. There were several taps on the antenna coil for adjusting the circuit to various lengths of antennas; the tap switch was mounted on the front panel of the receiver. With this tap adjusted for loose coupling (only a few turns in the antenna coil), good reception of high frequency stations was obtained. With tight coupling (many turns in the antenna coil), good reception at low frequencies was secured.

After the introduction of this first successful single dial receiver, many others followed. Some were without the variometer control, while in others the first variable condenser was omitted and the variometer was ganged to the variable condensers in the manner shown in Fig. *14A*. Some omitted the variometer entirely, using one section of the ganged variable condenser to tune the antenna circuit broadly, and using a trimmer or small variable condenser in parallel to permit accurate adjustment when receiving weak distant stations, as shown in Fig. *14B*.

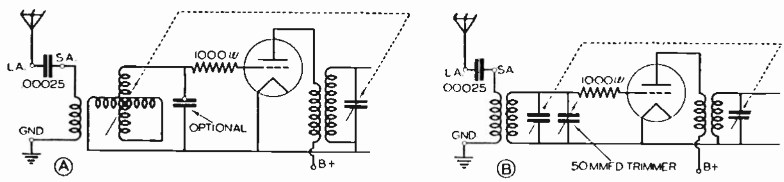


FIG. 14. Two methods by which the antenna circuit was tuned exactly to resonance when receiving weak distant stations are shown here.

At this stage in development, almost all receivers were tuned in exactly the same manner; strong stations were tuned in with the single tuning dial, while weak stations were first tuned in with this dial and then retuned by means of the antenna vernier trimmer.

B, C AND A BATTERY ELIMINATORS

All early radio receivers up to the single dial control sets obtained power from batteries of one type or another. Dry cells built into convenient blocks of five, fifteen or thirty cells, with all cells connected in series, were used to supply D.C. voltages to the plates of the tubes. The storage batteries used for filament power had to be removed for recharging at intervals of one to three weeks; many set owners bought their own battery chargers for this purpose. Later, trickle (low rate) chargers were placed on the market for use in homes; these charged the battery at a low rate during periods when the radio receiver was not in use. Relays were available for automatically connecting the trickle charger when the receiver was turned off and disconnecting the charger when the receiver was turned on.

Tubes with special filaments designed for operation from dry cells rather than storage batteries were developed at about this time. Examples of these are the UX199 and UX120 tubes, which required filament voltages of 3.3 volts. This voltage was obtained from three No. 6 dry cells connected in series, with a filament resistor to vary the applied voltage as the dry cells aged. The tubes did not meet with widespread popularity, however, because of a rapid loss in emission properties when operated with too high filament voltages.

The average radio receiver of the time required replacement of B batteries at intervals of two or six months, and replacement of C batteries every six to twelve months. Every one agreed that this constant replacement of batteries was a decided nuisance, and the radio public in general began calling for the newly-developed battery eliminators.

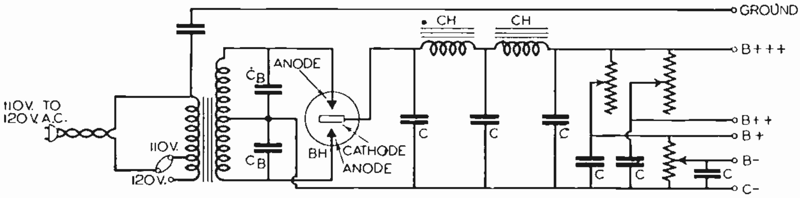
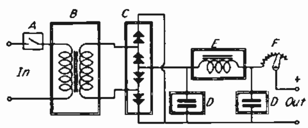


FIG. 15. Circuit diagram of an early B and C battery eliminator using a Raytheon BH tube as a full-wave rectifier. Condensers C_B were 600-volt, low capacity buffer condensers; filter condensers are at *C*. All condensers were of the waxed paper type.

In 1925 the Raytheon Company of Cambridge, Mass., perfected the cold cathode gaseous rectifier tube known as the Raytheon BH rectifier; this tube was quickly adopted by receiver manufacturers for use in *B and C battery eliminators*. A typical combination B and C battery eliminator using this tube is shown in schematic form in Fig. *15*. You will note that it is simply a standard full-wave rectifier circuit except that buffer condensers C_B were connected across the two diode sections of the tube to prevent surges of current from damaging the tube.

FIG. 16. Circuit of an A battery eliminator using a copper-oxide rectifier unit. *B* is a step-down transformer, *C* is a full-wave or bridge type copper-oxide rectifier unit, while *D* and *E* comprise a low voltage, high current filter. (Condensers *D* were 2,000 mfd., 25 volt electrolytic condensers.) Rheostat *F* controlled the output voltage, while *A* was the main power switch.



B and C battery eliminators met with instant popularity, and the public began calling for A battery eliminators as well. Engineers went to work again, and by using identical electrical principles succeeded in developing a low voltage, high current rectifier with a ripple filter which satisfactorily eliminated the filament batteries. Various rectifying devices were used in A battery eliminators; many units were built with a special type A Raytheon cold cathode rectifier tube or with the Tungar rectifier tubes originally developed for battery chargers, but the copper-oxide rectifier unit and the electrolytic rectifier unit were most widely used for A battery eliminators because of their lower cost and longer life. A typical A battery eliminator circuit using a copper-oxide rectifier unit is shown in Fig. *16*.

THE A. C. RECEIVER

A person who went into a radio shop late in 1927 or early in 1928 to purchase a radio receiver had to choose five different and separate items if he desired a complete installation; these were: *1*, a radio receiver in its table model cabinet; *2*, a loudspeaker; *3*, a set of tubes; *4*, an ABC power pack; *5*, a suitable table on which to place the receiver and loudspeaker, with a shelf underneath for the ABC eliminator. Each of these five units was available in a number of different brands, and oftentimes several different models were put out by one manufacturer.

The next step in the evolution of radio receivers was logically the combining of the ABC eliminator with the receiver itself to give a complete AC-operated receiver. At first the ABC eliminator pack was simply placed inside an enlarged receiver cabinet, giving a somewhat bulky receiver. The attention of designing engineers was then directed toward improvement of the power pack.

As far back as 1925, RCA Manufacturing Company had been building into their receivers special innovations which the rest of the radio manufacturing industry was unable, either because of patent rights or because of high cost, to use. One of these special features was the hot cathode diode tube used as a half-wave rectifier in the power pack; this tube was capable of furnishing as much as 60 ma. of rectified direct current, making it possible to connect the filaments of the type UV199 tubes in series and feed them with power obtained from the regular B and C battery eliminators. RCA was also the first to operate filament type power output tubes directly from a low voltage A.C. source in commercially built receivers.

Many schemes for operating receivers from A.C. power lines were being tried at about this time. In 1928 McCullough introduced the first A.C. tube. He reasoned that if the electron-emitting surface could be electrically separated from a source of heat, it would be possible to use alternating current for filament heating purposes without encountering trouble because of A.C. in the amplifying and detecting circuits. He designed the cathode as a metal sleeve coated with a good electron-emitting material, inside which was the heater filament, insulated from the sleeve by porcelain or some other insulating material. The McCullough tube, also known as the Kellog tube (after its manufacturer) had its filament terminals at the top of the tube, with the other electrodes connected to standard tube base prongs.

The McCullough tube worked well as an A.F. amplifier, an R.F. amplifier or as a detector. Shortly afterwards McCullough introduced a power amplifier tube. The principle of separating cathodes and filaments to permit A.C. operation of tubes is still in use today, although, of course, many refinements in tube construction have been introduced in recent years. For B and C eliminators, most set manufacturers used the popular BH cold cathode rectifier tubes.

In 1928 RCA introduced their famous Radiola 17, an A.C. operated receiver; at the same time they made available for general use three special A.C. tubes: the type 26 tube, having a filament which heated and cooled slowly and could therefore be operated from a low voltage A.C. source when used in R.F. or A.F. amplifier stages; the type 27 heater type tube, having a separate cathode and designed primarily for detector stages; the type 80 full-wave hot cathode rectifier tube. The types 12 and 71 power tubes, originally designed for battery receivers, were found suitable for A.C. operation in the power audio stage. The year 1928 marked the general introduction of A.C.-operated receivers.

DYNAMIC LOUDSPEAKERS

In the early days of radio, loudspeakers were made and sold independently of receivers, even after the introduction of A.C. operated receivers. The early horn type loudspeaker, shown in Fig. *17A*, used a single headphone as a driving unit; greatly improved units, with balanced magnetic driving unit and long exponential (curved) horns like that in Fig. *17B*, soon appeared and met with widespread acceptance. Next came the cone type loudspeaker, a paper cone driven by a balanced magnetic unit at its apex or peak. The first cone loudspeaker was made up of two paper cones cemented together at their rims, with the driving unit inside, mounted at the apex of one cone and driving the apex of the other cone as shown in Fig. *17C*.

Single-cone loudspeakers came next, with the edges of the cone attached to a fixed mounting ring by means of a soft leather washer; the driving unit was mounted inside, and was linked to the apex of the cone. Cone loudspeakers were made in various sizes ranging from 8 to 36 inches in diameter, with the larger sizes naturally giving excellent bass response. Some were placed in metal housings similar to that shown in Fig. *17D*.

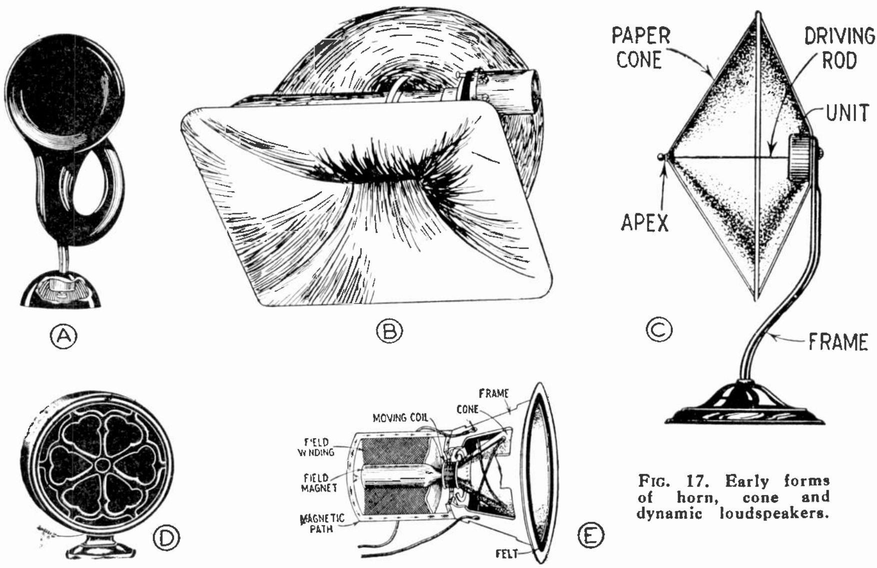


Fig. 17. Early forms of horn, cone and dynamic loudspeakers.

In 1925, Rice and Kellogg of the General Electric Company presented a technical paper describing their dynamic loudspeaker, a unit using a moving coil to drive a paper cone, the edges of which were clamped to a fixed rim; details of this loudspeaker appear in Fig. *17E*. The edges of this cone were made of soft, flexible leather, however, permitting the entire cone to move. These men also brought out the importance of the baffle in securing good low frequency response.

In 1925, RCA Manufacturing Company used this first dynamic loudspeaker with one of their superheterodyne receivers, an AC set using the old UV199 tubes (with filaments in series, getting power from a diode rectifier) and two type 210 power tubes connected in push pull for the output stage. Because of patent difficulties, however, other manufacturers were unable to take advantage of these new developments.

THE RADIO RECEIVER PATENT SITUATION

To describe things mildly, the Radio manufacturing industry prior to 1929 was decidedly "in a mess." Large scale production of receivers was risky, for the important radio patents were in many different hands and there was always the possibility of lawsuits for infringement of patent rights. Rather than give away all their profits in the form of royalties to patent holders, many manufacturers took the risk of lawsuits, knowing full well that a patent showdown would come very soon.

The Radio Corporation of America, formed during the World War at the suggestion of the United States Government in order to centralize radio facilities, had grown by leaps and bounds after the birth of radio broadcasting. This organization acquired the basic patents of the old American Marconi Company, together with American Telephone and Telegraph, Westinghouse and General Electric radio patents, the patents of other companies which it absorbed from time to time, patents obtained through outright purchase or through exchange with other radio manufacturers, and patents resulting from research in RCA laboratories. This organization was thus in a position to produce radio receivers and equipment without fear of serious litigation; it controlled the basic regeneration, T.R.F., superheterodyne, A.C. power pack, dynamic loudspeaker, vacuum tube, and vacuum tube circuit patents.

Realizing that order had to come from the existing chaos if the radio industry was to prosper, RCA proceeded to license reputable manufacturers. These then could, by combining their own patents with those of RCA and other patent holding companies to whom they were paying license fees, manufacture radio receivers with reasonable freedom from litigation (lawsuits).

At first, some manufacturers refused to pay license fees to patent-holding companies, and continued manufacturing receivers in the face of impending lawsuits; one by one these were compelled either to drop out of business or acquire patent rights. Other manufacturers, believing that the T.R.F. patent was the only obstacle to their progress, developed a circuit consisting of from two to four stages of fixed R.F. amplification preceded by at least three resonant circuits in cascade. Fair performance was obtained, but the pressure of public demand for patented features which they could not use, coupled with the decisions of various courts that they were infringing on certain other patents, finally forced these to join the crowd of patentees or else drop out of the picture. Today all reputable receiver manufacturers, both large and small, operate under a common patent agreement.

CONSOLE RECEIVERS

With patent problems at last out of the way, the Radio industry definitely entered the "big business" class. Receiving circuits had been developed up to the point where the demands of the public were pretty nearly satisfied for a time, and manufacturers now turned their attention to cabinets which would improve the appearance of their product.

Previous to 1929, a few radio manufacturers had recognized the desire of the public for a single cabinet which would house a receiver with all associated apparatus. For some time, large furniture manufacturers had been producing adaptions of lowboy and highboy console cabinets with provisions for housing the radio chassis, the loudspeaker and the ABC eliminator.

The production of complete radio receivers in several styles of console cabinets by the Grigsby-Grunow Co.,* incorporating all of the desirable technical features then available, was the outstanding event of

*Manufacturers of "Majestic" radio receivers.

the 1929 Radio season. The Majestic line met with instant popularity, and many of these early console types of cabinet receivers are still in use today. The circuit of this Majestic receiver, shown in Fig. *18*, is of special interest in connection with our studies of how practical requirements changed receiver circuits. You will observe that there are three T.R.F. amplifier stages (with four tuned circuits), a grid leak-condenser detector, an A.F. voltage amplifier stage, a push-pull audio output stage and a dynamic loudspeaker which received its field current from the power pack unit.

The Majestic receiver was entirely A.C. operated, with type 26 tubes in each R.F. and A.F. voltage amplifier stage. It had a single tuning dial, with an additional control for tuning the antenna circuit exactly to resonance (by adjusting the inductance of the input coil) when receiving distant stations. A variable resistor which served as volume con-

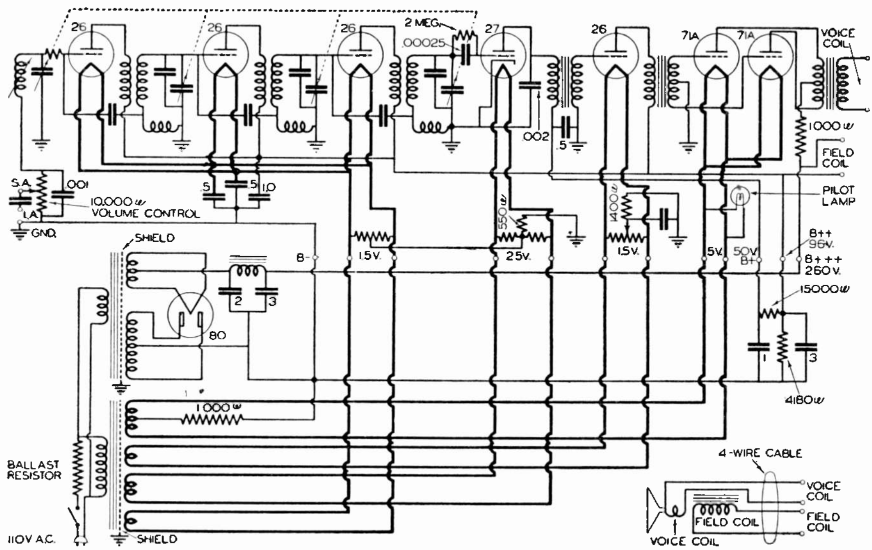


Fig. 18. Circuit of the Majestic model 70B receiver, the hit of the 1929 radio season.

trol coupled the antenna to the receiver input circuit. Each R.F. amplifier stage was neutralized. A very satisfactory sound output was obtained from the dynamic loudspeaker. An outstanding characteristic of this Majestic receiver was its false bass reproduction; this excessive amplification of low notes was pleasing to the public, and because of it, many radio listeners even today insist that the old Majestic was "king of them all."

During the years of 1929, 1930 and 1931, the T.R.F. receiver with four or even five tuned circuits reigned supreme. The public learned to rate the selectivity and sensitivity of a radio receiver in terms of the number of sections in the variable condenser gang. In order for a radio receiver to sell well during these years, it had to be A.C. operated, have a dynamic loudspeaker, be housed in a suitable console cabinet, have single dial operation, have an illuminated tuning dial and have a push-pull audio output stage.

NEW TUBES

At about this time, radio engineers developed standards for selectivity, sensitivity, fidelity and power output (with negligible distortion) for radio receivers. New receivers setting methods were brought out, and from the many important technical details which came to light, a host of new radio receiving tubes resulted.

It was found that the type 26 tube gave entirely too much hum. The type 27 was improved so it could be used in amplifier stages, thus eliminating this trouble.

Greater and greater power output was being demanded by the public. Some manufacturers used the older type 10 high voltage power amplifier tube, while others turned to the new type 50 output tube, but these high power output tubes were in general reserved for the higher priced receivers. Type 81 half-wave diode rectifiers used in either half-wave or full-wave rectifying circuits were generally to be found in the power packs of these receivers. To meet the public demand for low priced receivers, manufacturers used the type 45 power output tubes in push-pull with about 250 volts on the plates, thereby securing as much power output as either a single 10 or 50 tube would give at 450 volts.

The use of three and four stages of T.R.F. amplification, coupled with the increased power of broadcast transmitters, made the sensitivity of the square law grid leak-condenser detector unnecessary. Designers turned to the linear C bias detector in order to secure less distortion in the detector stage and increase the gain and selectivity of the last T.R.F. stage. About 1930, tube manufacturers introduced the type 24 screen grid tube, primarily for R.F. amplification purposes; this gave far more amplification than a triode and made obsolete the old neutrodyne circuit.

With increased R.F. gain in receivers, it became possible to couple the antenna loosely and inductively to the first tuned circuit and secure true single dial operation without any antenna trimmers. The well-designed receiver of 1930 consequently contained three stages of T.R.F. using screen grid tubes, a linear type 27 or type 24 detector tube, and a push-pull type 45 output stage preceded in some cases by an A.F. voltage amplifier stage. By this time the dynamic loudspeaker was considered an essential part of any receiver. The power pack used a full-wave type 80 rectifier tube. Volume control was commonly obtained by varying the C bias on the R.F. amplifier tubes.

THE RISE OF THE SUPERHETERODYNE

The difficulties encountered in amplifying radio frequency signals above 200 kc. had long been recognized by radio engineers, particularly Armstrong, who had already contributed to the development of regenerative and super-regenerative receivers. The heterodyne method of reducing the frequency of the R.F. carrier practically suggested itself as a solution to this problem, and thus was born the superheterodyne principle of R.F. amplification, near the close of the World War. Armstrong obtained phenomenal gain with intermediate frequencies of 30 to 45 kc. His superheterodyne patents were acquired by RCA, and about 1923 they produced the Radiola Super Heterodyne receiver, in which a 45 kc. I.F. section employing iron core transformers and a sharp filter was used. RCA claimed the superheterodyne circuit for its own, and continued to develop it to a high state of efficiency. A number of radio parts manufacturers produced I.F. transformers and special preselector and oscillator coils for home experimenters, and home-made superheterodynes thus were the only other source of these receivers.

Late in 1930, the superheterodyne patents were released by RCA for use among their patent licensees, and T.R.F. circuits faded out of the picture, slowly at first and then with a sudden sweep as the superheterodyne circuit climbed to its throne as king of receiver circuits.

In 1931, the RCA Manufacturing Company brought out the Radiola 80, a receiver which set a standard of performance that even today is difficult to exceed. The circuit diagram for this famous receiver is given in Fig. *19*. Note that the two I.F. amplifier stages had screen grid tubes. The oscillator and second detector used triode tubes, with the latter serving as a linear power detector and feeding two type 45 tubes in a push-pull audio power output amplifier circuit. The first detector was

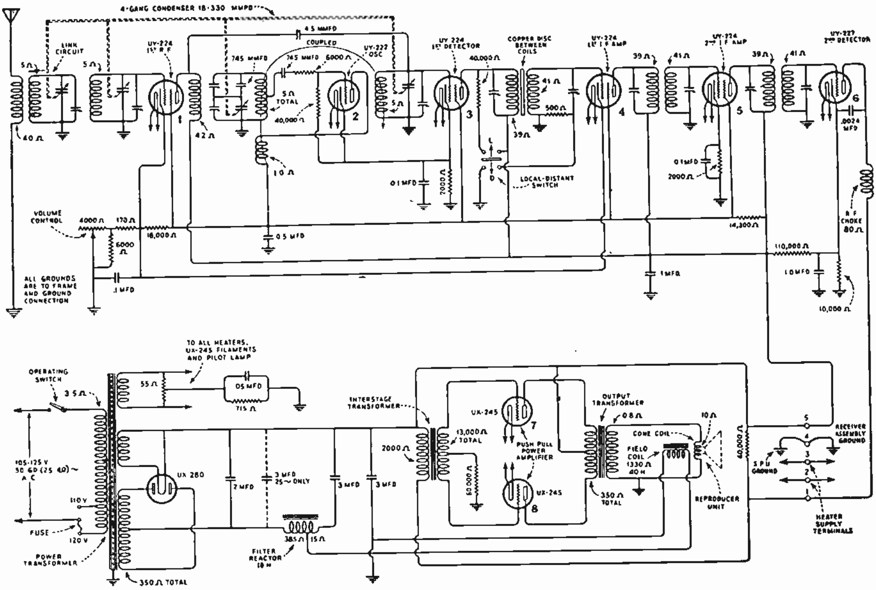


Fig. 19. Circuit of the Radiola 80, a nine-tube superheterodyne announced in 1931 by RCA Manufacturing Co., Inc. This same circuit was also used in the Graybar 700, General Electric 31 and Westinghouse WR5 receivers.

preceded by one stage of tuned R.F. amplification, with a double resonant circuit serving as antenna coupler, to prevent interference troubles. All of the features necessary for good selectivity, high sensitivity, good fidelity, interference suppression and high power output are present in this circuit; its development over a period of years was an indication that receiver designers were giving attention to the practical requirements of the public.

MORE NEW TUBES

The inability of the C bias type of volume control to reduce the gain for strong signals without distorting them resulted (in 1932) in the introduction of the type 35 and type 51 variable mu tubes. These tubes had long E_g-I_p characteristic curves, so that very high negative C bias voltages were required to reduce the plate current to zero. Cross modulation and modulation distortion effects were reduced by these tubes.

The inability of screen grid tubes, even those of the variable mu type, to handle wide variations in plate voltage practically forced the pentode R.F. amplifier tube into existence. In 1932 a new series of amplifying tubes, consisting of the type 56 triode, the type 57 pentode and the type 58 super-control pentode (which had a variable mu characteristic), appeared.

The type 45 triode power amplifier tube did not have quite enough amplification to operate directly from a triode acting as linear C bias detector, and the type 47 power amplifier pentode came into existence to meet this deficiency; the 47 tube was used either singly or in push-pull circuits.

When receivers were designed to be sensitive to weak signals, they invariably had too much gain for powerful local stations. For this reason the average broadcast listener had to tune with one hand on the tuning dial and the other on the volume control in order to prevent blasting when tuning from a weak to a strong signal.

To achieve more nearly ideal single dial receiver control, automatic volume control was introduced around 1932. The first AVC-controlled receivers contained an extra vacuum tube which acted as a C bias detector and produced the variable negative C bias voltage required for control of the R.F. amplifier tubes. The result was automatic reduction in gain when strong signals were tuned in, and to compensate for fading of signals to a certain degree.

The acceptance of the diode detector for signal demodulation purposes made unnecessary the use of a separate AVC tube. The diode detector gave considerably less distortion than the linear C bias detector, was able to handle higher R.F. voltages, and at the same time developed a negative D.C. bias voltage for automatic volume control purposes. Diode detectors are now practically universal in the second detector stages of superheterodynes. The lower A.F. output of the diode detector required the use of an audio voltage amplifier; rather than use an extra tube, two diodes and a triode were built into a single envelope, known as the type 55 duo-diode triode; here one diode section served as second detector and the other supplied the AVC voltage.

MIDGET, AUTO AND FARM RADIO RECEIVERS

Midget Receivers. The year 1929 was the beginning of a long period of business depression. Radio, being a new industry and a home substitute for more costly entertainment, kept right on going through the first years of the depression. By 1932, however, the greatly decreased income of the buying public began to make inroads on the volume of sales of high priced radio receivers. Manufacturers decided that low priced receivers were their only salvation.

The first midget receiver to attract widespread attention was the Jackson-Bell table model receiver, introduced about 1931. This first midget receiver was a T.R.F. set using screen grid R.F. amplifier tubes followed by a screen grid detector and a type 45 power amplifier. The power pack used a type 80 full-wave rectifier tube.

Then came a flood of midget receivers, together with new tubes designed especially for them. In 1932, midget superheterodyne receivers were introduced; they invariably used the type 24 tube as a combination first oscillator-mixer-detector and thus a single tube performed the entire frequency converter function.

Large manufacturers of radio sets began turning out both T.R.F. and superheterodyne table model receivers in various sizes ranging from the "overcoat pocket" and "cigar box" sets to large size table model receivers, all complete including loudspeaker, and some even having built-in antennas. Midget receivers, having space and cost limitations as practical requirements, resulted in two innovations, the use of multi-function tubes (particularly pentagrid converter tubes), and universal AC-DC operation, eliminating the need for a power transformer and permitting use of the receiver in either D.C. or A.C. localities. Midget receivers outlasted the depression, and are available now in a wide variety of styles, sizes, and even colors.

Auto Radios. Mobile (movable) radio equipment was by no means new, for it was being used extensively by the War and Navy Departments, as well as in airplanes. As far back as 1922, experimenters had been installing radio receivers in automobiles, but it was not until 1932 that radio manufacturers gave any considerable amount of attention to the auto radio receiver. Mass production technique was applied to the auto radio problem as another attempt to bridge the summer-time drop in radio sales.

The first auto radios to appear on the general market included a radio chassis in a steel box, a remote tuning and volume control unit, either B batteries or a dynamotor for supplying the required high D.C. voltages, a separate loudspeaker, and suppressor resistors and condensers for the electrical system of the car in order to suppress ignition interference; the entire radio system secured its power from the 6-volt auto storage battery.

It is interesting to note that auto radios went through the same development process as had home radios some years before. In each case the many separate units were gradually combined into one compact unit. The auto radio loudspeaker became an integral part of the radio chassis. The dynamotor was gradually replaced by the vibrator type of B supply unit, which also was built into the chassis. The superheterodyne became the standard auto radio circuit, and AVC was introduced to compensate for fading. An entire auto radio set could now be bolted to the bulkhead or just behind the dash. Tuning controls which harmonized with the dash panel design of various car models were made available about 1935.

Research work on auto radios naturally resulted in considerable benefit to radio receivers in general; perhaps the most outstanding contribution was the 6.3 volt line of vacuum tubes. The filaments in an auto radio receiver get their power from the 6-volt car storage battery, the voltage of which may vary from 5 to 7.5 volts under ordinary driving conditions. This wide fluctuation in voltage made it impractical to use the existing 5-volt or 2.5-volt filament tubes, for these required accurate control of filament voltage. The new series of 6.3-volt heater type tubes could be connected directly to the storage battery. They were built to withstand the strain of voltage variations and yet each drew only about .3 ampere of filament current.

Builders of universal AC-DC receivers tried using these 6.3 volt tubes, with the filaments connected in series, and obtained quite satisfactory results. A new group of tubes, drawing the same filament current as the 6.3-volt line but using higher filament voltages, now made its appearance; this group included the type 43 power tube (with a 25-volt filament), together with the 12Z3 (12.5-volt filament) and 25Z5 (25-volt filament) rectifier tubes, designed specifically for use in midget receivers where the filaments of all tubes were connected in series.

Farm Radios. Throughout the phenomenal rise of radio receivers, the attention of manufacturers had been focused on receivers designed primarily for either A.C. or D.C. power lines. Homes without electric power and particularly farm homes were still struggling along with the old battery receivers like those shown in Figs. *8* and *9*, purchasing new B batteries every few months and recharging storage batteries even oftener. To be sure, a few receivers were made with the type UV199 and UV 120 tubes, but these tubes were entirely too fragile to meet with widespread use.

Late in 1930, the National Carbon Company introduced their Air Cell Battery, which could deliver slightly over 2 volts at a current drain of about .65 ampere for at least 1000 hours. When used as filament supply battery on a radio set operated an average of three hours a day, this filament battery had a useful life of about one year and required no recharging.

The Air Cell Battery was designed for use with the line of 2-volt tubes announced at about the same time by RCA. The type 30 triode amplifier-detector tube and type 31 power triode tube, each required a filament voltage of 2 volts, with filament currents of .060 ampere and .130 ampere respectively. These tubes were rugged, small, and easily adapted to existing radio receiver circuits. They were quickly followed by the type 32 screen grid tube, the type 34 super R.F. pentode and the type 33 power audio amplifier pentode, all with 2-volt filaments. It now became easy to design efficient battery receivers for farm homes, but the power output was limited except in cases where considerable waste of supply power was permissible. To overcome this, the twin class B type 19 triode (two triode tubes in one envelope) appeared. It was used in a push-pull amplifier stage in farm radio receivers.

The efficiency of push-pull output amplifiers was recognized at about this time for home receivers; in rapid succession the type 46 (2.5 volts) and type 59 (2.5 volts) class B amplifier tubes, together with the type 53 (2.5 volts) and type 79 (6.3 volts) twin class B amplifier tubes came into use for push-push output stages. These tubes in turn were gradually replaced by the types 2A3 and 6A3 power tubes and by the type 6L6 beam power amplifier tube, all in class A operation.

ADAPTING RECEIVERS TO POWER SUPPLIES

After 1930, new tubes followed each other in rapid succession. In general these were produced either to satisfy a demand for tubes with special characteristics or to meet special power supply requirements.

So many tubes have been introduced in recent years that it has become almost imperative to refer to a tube chart whenever data on tubes is desired. One very interesting and comprehensive chart, shown in Fig. *20*, has been prepared by RCA Manufacturing Co. It lists tubes according to the number of electrodes (diodes, mixed triodes, tetrodes, etc.), according to function (voltage amplifier, power amplifier, rectifier, etc.), and according to filament voltage. Although this chart was prepared specifically for RCA tubes, it is typical of all tubes having the same type numbers. Metal tubes are designated in bold face (thicker) numerals; the more widely used tubes are indicated in larger type. Remember that metal tubes with eight prong (octal) bases are also made with glass envelopes by many tube manufacturers; the numbers of octal base glass tubes are always followed by the letter G.

With such a wide variety of tubes from which to choose, radio receiver de-

signers now have little difficulty in adapting a radio to any given power supply. It is perfectly possible to take a given signal circuit (R.F. amplifier, detector or audio amplifier) and adapt it to any power supply condition simply by rearranging the supply circuit and in some cases changing tubes. An example will show you how this is possible.*

Consider the superheterodyne circuit shown in Fig. *21A*, which consists of a type 1A6 pentagrid converter tube receiving input power from the antenna through a transformer having a tuned secondary; this first tube acts as a combination oscillator and mixer-first detector. It is followed by an I.F. amplifier stage containing two I.F. transformers, after which comes a duplex-diode-triode tube functioning as a diode detector, AVC tube and A.F. voltage amplifier. Then comes a pentode power audio amplifier stage having resistance-capacitance coupling. The supply connections for a battery operated receiver are shown here, with all supply leads in heavier lines. The filaments of all tubes are connected together in parallel. All B+ and B++ leads can be traced to tube elec-

Heater Volts	1.1	1.5	2.0	2.5	3.3	5.0	6.3	7.5	12.6	25	30
DIODES											
Detector (twin)							6H6				
Rectifier (half-wave)							1-v	81	12Z3		
Rectifier (full-wave vacuum)						5W4, 5Z4, 5Z3 80, 83-v	6X5, 84				
Rectifier (full-wave mercury)				82		83					
Rectifier Doubler										25Z6 25Z5	
TRIODES											
Voltage amplifier (medium mu)	11, 12	26	30	27, 56	'99	00-A, 01 A, 40	6C5, 76, 37				
Voltage amplifier (high mu)							6F5				
Power amplifier			31	2A3 45	20	71-A, 112-A		10, 50			
Class B amplifier (twin)			19	53			6N7, 6A6, 79				
Class B amplifier (dual grid)			49	46							
TETRODES											
Voltage amplifier (sharp cut-off)			32	24 A	22		36				
Voltage amplifier (remote cut-off)				35							
Power amplifier											48
BEAM POWER TUBES							6L6			25L6	
PENTODES											
Voltage amplifier (sharp cut off)			1B4 15	57			6J7, 6C6, 77				
Voltage amplifier (remote cut off)			1A4, 34	58			6K7, 6D6, 78 39/44				
Power amplifier			1F4 33	2A5, 47 59			6F6, 38, 41 42, 6A4, 89			25A6 43	
PENTAGRID CONVERTERS			1A6, 1C6	2A7			6A8, 6A7				
PENTAGRID MIXER							6L7				
DUPLEX-DIODE TYPES											
With medium-mu triode			1B5/25S	55			6R7, 85				
With high mu triode				2A6			6Q7, 75				
With pentode			1F6	2B7			6B8, 6B7				
TRIODE PENTODE							6F7				
ELECTRON-RAY TUBES											
With sharp cut-off triode							6E5				
With remote cut off triode							6G5				

FIG. 20. Tube chart prepared by RCA Manufacturing Co., Inc. All-metal tubes are shown in large boldface type.

trodes, then through the tubes to the filament circuit and to ground. All of the control grids in the R.F. section can be traced to the diode detector from which they receive AVC voltage. All of the grids in the audio stages can be traced to the C— or C—— power supply leads. Either a magnetic or a permanent magnet type dynamic loudspeaker is used hence no D.C. power is required by the loudspeaker to produce a steady magnetic field.

When this same signal circuit is adapted for A.C. operation, it will appear as shown in Fig. *21B*; again the power supply circuit and all power supply leads are shown in heavier lines. Heater-type tubes, designed to operate with A.C. filament voltages, have been substituted for the low drain battery type tubes. A conventional full-wave rectifier circuit using a type 80 tube constitutes the power pack here; it can be designed for any A.C. line voltage and frequency. The filaments of all tubes are connected together in parallel, and are completely isolated from the signal circuits. When electrode voltages lower than the power pack voltage are required, resistors are used in the power supply leads to drop the voltage.

*Experienced servicemen seldom attempt to change a receiver over from one type of power supply to another, for many problems are encountered. The various circuits are presented here only to illustrate the principles involved.

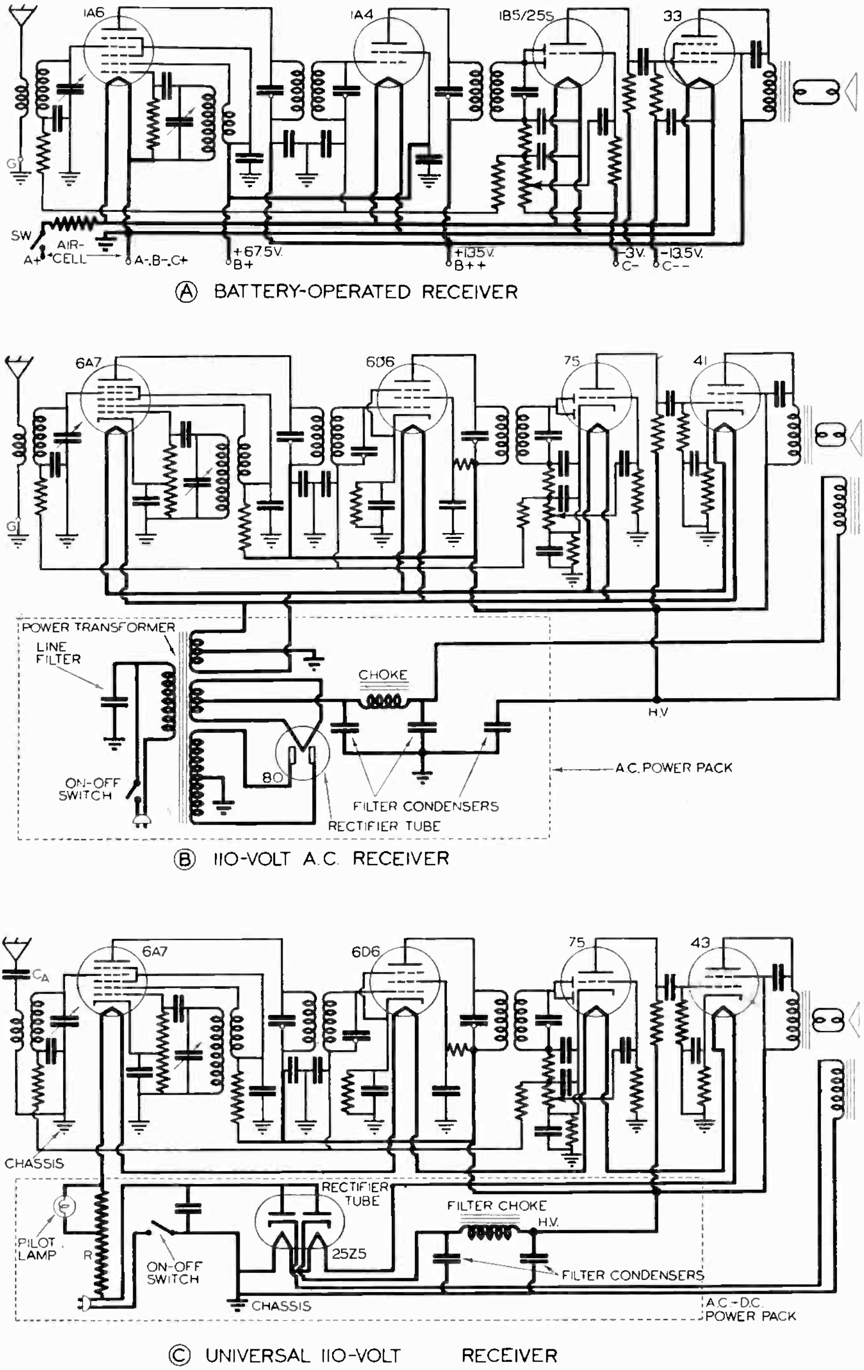
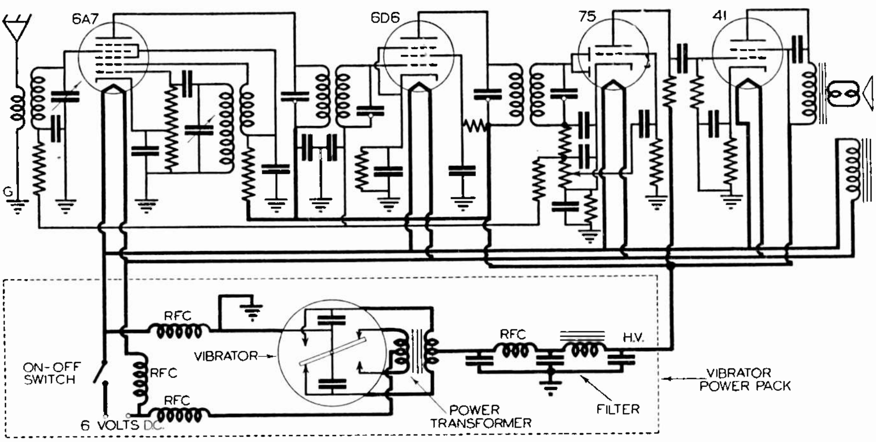


FIG. 21. Standard superheterodyne radio receiver circuit arranged for use with battery power (*A*), for 110-volt A.C. power (*B*), for either 110-volt A.C. or 110-volt D.C. power (*C*), and for 6-volt battery power (*D*, on following page). Suppressor grids for the types 41 and 43 tubes are not shown on these diagrams; in each case, they are connected internally to the cathode.

All of the *control* grids in this circuit can be traced to ground through resistors either directly or through the AVC tube circuit. Other grid electrodes and all plate electrodes can be traced to the point marked H.V., which is at the highest completely filtered D.C. voltage in the receiver. An electromagnetic type dynamic loudspeaker is used, with the field coil acting as a choke in the power supply filter.

When this same signal circuit is used for an AC-DC universal receiver, the circuit takes on the form shown in Fig. *21C*. Here a twin diode rectifier tube is used, with one diode furnishing half-wave rectified current for the field coil of a dynamic loudspeaker, and the other diode feeding into a filter which furnishes the D.C. electrode voltages. Supply leads are again shown in heavy lines; tube filaments are all connected together in series and are independently connected to the line voltage terminals through current-limiting resistor *R*.

Condenser C_A, in series with the antenna, allows R.F. current to flow but blocks D.C. or 60 cycle A.C.; it serves to prevent the receiver from damage in the event that the antenna is accidentally grounded at a time when the chassis



Ⓓ 6-VOLT AUTO OR FARM RADIO RECEIVER

FIG. 21D. Standard superheterodyne receiver circuit arranged for 6-volt power.

is connected to the "hot" side of the power line. The condenser also reduces the severity of the shock received when the antenna is touched under this condition. No ground is used with this receiver. All other features of this universal receiver are similar to those for battery operation.

The manner in which this basic receiver signal circuit is adapted for 6-volt operation, such as for automobile and farm radio receivers, is shown in Fig. *21D*. The filaments of all tubes and the field coil of the dynamic loudspeaker are here connected in parallel directly to the 6-volt storage battery. A synchronous vibrator, also connected to the battery, changes the D.C. to A.C., which is then stepped up by the power transformer and again converted back to pulsating D.C. by the vibrator. The pulsating D.C. is filtered and then fed to the various tube electrodes except the control grids. All control grids can be traced to ground through paths which conduct direct current. The chassis is the common return for all supply circuits in this set.

Reading Circuit Diagrams. The circuits in Figs. *21A*, *21B*, *21C* and *21D* show that with minor signal circuit changes, a standard radio receiver can be adapted to any power supply. The analysis of these circuits has also made it clear that any circuit diagram can be traced or read in three distinct steps: *1, trace the power pack and supply circuit leads* through the signal circuits and tubes; *2, trace the signal from the antenna to the loudspeaker* (or image reconstructor in the case of a television receiver); *3, trace any special control circuits*, such as AVC, tone control, AFC, etc.

ALL-WAVE AND HIGH FIDELITY RECEIVERS

Along with the expansion of radio broadcasting, other radio services on land, at sea and in the air grew to unusually large proportions. Police, aviation, commercial and amateur radio transmitters began crowding the frequency channels above the broadcast band frequencies; furthermore, broadcast stations in many foreign countries were sending out programs on these high frequencies, primarily to reach far distant colonies.

Radio enthusiasts soon learned that many interesting messages and programs could be picked up on the high frequencies (short waves). The building of receivers in homes again returned to popularity for a time, with regenerative receivers with or without a stage of R.F. amplification being most popular with the experimenters at first for use in the short-wave bands. Plug-in coils were used to change from one tuning band to another. This situation existed up to about 1930, at which time receiver manufacturers took recognition of the growing public interest in short-wave reception and began the production of short-wave converters. These converters consisted of a mixer-first detector stage which, when connected to an ordinary T.R.F. receiver, used that receiver as the intermediate frequency amplifier, as second detector, A.F. amplifier and loudspeaker. A short-wave converter thus changed the broadcast band T.R.F. receiver into a short-wave superheterodyne receiver.

The addition of a separate unit to a receiver has always been followed by a combination of that unit with the receiver; when the superheterodyne circuit became firmly established as the basic receiver circuit, this combination of broadcast and short-wave receiver units took place. With a superheterodyne, all that was required to make the change was a means of changing the preselector and oscillator coils for each frequency range desired. The I.F. value of all-wave receivers gradually rose from a low value of about 175 kc. to about 460 kc. in order to get away from the interfering signals which are inherent in a beat frequency system.

Users of all-wave receivers began demanding faster-acting automatic volume controls and special mixer-first detector circuits which would function satisfactorily at high frequencies; these were duly developed and placed into use by manufacturers. It became evident that highly selective all-wave receivers required tuning aids to simplify the locating of foreign short-wave stations; these appeared next, and were followed by automatic tuning circuits. Again practical requirements resulted in circuit refinements and developments.

The radio listening public has always been divided into two distinct groups, one containing those enthusiasts who prefer DX (long-distance) reception which is reliable and free from interference, and the other group preferring local reception only, but of the highest possible fidelity of reproduction. To be sure, the first group also desired a certain amount of fidelity, and consequently manufacturers had to make some compromise. While design engineers strove to improve selectivity and sensistivity, they attempted at the same time to bring up the fidelity as much as possible and eliminate interference troubles. Linear diode detectors became standard, and reasonably broad R.F. amplifiers together with broad-response audio amplifiers and good loudspeakers became essential requirements of all-wave superheterodynes.

The demand for higher and higher fidelity continued, resulting in band-pass R.F. systems and flat-response A.F. amplifiers feeding into a high fidelity loudspeaker with specially designed chambers or baffles. The problems of improving fidelity are by no means simple, for difficulties with noise, hum and volume range increase rapidly as fidelity is improved; nevertheless, receivers are today on the market which will faithfully reproduce anything which can be put on the air by modern broadcast transmitters.

Even though fidelity is all-important with certain listeners, they will not accept receivers which lack certain other desirable features. The high-priced, high quality all-wave receiver of today therefore incorporates a great many features, the outstanding of which are: high fidelity in the broadcast band, all-wave reception in all bands on which programs are regularly broadcast, variable selectivity and sensitivity, compensated volume range, bass and treble control, automatic frequency control, automatic tuning of the push-button or telephone dial type, either at the receiver or at a remote point, fast and slow speed tuning, fast and slow AVC action, tuning indicators, extension loudspeakers and all-wave antennas.

The radio industry, having gone through the code and sound signal development stage, now takes on the transmission of visual signals as well. The methods of modulating, broadcasting and receiving visual signals do not differ in principle from the methods used for code and sound signals; only the ranges of modulation and carrier frequencies differ.

It is only natural that the well-understood and thoroughly-tested principles of the superheterodyne circuit should be extended for television service. Because of the high picture frequencies involved, ultra high-frequency carriers are used. The preselector circuit in a television receiver must therefore tune to ultra-high frequency carriers, the I.F. amplifier must handle a wide range of side frequencies, the detector circuit must have no frequency distortion even at the highest picture frequencies, and the picture amplifier, if used, must likewise have no distortion. Special sweep circuits are needed to control the electron beam in the cathode ray image reconstructor tube.

Thus you can see how the radio receiver has passed through various stages of development, starting with the coherer and moving in rapid succession to the basic circuits of crystal detectors, regenerative vacuum tube detectors, tuned radio frequency amplifiers and finally to the superheterodyne circuit, which today is king of them all.

TEST QUESTIONS

Be sure to number your Answer Sheet 18FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What seven important technical requirements, set up by the public control the circuit chosen for any particular receiver?
2. Who predicted mathematically that an oscillating current will radiate electromagnetic waves which are identical with light waves except for frequency?
3. Why were loading coils sometimes inserted in the tuning circuits of early receivers?
4. Why is the super-regenerative receiver unsatisfactory for use in congested bands?
5. Why were grid suppressors used in some of the earlier T.R.F. receivers?
6. What objectionable effect compelled set designers to drop the idea of untuned antenna systems in single-dial receivers?
7. In what radio apparatus was the Raytheon BH rectifier first used?
8. What five separate items did a person have to select in the early part of 1928 in order to have a complete radio receiver installation?
9. In what year were A.C.-operated receivers generally introduced?
10. Name the three distinct steps involved in tracing or reading a circuit diagram.

MANUAL AND AUTOMATIC VOLUME CONTROLS

19FR-2

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THE MIDDLE COURSE

The old Romans had a phrase that was frequently on their lips. Translated into English, it was, "moderation in all things."

Most of us have been taught, from early childhood on, the necessity for moderation in eating and drinking. But the fact that moderation in all things is essential to happiness is largely overlooked.

Take for example the simple matter of opinions. You have certain ideas about things—certain opinions. If you can see only your own opinions—if you won't alter your opinions, even though your reason tells you you are wrong, you are opinionated. And opinionated people don't get along very well with other people—and for this reason are often unhappy.

On the other hand you may yield your ideas to another's too readily. Then you are weak-kneed—and also unhappy.

But if you can give and take—if you are open to reason, if you steer a middle course, you will be liked, and people will be comfortable in your company. As a consequence you will enjoy your association with others and you will have learned one of the first rules of happiness.

The same idea of moderation should guide you in everything. In your dress be neat but not foppish. In your association with people be courteous but not fawning or affectedly polite. Be sympathetic but not sentimental. Be self-confident but don't be led into difficult situations by overconfidence. Don't believe everything you hear but don't think that everything you are told is false.

Let "moderation in all things" be one of the guiding principles of your life.

J. E. SMITH.

WASHINGTON, D. C.

1941 Edition

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Manual and Automatic Volume Controls

Why Volume Controls Are Needed

THE most important control in a radio receiver is unquestionably that which allows the listener to choose one desired station from the many which may be on the air at any one time. Next in importance is the *volume control,* which directly or indirectly controls the acoustical level or volume of the loudspeaker sound output. Volume controls are of two general types: *1, Automatic volume controls; 2, manual volume controls.* All radio receivers require manual volume controls, *even when equipped with automatic volume control.*

Automatic Volume Control. Automatic volume control (commonly abbreviated A.V.C.) keeps the output volume level of a radio receiver essentially constant despite variations in R.F. signal input voltage. These variations may occur while the radio receiver is tuned to a single station (fading) or while the receiver is being tuned from station to station.

The R.F. input signal voltages which modern receivers are called upon to handle may vary from 1 microvolt for low-power or distant stations to 1 volt for high-power local stations, and thus the strongest signal handled is a million times greater than the weakest signal. If the gain of the R.F. amplifier were *fixed* at a value sufficient for reproduction of the weakest signals, there would be *blasting* (excessive volume) when the set was tuned to a strong signal. A.V.C. counteracts this blasting by *raising the gain* of the R.F. amplifier for weak signals, and *lowering the gain* automatically and almost instantly for strong signals.

Blasting is particularly annoying when the listener is tuning rapidly from station to station while searching for a desired program. Furthermore, blasting may be accompanied by *overloading* of the loudspeaker and of one or more stages in the receiver, with resulting distortion. A.V.C. prevents this overloading by reducing the gain of the R.F. amplifier for strong signals.

Programs received from distant and semi-distant stations, where the radio waves are totally or partially reflected from the sky before reaching the receiving antenna, are subject to *fading;* in other words, the strength of the signal at the receiving location varies considerably from minute to minute. A.V.C. can compensate for the effects of fading by raising and lowering the gain of the R.F. amplifier just enough to maintain the desired acoustical output, provided the signal does not become excessively weak. Automatic volume control is thus desirable in a radio receiver for these three important reasons: *1, it prevents blasting; 2, it prevents overloading; 3, it minimizes fading.*

Manual Volume Control. A manual volume control is essential in a radio receiver for a number of reasons: Low volume may be desired when a musical program is used as atmospheric background while eating, reading, playing games, or carrying on conversation; increased volume may be desired for news broadcasts, talks by important persons, radio plays, popular all-star broadcasts, symphonic music, or music for dancing; furthermore, some people can hear better than others, and the volume must be adjusted accordingly.

But what, exactly, is a volume control? To the average non-technical person, any control which permits him to change the volume of the sound coming out of the loudspeaker is a volume control. Radio men know, however, that volume controls are either voltage controls or gain (amplification or sensitivity) controls. In receivers which have automatic volume control (commonly abbreviated as A.V.C.), the manual volume control is always an A.F. voltage control; in all other receivers the manual volume control is always an R.F. circuit control.

Volume Controls Prevent Overloading

There is a definite limit to the amount of signal voltage which can be

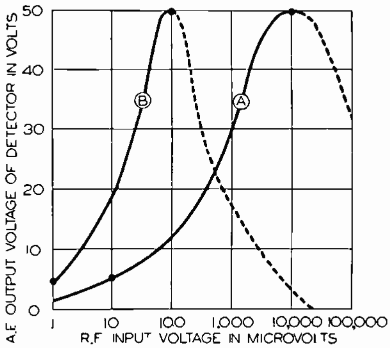


Fig. 1. Overload characteristic curves for a low-gain receiver (*A*) and for a high-gain receiver (*B*), neither of which have automatic volume control. The manual volume control is set for maximum output when securing data for an overload curve.

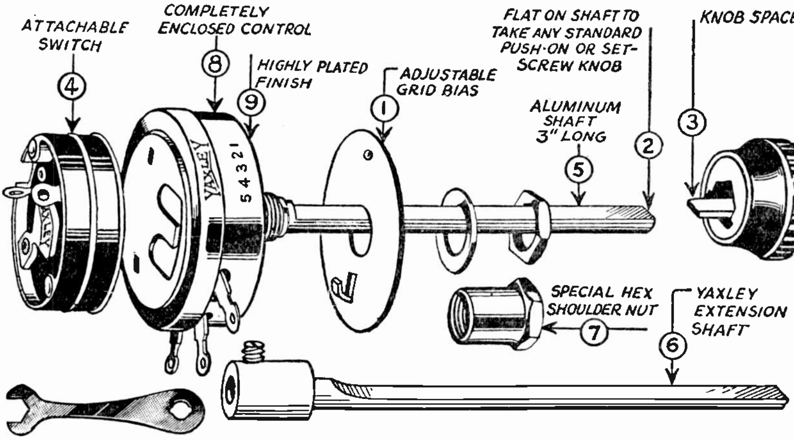
handled by each stage in a radio receiver. Excessively high input voltage to a stage results in distortion, because high input signals make the plate current swing over non-linear regions of the E_g-I_p characteristic of the tube. Because of this distortion, manual volume controls in receivers not having A.V.C. must be R.F. gain controls; they can then be adjusted to prevent overloading of *any* receiver stage.

Overload Characteristic Curves. The overload characteristics of the R.F. amplifier and detector sections of a radio receiver are often presented by engineers in the form of curves like those in Fig. *1*. The engineer measures the A.F. output voltage of the detector while feeding various measured R.F. input voltages into the receiver at constant percentage of modulation, then plots his results in order to secure a complete graphical picture of what is happening.

Curve *A* in Fig. *1* is representative of an R.F. amplifier having fairly low gain, while curve *B* is for a high-gain or high-sensitivity R.F. amplifier; in each case the manual volume controls are at their maximum output settings and there is no A.V.C. The dotted region of each curve indicates distortion; you can see that in the case of receiver *A*, an input signal of approximately 10,000 microvolts is required to give maximum undistorted detector output, while with receiver *B* this same undistorted output (about 50 volts A.F.) is obtained with a signal input voltage of about 100 microvolts. These input signal levels will give full output volume; it necessarily follows that signals exceeding these input levels will tend to cause overloading and distortion unless the gain of the receiver is reduced either by a manual or automatic volume control.

If the A.F. amplifier used with either receiver *A* or *B* (Fig. *1*) required an A.F. input of 50 volts to deliver the maximum desired loudspeaker volume, only signals 10,000 microvolts or stronger for *A* and 100 microvolts or stronger for *B* would give this maximum volume. When full loudspeaker output is desired for weaker signals as well, the designer must use an A.F. amplifier having higher gain.

Suppose, for example, the designer builds an A.F. system which will deliver full loudspeaker output at an A.F. input voltage of 5 volts; in the case of receiver *A* in Fig. *1*, an R.F. input signal of 10 microvolts would give the 5-volt A.F. output required for full loudspeaker volume. In the case of receiver *B*, a 1-microvolt input signal would be reproduced with full volume. On signals stronger than these values the manual volume control setting would have to be reduced to prevent overloading; signals weaker than these values would have less than maximum volume, but in many cases reduced volume would be entirely satisfactory.



Typical manual volume control with accessories (a unit made by the Yaxley Manufacturing Division of P. R. Mallory & Co., Inc.). A feature of this control is the adjustable grid bias plate (*1*) which permits adjusting the minimum resistance to 100, 200, 300, 400 or 500 ohms for fixed C bias purposes. Numbers on housing and indicating mark on plate tell which setting is used. With this plate removed, the control can be turned to zero resistance. The 3" shaft can be cut to any desired length with a file or hacksaw, or can be lengthened when necessary by using an extension shaft (*6*). A small metal spacer (*3*) is supplied with Yaxley controls for use with knobs designed for shafts having only 1/32" deep flats. The back cover plate of the control housing is easily removed to permit attachment of a power switch (*4*). The special nut (*7*) is used for mounting the controls on panels up to 3/4" thick. A small wrench like that shown is recommended for tightening this nut or the regular flat nut shown on the shaft, as pliers may wear off the corners of these nuts or scratch the panel.

Types Of Manual Volume Controls

The manual volume controls found in radio receivers are of three types, which may be used either singly or in combination: *1, R.F. voltage controls,* which reduce the voltage of the R.F. input signal either before it reaches the first R.F. amplifier stage or before it enters an R.F. stage which may overload; *2, A.F. voltage controls,* which reduce the A.F. voltage output of the demodulator stage or reduce the A.F. voltage at some point in the A.F. amplifier; *3, R.F. gain controls,* which reduce the gain (amplification) of an R. F. amplifier stage either by varying the load on that stage or by varying the mutual conductance of the tube in that stage. We will now consider the advantages and disadvantages of each of these forms of manual volume controls as applied to practical radio receiving circuits.

R.F. Voltage Controls

R.F. voltage controls can either vary the R.F. voltage which is fed from the antenna to the input of the R.F. amplifier or can vary the R.F. voltage which is fed from one R.F. amplifier stage to another. These R.F. voltage controls were widely used in older receiver circuits for the purpose of controlling volume, the antenna circuit control having been the more popular.

Five typical R.F. voltage control

circuits are shown in Fig. *2*. As you can see, the control device in each case was a potentiometer with two fixed terminals (labeled *R* and *L*), and a movable contact arm connected to a third terminal (labeled *C*); the significance of these *R, L* and *C* (right, left and center) designations for these volume control potentiometers will be explained to you later. The value of the voltage fed to the following R.F. circuit depends upon the position of the movable arm of the potentiometer.

With the circuit of Fig. *2A,* the fixed terminals of the potentiometer were connected to antenna and ground, and the variable tap on the potentiometer was connected directly to the grid of the first R.F. amplifier tube. The potentiometer thus controlled the R.F. voltage which was applied to the grid of this tube. This circuit had no selective or signal-boosting properties; therefore, only the characteristics of the antenna determined which signals would be favored. The antennas used at the time were generally of such a length that they were in resonance at the higher frequencies in the broadcast band, and consequently these higher frequencies were favored.

To make the simple antenna circuit volume control of Fig. *2A* respond equally well to low and high frequencies, inductance L_A was connected between grid and cathode of the first R.F. tube in the manner shown in Fig. *2B*. The inductance and distributed capacity of coil L_A acted together to form a parallel resonant circuit whose resonant frequency was in the lower region of the broadcast band. This resonant circuit acted as a high impedance to low frequency signals, developing maximum R.F. voltage for transfer to the grid of the tube, and acted as a capacitive reactance path to ground (a shunting capacity) for higher frequency signals. By choosing the proper ratio of inductance to capacity for coil L_A, it was possible to make the antenna circuit respond uniformly to both low and high frequencies in the broadcast range.

The volume controls shown in Figs. *2A* and *2B* worked well in receivers located at a distance from powerful broadcast stations, but in the vicinity of a powerful station the capacity path between the leads and parts of the volume control was sufficient at radio frequencies to transfer the signal of the local station to the grid of the first tube at all volume control settings. When the volume control was turned up to receive a weak signal, the signal of the local station overloaded the first R.F. amplifier tube, making this tube act as a detector which modulated the weak signal with the program of the strong signal; cross-modulation resulted, with both the desired and the undesired programs being reproduced by the loudspeaker. Cross-modulation quickly doomed these two volume control circuits, and consequently you must be on the lookout for this trouble when you encounter an older receiver which uses one of these volume control circuits.

The next move of the radio receiver designer was to provide selectivity for the antenna circuit in order to counteract cross-modulation effects. One of these selective circuits is shown in Fig. *2C;* as you can see, the voltage output of the volume control was fed into the primary of an R.F. transformer, and the resulting R.F. current induced a stronger R.F. voltage in the tuned secondary of this transformer for transfer to the grid of the first tube. The chief drawback of this circuit was the fact that whatever resistance existed between terminals *C* and L of the potentiometer was reflected into the resonant circuit as a resistance; this made selectivity very poor at low volume control settings.

The modified potentiometer connection shown in Fig. *2D* gave improved selectivity. Note that the variable tap of the potentiometer was grounded and that the entire potentiometer resistance was connected across the primary of the R.F. transformer. This resulted in a constant and high resistance being reflected into the resonant circuit, keeping the selectivity essentially constant. Antenna and ground connections were made to points L and C on the potentiometer. As the resistance between these two points was increased, more of the antenna current flowed through coil L_A and therefore a higher R.F. voltage was induced in the resonant circuit.

The usual form of R.F. voltage control used between two R.F. stages was that shown in Fig. *2E*. Here the voltage developed across series resonant circuit L_1-C_1 was fed to the two fixed terminals of the volume control potentiometer, and the variable tap of the potentiometer was connected directly to the grid of the following R.F. amplifier tube. The potentiometer resistance was generally between .25 megohm and 1 megohm, so the load placed upon the resonant circuit by the volume control was negligible. One disadvantage of this circuit was the fact that body capacity, such as placing the hand near the volume control, tended to detune the circuit; this made it necessary to use a long shaft of insulating material between the potentiometer and its control knob. Furthermore, this volume control and the antenna circuit R.F. voltage controls were quite noisy, for they con-

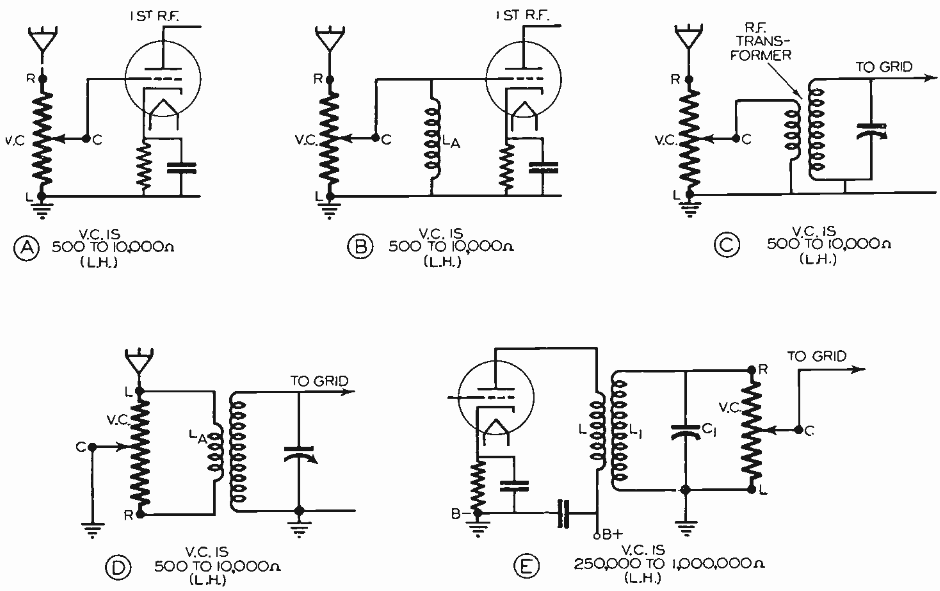


FIG. 2. Typical manual volume control arrangements which vary the amount of R.F. voltage transferred from one circuit to another. The resistance values indicated for *V.C.* are maximum values; the minimum resistance in each case is zero. The designations *R, L, C, R.H.* and *L.H.* are explained later in this text-book.

trolled low R.F. voltages in high-gain circuits.

A.F. Voltage Controls

Several different ways of connecting manual volume controls into audio frequency amplifier circuits are shown in Fig. *3*. Controls such as these are essential in the audio amplifiers of public address systems, in intercommunicating systems, in electric phonographs and in all radio receivers which employ A.V.C. in the R.F. amplifier. Basically, an A.F. voltage control varies the amount of A.F. voltage which is fed from one circuit (acting as source) to another circuit (acting as load).

Perhaps the most widely used form of A.F. voltage control for public address amplifiers is that shown in Fig. *3A*. Here audio transformer *T* couples the A.F. signal source to volume control potentiometer *V.C.* In cases where the signal source has a high impedance, approaching that of the volume control, the transformer may be omitted and the source connected directly to terminals *R* and *L* of the potentiometer. Any desired portion of the voltage applied across the potentiometer is fed to the grid and cathode terminals of the following A.F. amplifier tubes. This arrangement gives good frequency response over the entire A.F. range, for the volume control acts as a load on the transformer. Condenser C_C, which together with R_C provides automatic C bias, should have a negligible reactance to the lowest audio frequencies being amplified in order that currents at these frequencies can pass from cathode to ground without attenuation.

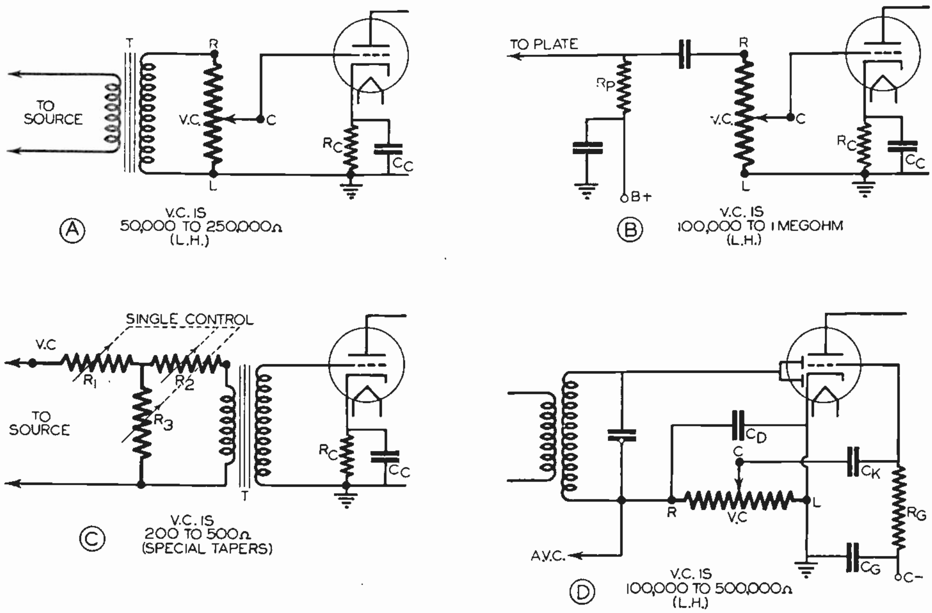


Fig. 3. Typical manual volume control arrangements which vary the amount of A.F. voltage transferred from a source of A.F. voltage to a following circuit.

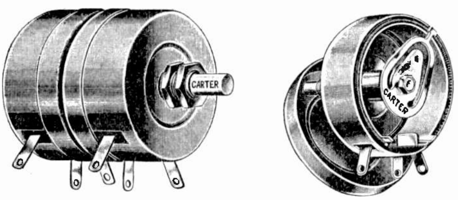
With resistance-capacitance coupled audio amplifiers, the arrangement of the A.F. voltage control is as shown in Fig. *3B*. With an impedance-capacitance coupled audio amplifier, where an A.F. choke coil would be used in place of R_P, the same volume control arrangement is used. The volume control is in parallel with the load of the preceding stage, but its resistance is made sufficiently high (somewhere between 100,000 ohms and 1 megohm) so it has no appreciable effect upon the load.

When inserting a volume control in the input of a circuit which is acting as a load for an A.F. signal source, the volume control must not alter the impedance match between the source and load. In cases like this, special constant-impedance volume controls or pads are used; these consist of two or more variable resistors which are adjusted simultaneously. The circuit in Fig. *3C* is an example; here a so-called T-pad volume control having three variable resistors (this name results from the fact that the resistors are arranged to form the letter "T") is so connected that the resistance across the input terminals and the output terminals of the T-pad remains constant (at 200 ohms for a 200-ohm T-pad or at 500 ohms for a 500-ohm T-pad) regardless of the setting of the control knob. Only the A.F. voltage across the output terminals of the T-pad varies with the control knob setting. This subject is covered in greater detail in advanced lessons; for the present it is sufficient for you to know what this type of A.F. voltage control is and why it is used.

A type of A.F. voltage control which you will constantly encounter in radio receivers using diode detectors and A.V.C. is shown in Fig. *3D*. Here the volume control serves as load for the diode demodulator or second detector. The R.F. signal is by-passed around this volume control by condenser C_D; this condenser also serves to smooth out the rectified R.F. voltage, producing the desired A.F. signal across the volume control. The A.F. voltage between points L and C is fed to the grid of the first A.F. amplifier tube (in the same envelope as the diode detector) through D.C. blocking condenser C_K. Other types of A.V.C. circuits in which manual volume controls are incorporated will be considered later in this book.

R.F. Gain Controls

Volume Controls Which Vary the Load in an R.F. Circuit. In the days of battery-operated receivers, volume was controlled simply by varying the



Left: Dual volume control unit made up of two ordinary potentiometer units mounted on a common shaft, used when simultaneous control of two different circuits is desired. Right: A typical wire-wound potentiometer widely used as a manual volume control in circuits where the total potentiometer resistance must be less than 10,000 ohms.

filament current of one or more tubes in the receiver. With the advent of A.C.-operated receivers, volume control became a more difficult problem, for varying the filament currents in heater type tubes did not give a satisfactory control over volume.

One of the first manual volume control schemes used in A.C. receivers was that shown in Fig. *4A*, which involved placing a variable resistor across the plate load resistance of an R.F. stage. Without this variable resistor the tuned secondary R.F. transformer made up of L_1, L_2 and C_2 offered a definite load in the plate circuit of tube VT_1, and the stage consequently had a definite amplification or gain. Shunting a volume control across L_1 permitted reduction of the plate load impedance and the gain to any desired lower value. Because of the fact that decreasing the load impedance increased the curvature of the E_g-I_p curve, making strong R.F. signals swing over non-linear portions of the curve, this scheme could be used only in the plate circuit of an R.F. stage which handled low R.F. voltages. This method of controlling volume also served as a control on regeneration, for it varied the A.C. plate voltage and thus varied the feed-back voltage.

Potentiometers are almost universally used for volume controls. When a rheostat connection is required for the volume control, as in Fig. *4A*, one of the fixed terminals of the potentiometer (*L* or *R*) is simply left unconnected.

A similar scheme for varying a load in order to control volume is shown in Fig. *4B* as applied to the input circuit of an R.F. amplifier. Reducing the resistance of the volume control reduced the impedance of the load between antenna and ground, thereby reducing the proportion of antenna voltage which was developed across this load (across points *L* and *C*). With reduced voltage there was reduced current in the primary coil and reduced voltage induced in the tuned secondary winding.

It is also possible to control volume by introducing a variable resistor into a series resonant circuit, as shown in Fig. *4C*; varying the volume control resistance then varied the resonant voltage step-up of the circuit, varied the amount of power transferred to the resonant circuit, and also served as a control on regeneration. This arrangement was used (as also was the circuit of Fig. *4A*) in battery receivers which did not have neutralizing circuits.

Volume Controls Which Vary the Screen Grid Voltage in an R.F. Stage. The amplification of a vacuum tube amplifier can be controlled to a considerable extent by varying the D.C. voltages applied to the electrodes of the vacuum tube used in the stage. Any change in electrode operating voltages which affects the mutual conductance of the tube will also affect the amplification provided by the

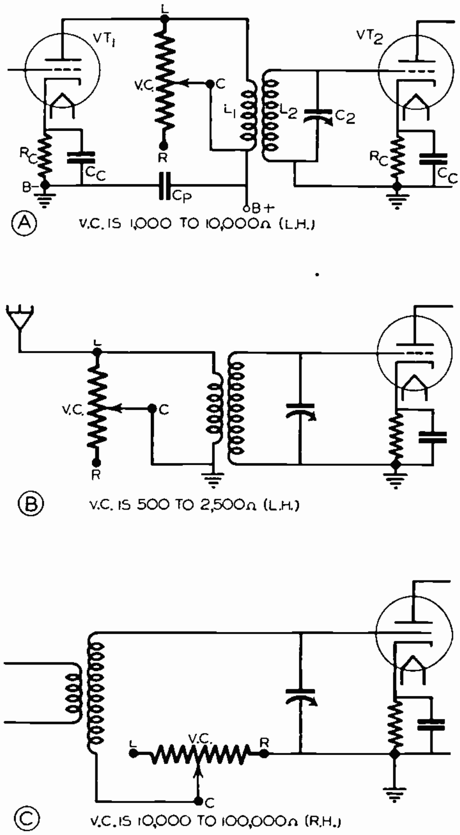


Fig. 4. Typical manual volume control arrangements which vary the impedance of a load in an R.F. circuit and thus vary the gain of the R.F. amplifier.

stage; this is true because, as you will recall, mutual conductance is equal to A.C. plate current divided by A.C. grid voltage. Reducing the A.C. plate current therefore reduces the mutual conductance and at the same time reduces the A.C. voltage which is developed across the plate load for transfer to the following stage.

As a general rule, reducing the D.C. plate voltage, reducing the D.C. screen grid voltage or increasing the negative C bias voltage will reduce the mutual conductance of a tube. Making the suppressor grid negative with respect to the cathode and increasing its negative voltage will also decrease the mutual conductance. It is not customary, however, to vary the suppressor grid voltage for the reason that very large changes are required in voltage in order to secure any appreciable reduction in mutual conductance.

The usual method for controlling the screen grid voltage was that shown in Fig. *5A*; the volume control potentiometer was made part of a voltage divider connected across the plate supply source, with resistor R_L serving to determine the maximum screen grid voltage. Condenser C_S was necessary in order to provide a path to ground for any feed-back current coming from the plate, for regeneration would result if this current reached the control grid. This condenser also helped to prevent noisy volume control action, for it shunted the *L-C* section of *V.C.* and thus by-passed to ground any current impulses created by a varying contact resistance at *C*.

Volume Controls Which Vary the Plate Voltage of an R.F. Amplifier Tube. A method widely used in battery receivers for varying the plate voltage of a tube as a means of controlling volume was that shown in Fig. *5B*, where a variable resistor was placed in series with the plate supply voltage and the R.F. plate load. This method was advantageous in that it did not place any unnecessary drain upon the B batteries, but had the disadvantage that a very high-resistance rheostat, which burned out easily, was required.

Plate voltage can also be controlled by using a potentiometer connected across the plate voltage supply in the manner shown in Fig. *5C*. With this potentiometer across the B battery at all times, there was naturally a higher current drain than in the case of Fig. *5B*, but the potentiometer was lower in resistance, making possible a more

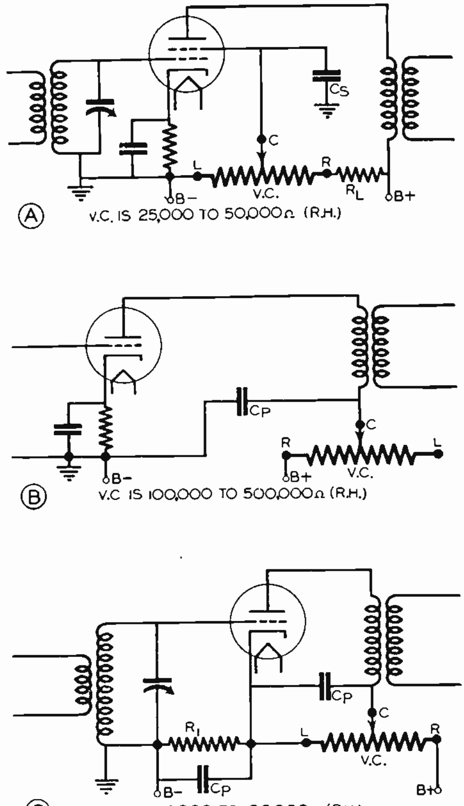


FIG. 5. Typical manual volume control arrangements which vary the mutual conductance of an R.F. amplifier tube by varying the screen grid voltage (*A*) or the plate voltage (*B* and *C*).

rugged design and consequently reducing the tendency to burn out.

Unfortunately, these methods of controlling volume by varying screen grid and plate voltage did not prove entirely satisfactory. Reducing these electrode voltages any reasonable amount affected the dynamic E_g-I_p characteristic of the tube enough to cause distortion at low volume control settings. These circuits were quickly replaced by the still popular C bias method of volume control, which will now be considered.

Volume Controls Which Vary the C Bias Voltage of an R.F. Amplifier Tube. The most effective way of varying the mutual conductance of a tube in order to control volume is *by varying the control grid voltage* (the C bias voltage). This method of controlling volume proved so satisfactory and came into such widespread use that tube designers developed special remote cut-off tubes, first the *variable mu screen grid tube* and later the *super-control pentode tube,* which gave even better results. These tubes allowed the A.C. grid voltage to swing over an essentially linear portion of the dynamic E_g-I_p characteristic curve at all volume control settings. A number of typical C bias volume control circuits are shown in Fig. *6*; although triode tubes are indicated for simplicity, the circuits also apply to screen grid and pentode tubes.

A scheme widely used in early battery receivers for varying the C bias voltage was that shown in Fig. *6A,* where the negative C bias voltage was increased and the filament current was reduced simultaneously (by increasing the resistance of volume control *V.C.*) in order to reduce the mutual conductance of the tube. When the filaments of several tubes are in parallel and the grid return lead for each tube circuit is grounded, a volume control such as this will affect all such parallel-fed circuits.

Another C bias voltage control for battery receivers, used even at the present time when filament voltage is to be fixed in value, is that shown in Fig. *6B*. Here potentiometer *V.C.* and resistor R_1 are placed in series across a C battery which is connected with the indicated polarity. The combined resistance of the potentiometer and the resistor may be 2 or 3 megohms in value in order to prevent excessive drain on the C battery. At the same time the value of R_1 must be low enough to develop the minimum C bias required for the circuit. (A high-resistance load on the C battery will make it last longer than the B batteries; with normal C bias and low B voltages, certain tubes will distort severely. For this reason it is becoming common practice to use values for *V.C.* and R_1 which are low enough to make the B and C batteries run down at approximately the same rate.) Switch *SW* opens both the A and C battery supply circuits in order to prevent current drain when the receiver is not in use.

The basic C bias voltage volume control for heater type tubes is that shown in Fig. *6C*. The volume control is placed in series with the usual cathode bias resistor R_C, with condenser C_C connected between the cathode and the movable tap of the volume control. Increasing the resistance setting of the volume control increases the C bias voltage and therefore reduces volume; resistor R_C determines the minimum C bias voltage. The chief disadvantage of this circuit is that as the negative C bias voltage is increased, the plate current which flows through the cathode resistor combination is greatly reduced, counteracting the effect of the volume control. For example, if a cathode bias resistance of 600 ohms gives a 3 volt negative bias, it may be necessary to increase this resistance to as much as 25,000 ohms in order to secure three times as much bias voltage (—9 volts).

Where the movable tap of the volume control is grounded, as in Fig. *6C,* receiver manufacturers will often use a potentiometer in which the movable tap or middle terminal *C* is grounded internally to the metal shaft of the control. This eliminates the need for making a soldered connection to the middle terminal, for mounting the potentiometer on the metal chassis automatically grounds the housing.

An improved C bias volume control arrangement is shown in Fig. *6D*; by having between the plate voltage lead and cathode a bleeder resistor R_B which forces or "bleeds" a current through the C bias resistor R_C at all times, the volume control current is made essentially independent of the plate current. The volume control now has greater control over the C bias voltage and can be considerably lower in value than in the case of Fig. *6C*.

In some receivers the volume control is actually a part of the power pack voltage divider system or is an additional voltage divider across a part of the main voltage supply in the manner shown in Fig. *6E*. Here volume control potentiometer *V.C.* varies the voltage between the cathode and the B— terminal, with resistor R_1 determining the minimum C bias voltage and resistor R_2 determining the maximum C bias voltage. The total resistance of R_1, *V.C.* and R_2 in series across the power pack determines the value of bleeder current which flows at all times. Both the plate current of the tube and the bleeder current flow through R_1 and the *R-C* section of the volume control, producing a C bias voltage which is dependent upon the position of movable tap *C*.

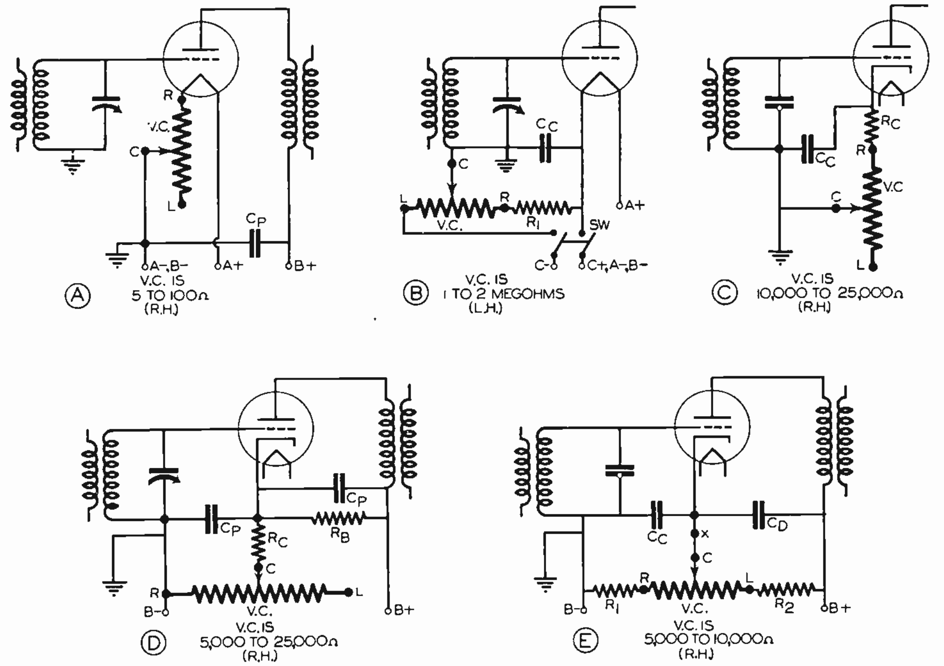


Fig. 6. Typical manual volume control arrangements which vary the mutual conductance of an R.F. amplifier tube (thereby varying the gain of the R.F. amplifier) by varying the C bias voltage applied to the control grids of one or more R.F. tubes.

Volume Controls Which Vary Both the Antenna Input and C Bias Voltages. We cannot pass over C bias voltage volume controls without pointing out that with the earlier triode and screen grid tubes, increasing the negative C bias beyond a certain point changed an R.F. amplifier stage into a detector, with resulting modulation distortion and cross-modulation on strong signals. With variable mu screen grid tubes and super-control pentode tubes this is naturally no longer a problem, but it will be of interest to see just how receiver manufacturers combined two types of volume control circuits in solving this problem.

One typical combination volume control circuit is shown in Fig. 7A. Here fixed resistor R_C controls the minimum C bias voltage and hence the maximum amplification of the stage. That section of the volume control potentiometer between points *C* and *R* also serves as cathode bias resistor, while the remaining section shunts the input transformer primary winding. Moving contact *C* away from point *R* increases the C bias voltage and at the same time reduces the resistance across the primary winding, thus giving a double reduction in R.F. signal gain.

Another type of antenna-C bias voltage control is shown in Fig. 7B; here the volume control potentiometer has a fixed tap at point *T* which is connected to ground. Resistor R_C determines the minimum C bias voltage, and the bleeder current flowing through R_1 and the *T-R* section of the volume control determines to a large extent the maximum C bias voltage. Moving contact *C* from *R* towards *T* increases the C bias, reducing volume; moving contact *C* still farther, from *T* to *L*, has no further effect upon C bias since the grid now remains at ground or B— potential (no direct current flows through section *L-T*), but the resistance shunting the primary of the antenna transformer is reduced and thus the R.F. input voltage is lowered.

Variations of Manual Volume Control Circuits. You are now familiar with the important basic manual volume control circuits. Of course you will encounter many variations of these circuits in radio receivers, but as a rule these variations will be easily recognized as one of the types which you have studied.

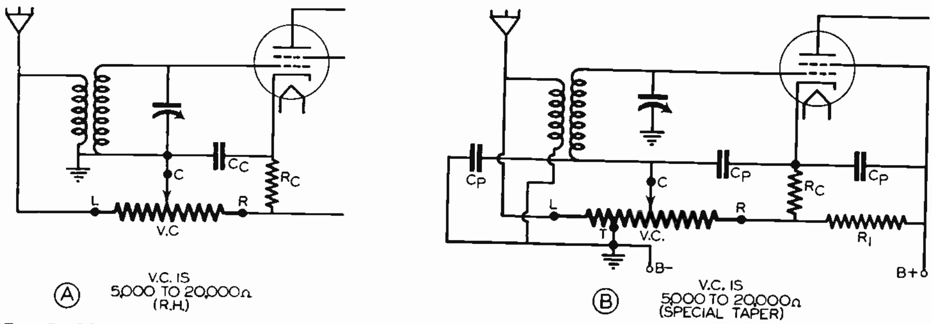


FIG. 7. Manual volume control arrangements which vary both the antenna input R.F. voltage and the C bias voltage of the first R.F. stage in order to change the R.F. amplifier gain and thus change the loudspeaker output volume.

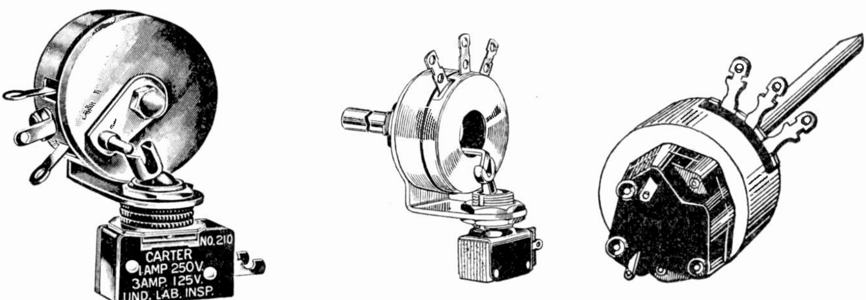
Before beginning our study of automatic volume control circuits, I want to state definitely that with A.V.C.-controlled receivers, the manual volume control must be *in the audio system*, except in those cases where the manual control is of a type which changes the effectiveness of the A.V.C. control. You can readily understand that any attempt to reduce the R.F. output of the R.F. amplifier manually would simply cause the A.V.C. system to increase the amplification and counteract the change in the manual volume control setting.

Automatic Volume Controls

A.V.C. action is basically simple. When the carrier level of the R.F. input signal is excessively high, A.V.C. lowers the gain of the R.F. amplifier by increasing the negative C bias voltage on one or more R.F. amplifier tubes. This is accomplished automatically by rectifying the R.F. carrier signal, then filtering out all but the resultant D.C. voltage, whose value is always proportional to the R.F. carrier level. This D.C. voltage is so applied to the grids of the R.F. amplifier tubes that *increases* in carrier level make the grids *more negative*. The R.F. amplifier gain is thus reduced enough to keep the R.F. amplifier output level essentially constant and prevent overloading of any tubes. Likewise, *reductions* in input carrier level result in *less negative* C bias voltages and greater amplification.

It is clearly impossible for A.V.C. to maintain the R.F. carrier level perfectly constant at the output of the R.F. amplifier, for it is the change in this level which produces the change in negative C bias voltage required for automatic volume control. With proper design, however, A.V.C. can keep the carrier level constant enough for all practical purposes. Exact control of carrier level is not required, for the output voltage of a receiver can be increased or decreased about 40 per cent before the change can even be detected by the human ear. When working with A.V.C.-controlled circuits, then, never depend upon your ears as a judge of performance; always use an output meter or some other type of indicator.

The action of a receiver having A.V.C. is best represented by overload curves like those in Fig. *8*, which are obtained by plotting the R.F. input voltage of the receiver against the A.F. output voltage of the demodulator or second detector. You are already familiar with curve *1* in Fig. *8*, which represents the overload characteristics of a receiver not having A.V.C. Notice that overloading takes place at an R.F. input voltage of about 100 microvolts in this particular example. When this receiver is equipped with A.V.C., its overload characteristic is represented by curve *2*. You can readily see that with A.V.C., the receiver will handle all carrier signal levels below 100,000 microvolts (.1 volt) without overloading. On the other hand, however, this A.V.C. curve shows that the sensitivity of the receiver will be considerably lower with A.V.C. than without it for medium-strength signals (R.F. input voltages in the region between about 10



Today it has become an almost universal practice among receiver designers to make the manual volume control or some other manual control serve also as an on-off switch. Earlier forms of dual potentiometer-switch arrangements appear at the left (a Carter unit) and in the center (a Yaxley unit); in both of these, rotation of the control knob to the extreme counter-clockwise position caused an arm on the control shaft to flip the toggle switch to its off position. At the right is a modern universal replacement volume control (a Philco unit) with a special power switch attached to its cover plate for this same purpose.

and 100 microvolts). Let us see how this drawback of A.V.C. is overcome in some receivers.

Delayed A.V.C. Since ordinary A.V.C. circuits prevent the maximum amplification of the receiver from being effective at low carrier levels, and since A.V.C. action is not particularly required at these low carrier levels since they cannot possibly cause overloading, the receiver designer simply arranges the A.V.C. system so it is inactive until the carrier level reaches a definite and fairly high value. This arrangement, which utilizes the full sensitivity of the receiver at low carrier levels, is known as *delayed A.V.C.*; the *R.F. input voltage level at which A.V.C. action begins* is called the *threshold point* or the *threshold voltage*. The overload characteristic curve for a receiver having delayed A.V.C. is represented by curve *3* in Fig. *8*. Notice that it follows curve *1*, that for a receiver without A.V.C., up to the threshold voltage, after which it levels out and effectively prevents overloading.

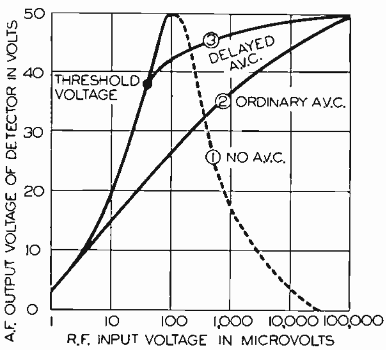


FIG. 8. Overload characteristic curves for three different superheterodyne radio receivers, obtained by feeding various R.F. input voltages into each receiver (the manual volume control being set for maximum volume) and measuring the A.F. output voltage of the second detector. Curve *1* is for a sensitive receiver which does not have A.V.C. Curve *2* is for the same receiver with ordinary A.V.C. added. Curve *3* is for the same receiver with delayed A.V.C. added. These curves illustrate receiver performance in general, and will naturally vary greatly with different receivers.

Since the A.F. output voltage of the second detector in a receiver having delayed A.V.C. is quite high at the threshold point, further increases in output voltage should be prevented as much as possible. To do this, the negative C bias voltage produced by A.V.C. action should be applied to as many R.F. tubes as possible; if even this is insufficient, the A.V.C. voltage can be amplified by an extra vacuum tube stage, giving what is known as an *amplified delayed A.V.C. circuit.*

Definitions. Those R.F. amplifier stages in an A.V.C. receiver which are to vary in gain as the incoming carrier level varies are called the *A.V.C.-controlled stages* or simply the *controlled stages*. The tubes in these controlled stages are called *A.V.C.-controlled tubes* or simply *controlled tubes*. The vacuum tube or tube section which converts the amplified modulated R.F. carrier into a D.C. voltage suitable for A.V.C. purposes is called the *A.V.C. tube* or *A.V.C. stage*, and the D.C. voltage is called the *A.V.C. voltage*. The A.V.C. voltage may be produced as a part of the action of demodulation, or may be produced independently by an extra stage in the receiver.

Simple Diode Detector—A.V.C. Circuits

A simple diode demodulator or detector circuit like that shown in Fig. *9A* is not only capable of separating the modulation signal from the R.F. carrier, but can also produce the negative C bias voltage required for A.V.C. purposes. The modulated R.F. carrier signal at points *1* and *2* in the final I.F. amplifier stage passes through the final resonant circuits, L_p-C_p and L_s-C_s, and is applied directly to the plate and cathode of diode detector tube VT_2. Condenser C_D offers no opposition to this signal, for it has a low reactance at radio frequencies.

The modulated R.F. carrier is rectified by the diode tube, since this tube allows current to pass only in one direction; the wave form of the current passing through this tube is therefore like that shown in Fig. *9B*. The charging and discharging action of condenser C_D on this pulsating current condenser C_B, which blocks out the D.C. voltage component. The circuit is completed through the chassis.

Let us trace D.C. electron flow in the diode detector circuit of Fig. *9A*. We start with the diode tube, for we know that electrons flow from the cathode to the plate. These electrons flow

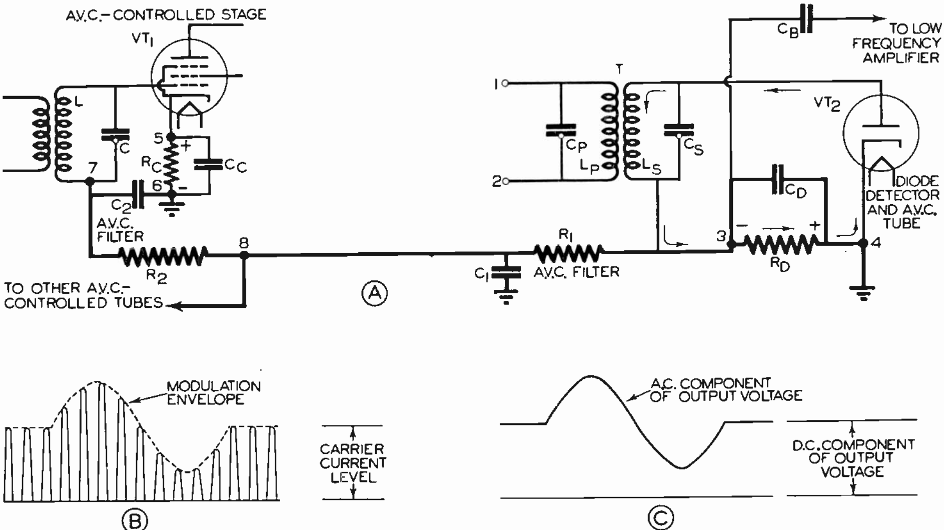


FIG. 9. These diagrams, together with the accompanying text, give the complete story of how an A.V.C. voltage can be produced by a simple diode detector, how this voltage can be filtered, and how the voltage is applied to an A.V.C.-controlled R.F. stage. When self-bias is present in A.V.C.-controlled stage, it is applied to the control grid through the chassis, the A.V.C. load resistor and the A.V.C. filter resistors. Thus, in this circuit the negative potential of point *6* (with respect to point *5* and the cathode) is applied to point *7* and the grid through the common chassis path from point *6* to point *4*, then through A.V.C. load resistor R_D and A.V.C. filter resistors R_1 and R_2. The automatic C bias voltage thus acts in series with, and adds to the A.V.C. voltage.

passing through R_D serves to filter out the R.F. variations, making the voltage across R_D have the wave form shown in Fig. *9C*. Observe that this wave is made up of a D.C. component which is proportional to carrier level and an A.C. component which is proportional to the percentage of modulation and the carrier level; if the values of C_D and R_D are properly chosen, this A.C. component will be an exact reproduction of the audio or video intelligence signal. This intelligence signal is fed into a low frequency amplifier (not shown in circuit) for further amplification by coupling the grid of the first low frequency amplifier stage to point *3* on resistor R_D through blocking through coil L_s in the direction indicated by the arrows, then enter terminal *3* of resistor R_D, making this terminal negative with respect to the other resistor terminal (*4*); terminal *3* is therefore negative with respect to chassis or ground. Furthermore, since the D.C. component of the voltage between terminals *3* and *4* is proportional to the level of the modulated R.F. carrier, these terminals may be used as a source for the desired A.V.C. voltage provided that the low frequency component is removed. Application of an A.F. signal to the grid of a controlled tube would place extra modulation on the carrier, a clearly undesirable condition; for this reason it is necessary to filter the A.V.C. voltage in a radio receiver in order to keep the *A.F. signal voltage* out of the A.V.C.-controlled stages.

Filtering the A.V.C. Voltage. The fact that the control grids of R.F. amplifier tubes are negative, so that no D.C. grid current is drawn from the A.V.C. circuit, simplifies the problem of filtering the A.V.C. voltage. In Fig. *9A* you will find two A.V.C. filters connected between point *3*, at which both D.C. and A.F. components of voltage exist, and point *7* in the grid circuit of an A.V.C.-controlled stage, at which only the D.C. component of voltage is desired. These A.V.C. filters keep the *A.F. signal voltage* out of the A.V.C.-controlled stages of the R.F. amplifier.

Let us consider first the A.V.C. filter made up of C_1 and R_1. Resistor R_1 is high in ohmic value and therefore offers considerable opposition to the flow of A.C. Whatever alternating current gets through R_1 finds a low-reactance path to ground through condenser C_1. Resistor R_2 and condenser C_2 in the second A.V.C. filter provide additional filtering in the same way, making the voltage at point *7* a practically pure D.C. voltage. Condensers C_1 and C_2 naturally have no effect upon the D.C. voltage, and since no direct current flows through the filter circuit, resistors R_1 and R_2 likewise have no effect upon the value of D.C. voltage at point *7*.

The flow of plate current through resistor R_C and condenser C_C in the A.V.C.-controlled stage containing tube VT_1 produces across R_C a D.C. voltage which makes point *6* negative with respect to the cathode; this is ordinary automatic C bias action. The voltage drop across cathode resistor R_C is applied to the grid of tube VT_1 through the chassis path between grounded points *6* and *4*, then through R_D, R_1, R_2 and coil L in turn, thus placing on the grid its normal C bias.

When an R.F. carrier signal is present in the receiver, the D.C. component of voltage produced across R_D acts in series with and aids the automatic C bias voltage. Thus the A.V.C. voltage and the automatic C bias voltage add together to make the grid of each controlled tube more negative than would be the case without A.V.C. An increase in carrier signal level boosts the D.C. component of voltage across R_D, driving the grid of each A.V.C. controlled tube more negative and thereby reducing the amplification of each tube sufficiently to keep the signal voltages in all stages of the receiver below the overload values. In an A.V.C. system a condition of equilibrium exists where the carrier level at the detector is kept just enough above the desired constant value to provide the required A.V.C. voltage.

Condenser C_2 in the circuit of Fig. *9A* has another important task, that of providing a path to point *6* for the R.F. voltage developed across coil L. If this condenser were omitted, the R.F. current would have to flow through R_2 and C_1 to ground; R_2 would naturally offer considerable opposition to the flow of R.F. current, and there would also be the possibility that R.F. current would stray into circuits where it could cause interference and undesirable feed-back. Since the reactance of C_2 is less than the reactance of the R_2-C_1 path to ground, R.F. currents will take the C_2 path to ground.

The A.V.C. filter system made up of C_2 and R_2 can be and often is omitted, leaving C_1 and R_1 to do the A.F. filtering and R.F. isolating, particularly when only one tube is being controlled by A.V.C. When several R.F. amplifier tubes are being controlled, it is customary to use an A.V.C. filter similar to R_2 and C_2 in each controlled stage, making connections from each controlled stage to point *8*. This serves to isolate the tube circuits from each other, preventing undesirable feed-back.

Time Constant Of The A.V.C. System

An A.V.C. system must prevent blasting when a receiver is tuned suddenly from a weak to a strong signal, and must also compensate for more or less rapid fading effects. For this reason we are interested in knowing exactly how long it takes for the A.V.C. system to get into action when the R.F. carrier level is suddenly changed.

The D.C. component of voltage across R_D in Fig. *9A* changes immediately after a change in carrier level, but it takes a certain amount of time for condenser C_1 in the first A.V.C. filter to charge or discharge to a new voltage value; this is because resistor R_1 offers considerable opposition to that flow of condenser current which produces a change in condenser voltage. It thus takes a certain amount of time for point *8* to assume new voltage values; technicians express this by saying that the A.V.C. action is *time delayed.*

The amount of time delay introduced by A.V.C. filter R_1-C_1 depends upon the ohmic value of resistor R_1 and the capacity of condenser C_1; this time, when expressed in seconds, is known as the *time constant* of the A.V.C. filter system, and can be computed quite easily. In the case of Fig. *9A,* this can be done by multiplying the ohmic value of R_1 in megohms by the capacity of C_1 in microfarads. The result will be the time constant of the circuit in seconds, or the time required for the A.V.C. voltage to reach approximately 63% of its final new value after a change in carrier level. (It is standard practice among engineers to specify time constants for 63% of the total change, this having proved more convenient than a time constant based upon a total change.) The A.V.C. filter made up of R_2 and C_2 likewise introduces a time delay, which *increases* the time constant of the entire A.V.C. filter system. Remember—the time constant of an A.V.C. filter system is determined by *the values of the resistors and condensers in the A.V.C. filter system.*

A low time constant is naturally desirable in order to make the A.V.C. system respond as rapidly as possible to changes in carrier level; this can be secured by making the values of R_1, R_2, C_1 and C_2 low, but doing this impairs the filtering action which is so essential to the operation of an A.V.C. system. Receiver design engineers therefore resort to a compromise which uses filter system parts large enough to provide satisfactory filtering and at the same time small enough to provide a sufficiently short time delay. A time constant of *one-fifth to one-tenth of a second* for the A.V.C. filter system is considered satisfactory by most engineers for the prevention of blasting and reduction of fading.

The value for condensers C_1 and C_2 in an A.V.C. filter system have become essentially standard among receiver designers. A capacity of .1 mfd. for C_1 and .05 mfd. for C_2 are generally used, for these condensers are inexpensive and at the same time have a reactance of less than 20 ohms for any I.F. or R.F. signal which may be attempting to flow from resonant circuit *L-C* into the diode load. A .1 mfd. condenser, when used with a 1 megohm resistor, gives a time constant of one-tenth second; the filter action of these parts is such that they will reduce the strength of the lowest audio frequency signal which tries to get into the R.F. and I.F. amplifiers about 100 times. Two of these filter combinations would reduce the time constant to one-fifth second and would increase the audio frequency filtering factor to 10,000 times. Ordinarily you will find that the values of resistors R_1 and R_2 range from .1 to 1 megohm, while condensers C_1 and C_2 range from .02 to .1 mfd. Do not be surprised, however, if you occasionally encounter quite different values than these; circuit conditions and the opinions of engineers vary widely. Changing the values of A.V.C. filter resistors or condensers affects the speed of A.V.C. action.

Typical A.V.C. Circuits

Automatic volume controls are usually found only in superheterodyne receivers, for the simple reason that A.V.C. did not come into widespread use until after the superheterodyne circuit was well established, and practically all receivers made since then have been superheterodynes. A.V.C. could just as well be used in tuned R.F. receivers.

The sections of a superheterodyne receiver which are usually A.V.C.-controlled are as follows: *1*, The *R.F. amplifier,* which amplifies the incoming modulated R.F. carrier signal; *2*, the *mixer-first detector,* which mixes the incoming R.F. signal with the local oscillator signal to give a modulated I.F. signal; *3*, the *I.F. amplifier.*

It is common practice to apply the A.V.C. voltage to all preselector stages, in order to prevent overloading of the mixer-first detector. In those cases where a variable mu or super-control R.F. pentode tube is used for the mixer-first detector, this stage is sometimes A.V.C.-controlled. The first I.F. amplifier stage following the mixer-first detector is invariably A.V.C.-controlled. If there are three I.F. stages, the second is also A.V.C.-controlled. The final I.F. stage ordinarily has no A.V.C. control, or the control on this stage may be greatly reduced. This is because each succeeding stage handles greater and greater modulated carrier signal levels, and driving the C bias of a heavily loaded stage highly negative results in amplitude distortion and even partial or complete cut-off of the signal.

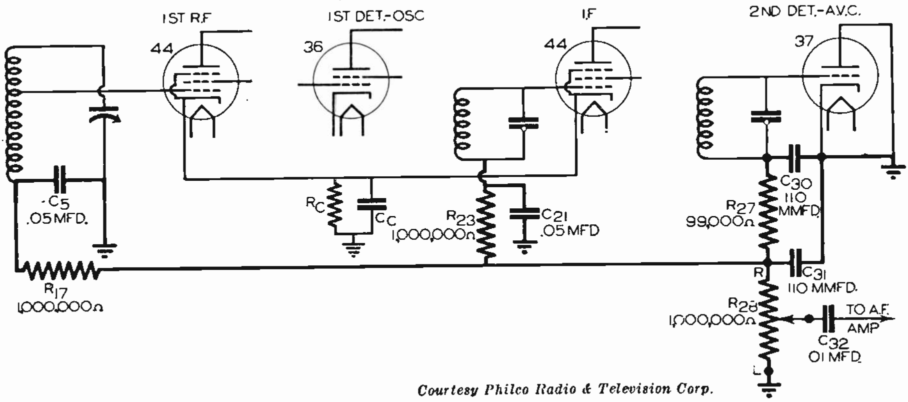
The more stages which are A.V.C.-controlled, the more uniform will be the receiver output and the less chance there will be for overloading. With these facts in mind, let us examine a few typical A.V.C. systems as used in actual receivers. Since we are interested only in the A.V.C. circuit and the A.V.C.-controlled stages, we will simplify the circuit diagrams by showing only these circuits.

A.V.C.-controlled tubes should always be variable mu screen grid tubes or super-control pentodes, for these tubes give essentially linear amplification over a wide range of C bias voltage values. If ordinary triode, screen grid and pentode tubes were A.V.C.-controlled, changes in C bias voltage would cause the R.F. signal to swing beyond the linear region of the tube characteristic, or even beyond the plate current cut-off point, with distortion resulting.

Early Diode Detector-A.V.C. Circuits. One of the first receivers to use a diode tube as a combination demodulator and source of A.V.C. voltage was the Philco Model 71, the circuit diagram of which is shown in simplified form in Fig. *10*. Since diode tubes were not available at the time this receiver was manufactured, the grid and cathode elements of a triode were used, with the plate connected to the cathode as shown in Fig. *10*. The diode load, across which exists the A.C. and D.C. components of the rectified detector output, is here made up of two resistors in series, R_{27} and R_{28}, with A.V.C. voltage being taken from the mid-point of the two resistors. R_{28} is a 1-megohm potentiometer with the movable tap connected through a D.C. blocking condenser to the input of the

A.F. amplifier, thus providing manual volume control. R.F. currents are kept out of the A.V.C. system and the A.F. amplifier by the filter combination consisting of C_{30}, R_{27} and C_{31}.

The D.C. voltage developed across R_{28} for A.V.C. purposes is filtered for the first I.F. amplifier tube by R_{23} and C_{21}, and is filtered by R_{17} and C_5 for the first R.F. amplifier tube. The time constant of each filter is about .05 second. Notice that both the R.F. and I.F. amplifiers get their minimum C bias voltage from the combination of R_C and C_C in the common cathode lead of the first R.F. tube and the I.F. tube. In this receiver the mixer-first detector has no A.V.C. control. The set has only one I.F. stage.



Courtesy Philco Radio & Television Corp.

FIG. 10. Simplified diagram showing (in heavy lines) the A.V.C. system of the Philco Model 71 superheterodyne broadcast receiver. The values of the parts are the same as those used by the manufacturer.

Staggered A.V.C. Circuit. An example of a superheterodyne receiver circuit in which less A.V.C. voltage is applied to the amplifier stages near the second detector than to the first R.F. stages is the Arvin Model 25 auto radio circuit, shown in simplified form in Fig. *11*. The chief disadvantage of a diode detector, its lack of amplification, is here offset by the use of a type 6B7 duo-diode-pentode tube, with the two diode plates connected together to serve as a single diode detector and the pentode section connected to serve as the first A.F. amplifier stage. This three-in-one tube was created along with the duo-diode-triode to meet the demands of receiver manufacturers who recognized the many advantages of a diode detector in A.V.C.-controlled receivers.

The diode detector load in Fig. *11* is made up of four resistors, R_7, R_8, R_9 and R_{10}, connected in series between point *4* and ground. Condenser C_{17} provides a path to cathode for R.F. signals in the detector circuit. The A.C. and D.C. components of the detector ouput voltage appear across the resistor combination, with points *1*, *2*, *3* and *4* increasingly more negative with respect to the chassis or ground; when several different values of A.V.C. voltage are provided in this way, the voltages are said to be *staggered*. The A.F. voltage is fed to the control grid of the pentode section from the movable contact of potentiometer R_{11} which, with D.C. blocking condenser C_{16}, is connected across the diode load resistors.

As you can see, the grid of the first R.F. tube is connected to point *3*, where it gets the highest A.V.C. voltage of any tube. The filter network for this tube, made up of C_4 and R_1, has a time constant of .0075 second. This is the only tube in the receiver which has time delay, for fast A.V.C. action is desirable in an auto radio to compensate for changes in signal level when driving.

The mixer-first detector tube gets the lowest A.V.C. voltage, from point *1*, while the I.F. amplifier tube gets a greater A.V.C. voltage from point *2*. There are no filter resistors in the A.V.C. leads for these last two stages, fast A.V.C. action being desired in preference to complete protection from A.F. signal feed-back.

Circuits with Separate A.V.C. Tubes. Before the diode detector came into widespread use, a triode tube in a separate A.V.C. stage was commonly used to provide the required A.V.C. voltage. One basic circuit for this A.V.C. arrangement is shown in Fig. *12*; since a great many of these older receivers are still in use, it will be of value for you to know how the circuit works.

Let us consider the circuit first for the condition where no R.F. signals are being fed to the grid of the A.V.C. tube. Resistors R_1, R_2 and R_3 form a voltage divider network which is connected across the power pack output terminals, hence electron flow is from B— to B+ through these resistors. This makes point x negative with respect to point z, and the grid of the A.V.C. tube (connected to x through grid resistor R_g) is therefore *negative* with respect to its cathode.

the A.V.C. tube is biased to cut-off when there is no R.F. signal; under this condition no current flows through R, making the plate of the A.V.C. tube positive with respect to its cathode by an amount equal to the voltage across R_2. Furthermore, under this condition points u and w are at the same potential, that of the chassis or ground, and no voltage is fed to the A.V.C.-controlled stages. A cathode resistor R_C is therefore required in each controlled stage to provide normal C bias voltage.

When an R.F. signal acts on the grid of the A.V.C. tube through C_1, it swings the grid in a positive direction on alternate half-cycles; this allows a pulsating R.F. plate current to flow, with the peaks of the pulses varying according to the modulation signal. The R.F. component of this plate current is filtered out by C_2 and C_3, while the D.C. and A.F. components appear across R. Electron flow is from u to w through R, hence point u is negative with respect to ground. A.V.C. filters in each controlled stage filter out the A.F. component, while the D.C. component, which varies with R.F. carrier level, is fed from point u to the grids of the controlled tubes. An increase in carrier level at the grid of the A.V.C. tube increases the D.C. component of voltage across A.V.C. load resistor R just enough to make the grids of the controlled tubes sufficiently more negative to hold the carrier level essentially constant, as in normal A.V.C. action.

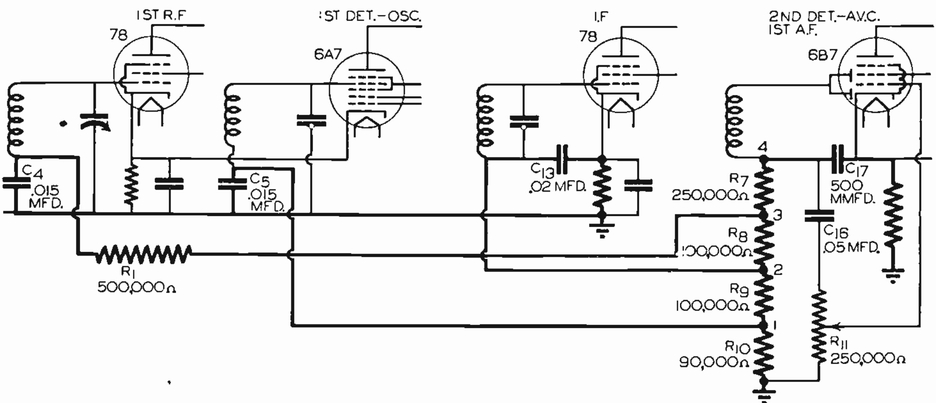


FIG. 11. Simplified diagram showing the A.V.C. system of the Arvin Model 25 superheterodyne auto radio. Notations on the parts are the same as those used by the manufacturer.

How does the A.V.C. tube secure its plate voltage? Trace from point z through the cathode-plate path of the A.V.C. tube to point u, through A.V.C. load resistor R to point w and the chassis, then through the chassis to grounded point y on the voltage divider; this shows that the tube and R are in series across voltage divider section R_2, with each getting a portion of the voltage across R_2. The values of R_1 and R_2 are so chosen by the designer that

Example of Receiver Using Separate A.V.C. Tube. The RCA Model R-74 superheterodyne receiver is an example of a circuit using a separate A.V.C. tube. A simplified diagram of this circuit appears in Fig. *13*. First of all, notice that the R.F. amplifier tube, the mixer-first detector tube and the I.F. amplifier tube are A.V.C.-controlled; you can tell this because in each case the grid return lead from the grid coil does not go directly to ground or cathode but to points *u* and *v*, which are sources of A.V.C. voltage. The connection is in each case made through an A.V.C. filter consisting of a .05 mfd. condenser and either a 100,000 or 500,000 ohm resistor.

Resistors R_2 and R_3 in Fig. *13*, serving as the load for the A.V.C. tube, divide the A.V.C. voltage into two values, the lower of which is fed to the mixer-first detector and the I.F. amplifier stage. Reduced A.V.C. voltage is necessary here because the mixer-first detector tube must handle a strong local oscillator signal in addition to the regular R.F. signal, and cannot therefore be driven as far negative as the amplifier tubes which get the full A.V.C. voltage.

Now let us see how the A.V.C. tube produces a negative bias voltage which increases with carrier level. We start at the B— terminal of the power pack, knowing that we should be able to trace all D.C. electron flow paths from this point to the B+ power pack terminal, and remembering that electrons flow into the minus terminal of a resistance and out of the plus terminal. One path is from B— to chassis through choke coil L_{18}, through the chassis to grounded points in the receiver stages, through a cathode bias resistor and through each tube from cathode to plate, and then back to B+ through the plate loads. This complete path through the first R.F. tube is indicated in Fig. *13*, with the direction of electron flow shown by arrows and the chassis path indicated by a dotted line; the other paths between ground and the B+ terminal of the power pack, one for each tube, are all in parallel with this one and can be traced in the same way. Another path is from B— through L_{18} to chassis and then through voltage divider resistors R_5 and R_4 directly to B+.

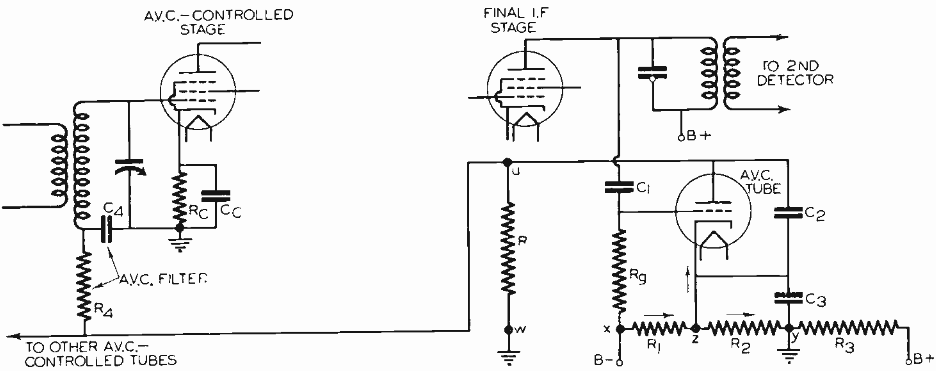


FIG. 12. Basic circuit for an A.V.C. system in which a separate triode tube is used to provide the A.V.C. voltage.

Now we are ready to trace electron flow through the A.V.C. tube (assume for the time being that no R.F. signals are present). Electrons flow from the B— terminal of the power pack through filter choke L_{17}, then through part of manual volume control potentiometer R_{16} to point *z*, where the electron flow divides. Some electrons go through the remainder of R_{16} and through resistor R_{17} to ground, from whence they take the various all-in-parallel paths through the tubes and voltage divider R_4-R_5 to the B+ power pack terminal, while other electrons go through the A.V.C. tube.

Since electrons enter R_{16} at *x* and travel to *z*, *x* is more negative than *z* and the cathode of the A.V.C. tube. The grid of this tube, being connected to x through resistors R_{14} and R_{15}, thus gets a definite value of negative bias voltage which makes the tube pass a definite value of D.C. plate current. Electron flow is from z to cathode to plate, through R.F. choke L_9 and A.V.C. tube load resistors R_2 and R_3 to ground, and then to the B+ terminal of the power pack through the chassis and the other tubes in the usual manner. The voltage drops produced across R_2 and R_3 by this current make points u and v negative with respect to ground (point w); these negative voltages, applied to the grids of the controlled tubes through the A.V.C. filters, add to the automatic C bias voltages developed across the cathode resistors of the controlled tubes. There is thus a different normal C bias value for each setting of the manual volume control.

Potentiometer R_{16} serves as a manual volume control, for moving contact arm z closer to x reduces the negative bias on the A.V.C. tube and at the same time increases the plate voltage of the tube slightly; this increases plate current flow, increases the voltage drops across R_2 and R_3, increases the negative C bias voltage on the controlled tubes, reduces amplification and therefore reduces volume. Moving contact arm z away from x therefore increases volume; with z at t, we have the same arrangement as in the basic circuit of Fig. *12*, where the A.V.C. tube has a high enough negative bias to cut off its plate current. Under this condition, it is obvious that no A.V.C. voltage is applied to the controlled tubes, and gain is a maximum.

The plate voltage on the A.V.C. tube is fairly low, for the maximum voltage it can obtain is that which is produced across choke L_{18} by the flow of power pack output current through the D.C. resistance of the choke; as you can see, the A.V.C. tube connects across this choke through R_3, R_2, L_9, the z-x section of R_{16}, and L_{17}. The voltage across L_{18} is therefore divided among all these parts and the A.V.C. tube.

When an R.F. signal enters the A.V.C. tube through C_{18}, the tube acts as a C bias detector in rectifying the signal. R.F. components are filtered out by C_{20} and L_9, while the D.C. and A.F. components of the rectified R.F. signal appear across R_2 and R_3. The A.F. component is filtered out in the usual manner by the A.V.C. filters. The D.C. component, proportional to carrier level, increases the normal D.C. voltages across R_2 and R_3 and thereby increases the bias voltages applied to the controlled tubes. An increase in R.F. carrier input to the A.V.C. tube produces an increased negative bias for the controlled tubes, reducing amplification just enough to keep the carrier input to the second detector essentially constant. Thus we have conventional A.V.C. action.

How A.V.C. Affects Receiver Selectivity. Undoubtedly you noticed in Fig. *13* that the R.F. input for the A.V.C. tube is taken from a point which is two tuned circuits (L_1-C_1 and L_2-C_2) ahead of the second detector. There is a definite reason for taking the R.F. input voltage for the A.V.C. tube ahead of these highly selective tuned circuits.

In ordinary A.V.C. circuits like those in Figs. *9*, *10* and *11*, where a diode tube serves both for A.V.C. purposes and for demodulation, we know that when all of the receiver tuning circuits are adjusted exactly to resonance the A.V.C. circuit will vary the gain of the R.F. amplifiers in accordance with the level of the desired carrier. But when the receiver is tuned slightly off the desired carrier frequency, as occurs when a station is tuned in, the carrier level at the A.V.C. input point is greatly reduced by the selectivity of the tuning circuits, and the A.V.C. circuit naturally increases the amplification to offset this. The broadcast thus comes in with about the same volume as before, but is slightly distorted due to incorrect tuning and has a strong noise signal in the background. In the older receivers this was quite objectionable, for listeners were accustomed to tune a receiver according to loudness and this A.V.C. action prevented them from using loudness as a guide. The radio expert would tune a receiver like this for minimum noise, but the average person did not know this little trick and blamed the receiver for the distortion and the apparently poor selectivity.

The solution to this tuning problem involved connecting the A.V.C. tube to a point farther ahead of the demodulator, where there was less selectivity and where the carrier level for the A.V.C. stage remained fairly constant as the receiver was tuned slightly off the incoming signal frequency. This kept the gain of the receiver fairly constant, allowing the listener to tune for maximum output from the remaining I.F. stages. The R.C.A. circuit in Fig. *13* is an example of this arrangement; with this receiver, loudness could be used as a guide in tuning and good selectivity was obtained.

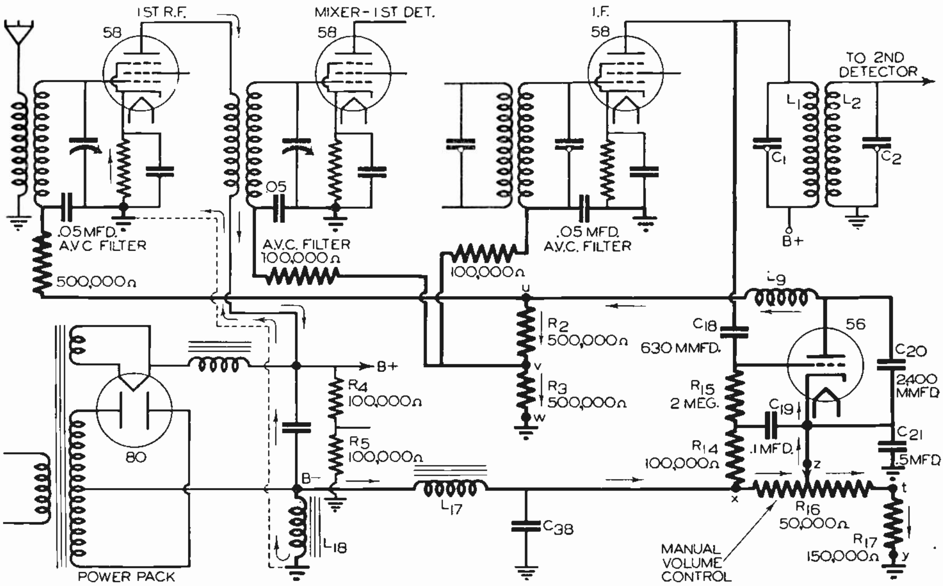


Fig. 13. Simplified diagram showing the A.V.C. system of the RCA Model R-74 superheterodyne receiver. This set uses a separate triode A.V.C. tube for producing the A.V.C. voltage. The arrows indicate the directions of electron flow for D.C. Notations on the parts are the same as those used by the manufacturer.

You will occasionally find the A.V.C. system connected considerably ahead of the second detector in modern receivers; although this practice is desirable it is not entirely necessary. Most receivers are now equipped with tuning aids to indicate when the receiver is correctly tuned.

Delayed A.V.C.

As you already know, A.V.C. action is undesirable on weak signals, for it reduces amplification a certain amount even on these weak signals. The "trick" which receiver designers use to delay the action of A.V.C. until a definite R.F. input signal (the threshold voltage in Fig. *8*) comes through is quite simple, and involves merely the insertion of a fixed D.C. voltage in series with the load resistor of the diode A.V.C. tube.

The basic circuit arrangement for delayed A.V.C. is shown in Fig. *14A;* a separate diode rectifier tube here is used for A.V.C. purposes. D.C. voltage E_D is placed in series with load resistor R_D with polarity as indicated. When there is no R.F. signal input, only this D.C. delay voltage is acting on the plate of the diode A.V.C. tube; it makes the plate negative with respect to cathode, and thus no current can flow through R_D. Any R.F. input voltage e_s (secured from the I.F. amplifier) which has a peak value less than the delay voltage E_D will not make the diode plate positive, and hence there will be no A.V.C. voltage developed on weak signals. This is indicated in Fig. *14B,* where the R.F. signal peak is considerably lower than the delay voltage E_D and cannot therefore make the plate positive. In Fig. *14C* the peak input signal just equals the delay voltage; plate voltage is thus zero on peaks, but still is never positive. In Fig. *14D*, however, the R.F. input signal peak is greater than the delay voltage, and the difference between these two voltages (the shaded area of each pulse) is effective in sending rectified current through R_D for the production of an A.V.C. voltage.

When the positive terminal of the delay voltage source is grounded, as in Fig. *14*, this delay voltage places a negative bias on the grids of the controlled tubes at all times. By careful circuit design this can be made to serve as normal C bias for the controlled tubes, eliminating the need for automatic C bias. The negative terminal of E_D could just as well be grounded, however; in this case voltage E_D would have

The output R.F. signal e_s from the I.F. amplifier is fed directly to diode detector D_1 through C_{15}, causing rectified current to flow from cathode to plate, through L, R_4 and R_5 to the chassis, and then through the chassis to the cathode of D_1. The A.F. voltage developed across a part or all of R_5 is fed through C_{22} to the grid of the 6F5G first A.F. amplifier tube. Incidentally, the grid of this A.F. tube gets its negative bias voltage from the voltage drop across resistor R_{11} (one of the delay voltage resistors).

Now let us analyze the delayed A.V.C. circuit. Condensers C_{14} and C_{15} feed the R.F. signal e_s into diode section D_2. The plate of this diode is made negative with respect to its cathode (which is grounded) by a connection through load resistor R_7 to one end of resistor combination R_{10}-R_{11},

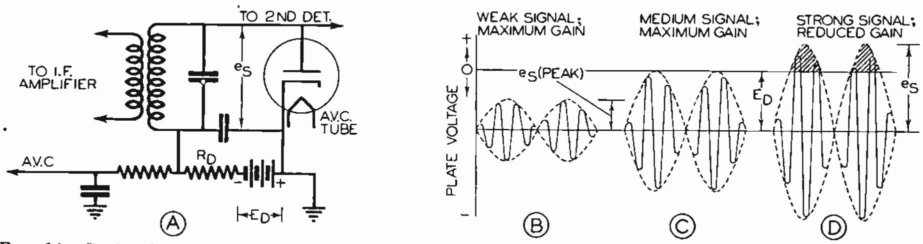


FIG. 14. Basic circuit for delayed A.V.C. action, and curves illustrating how delayed A.V.C. provides maximum amplification for weak signal. E_D represents the D.C. delay voltage, while e_s represents the peak value of the amplified R.F. signal.

no direct effect upon the controlled tubes, and would serve only its normal function of delaying A.V.C. action.

A separate diode is a necessity when delayed A.V.C. action is employed to give maximum amplification of weak signals, for with a common detector-A.V.C. tube the delay voltage would prevent demodulation of weak signals and would cause distortion on medium-strength signals through cutting off of the negative peaks of the A.F. signal.

Delayed A.V.C. Circuit Using Double-Diode Tube. An excellent practical example of delayed A.V.C. is the Silvertone receiver circuit shown in Fig. *15*. Section D_1 of the double-diode 6H6G tube serves as second detector, section D_2 serves as A.V.C. tube, and the voltage drop across resistors R_{10} and R_{11} in the power pack circuit provides the delay voltage E_D. Let us analyze the detector circuit action first.

through which the power pack output current flows to produce a delay voltage. This delay voltage also serves as minimum or normal C bias for the controlled tubes.

Weak signals undergo detection in the conventional manner in D_1, but cannot overcome the delay voltage which makes the plate of D_2 negative and hence no A.V.C. voltage is developed across R_7. Strong signals are likewise detected normally by D_1; they also make the plate of D_2 positive on the peaks of alternate half-cycles, and electron flow is from cathode to anode of D_2, then through A.V.C. load resistor R_7 and through resistors R_{10} and R_{11} to ground and back to the cathode of D_2. The D.C. component of the voltage developed across R_7 is the A.V.C. voltage; it adds to the normal negative bias voltage E_D and thus amplification is reduced when strong signals come through. The A.F. component of voltage across R_7 is kept out of the controlled tubes by A.V.C. filter R_6-C_8.

Identifying A.V.C.-Controlled Tubes

Ordinarily you will have no trouble in locating the A.V.C. tube on a schematic circuit diagram, for it is now general practice to identify tubes and their functions right on these diagrams. It is not customary, however, to indicate which tubes are A.V.C.-controlled. In order to determine this, you must know the usual methods of applying the A.V.C. voltage to a tube. Three common methods are shown in Fig. *16;* you will observe that in each of these circuits the control grid does not trace directly through a conductive path to ground, chassis, B— or C—, but instead traces through an A.V.C. filter resistor to the A.V.C. tube load.

In the circuit of Fig. *16A* the A.V.C. voltage is fed to the control grid through the coil (L_1) of the tuned input circuit after being filtered by R_F and C_F; R_C and C_C together furnish the minimum negative C bias for the tube, this being applied to the grid through the chassis and the conductive path of the A.V.C. system (this path is not shown here but can be traced in any of the A.V.C. circuits already studied). With this arrangement, tuning condenser C_1 cannot be connected directly to point x on coil L_1, because of the fact that the rotor of this condenser is nearly always grounded directly to the chassis. Condenser C_F therefore serves also as an R.F. by-pass path from the tuning coil to ground.

In the I.F. amplifier stages of superheterodyne receivers the tuning condenser is of the trimmer type and is shunted directly across the tuning coil. The circuit arrangement in this case is as shown in Fig. *16B,* the A.V.C. voltage still being fed through the tuning coil.

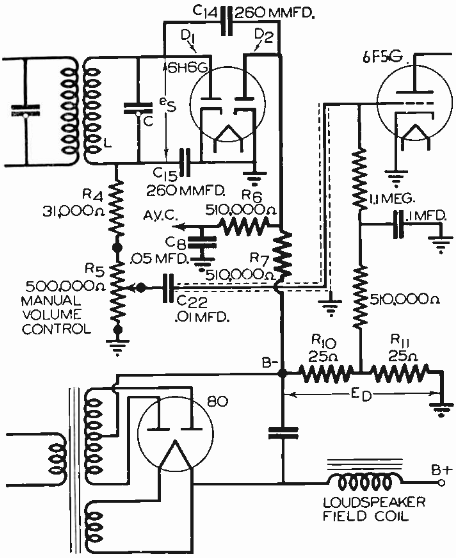


FIG. 15. Simplified diagram showing the delayed A.V.C. system of the Silvertone Model 1986-1987 superheterodyne broadcast receiver (chassis No. 100150). Section D_2 of the double-diode tube produces across resistor R_7 the desired A.V.C. voltage.

Occasionally the low R.F. potential end of the tuning coil (point x in Fig. *16C*) is grounded, thus giving a direct connection between this coil and the grounded rotor of the tuning condenser. In this case the A.V.C. voltage must be applied through grid resistor R_g, with blocking condenser C_B used to prevent the A.V.C. voltage from being grounded by tuning coil L_1. Again the grid traces conductively to the A.V.C. system. To prevent loading of resonant circuit L_1-C_1 and broadening of its response characteristic, resistor R_g must have a resistance of at least 500,000 ohms. Observe that the cathode is grounded directly; this indicates that the

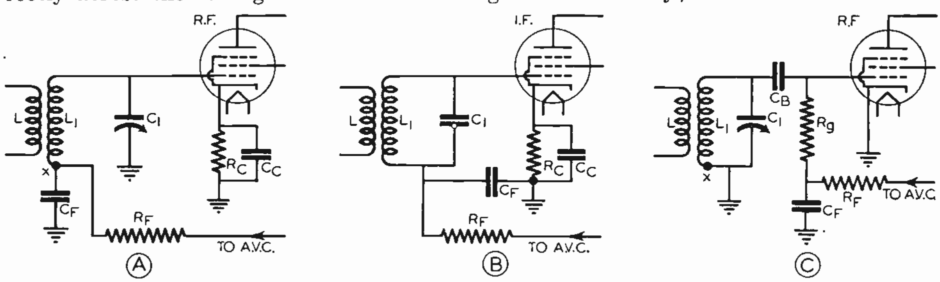


FIG. 16. Common methods of applying A.V.C. voltage to the grids of A.V.C.-controlled tubes.

A.V.C. system furnishes the minimum negative C bias voltage in this arrangement. There are two A.V.C. filters, R_F and C_F being the first, and R_g with C_B making up the second.

Construction Of Manual Volume Controls

Variable resistors or potentiometers which are used as manual volume controls are either of the wire-wound type or of

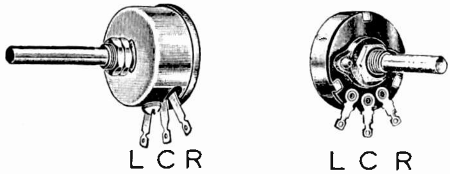


FIG. 17. Two representative manual volume control potentiometers. In each case two nuts are provided on the threaded tubular projection of the housing (through which the shaft runs) to permit clamping the control to a receiver chassis. Only a single mounting hole is needed.

the carbon type. Examples of each type are shown in Fig. *17*; as you can see, the general appearance gives no clue toward identifying a particular unit.

The total resistance as measured with an ohmmeter between the left (*L*) and right (*R*) terminals of a volume control is a rough guide for identifying the type of construction used. Units which have resistances below 5,000 ohms are generally wire-wound; small-diameter resistance wire such as nichrome wire is wound on a thin, long and flexible rectangular strip of fibre and the strip is then curled into a semi-circle which fits into the cylindrical metal or bakelite housing of the unit. Insulating material separates the resistance unit from the housing. A movable contact arm, connected to the center terminal *C* of the control, slides over the winding and provides a means of connecting to any point on the winding.

Volume controls which have resistances above 10,000 ohms are ordinarily of the carbon type, although wire-wound resistances can be obtained with ohmic values up to 50,000 ohms for special purposes. It is safe to assume that all volume controls above 50,000 ohms are of the carbon type.

It is interesting to know how carbon type volume controls are made. In one type of construction, a thin rectangular strip of insulating material is first coated with a kind of carbon paint, made by mixing highly pulverized carbon particles with water; one mixture of this nature is sold under the trade-name *Aquadag*. The strip is then curled as shown in Fig. *18A* and mounted in the metal housing of the control.

The insulating strip is often cut in the shape of a round horseshoe like that shown in Fig. *18B*, so the element can be mounted flat against the back of the housing without curling it. Another scheme involves the molding of a grooved circular horseshoe from bakelite, and pressing into the groove a carbon paste which serves as the resistance element; this type of construction is shown in Fig. *18C*.

Each resistor manufacturer generally has his own method of applying the carbon solution or paste and treating it to give greatest dependability during use. Although sliding friction contact arms are used on wire-wound resistors, some form of roller contact which applies direct pressure to the resistance element is generally used with carbon type controls. This is necessary because the carbon elements do not stand up well under constant friction.

Wire-wound volume controls can be made with less than 5% variation in their resistance values (making the resistance of a 1,000 ohm unit anywhere between 950 ohms and 1,050 ohms; engineers call this

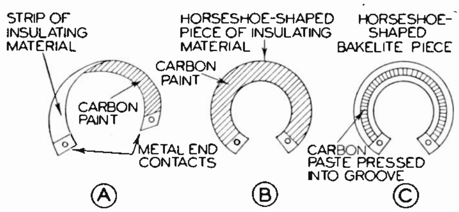


FIG. 18. Three types of construction used in carbon type volume control potentiometers.

a 5% *tolerance*). Carbon resistors cannot ordinarily be made to such close tolerances; a tolerance of 20% appears to be customary with ordinary controls.

Exact values of resistance for volume controls are fortunately not required in ordinary circuits; only where the volume control is a part of a power voltage-dividing system is it necessary to observe a close tolerance. Variations of from 20%

to 40% in the total resistance of a volume control are perfectly satisfactory in ordinary receiver circuits; this is important for you to remember, as you can replace a defective 100,000 ohm volume control with either a 75,000-ohm or 140,000-ohm unit and still secure satisfactory results.

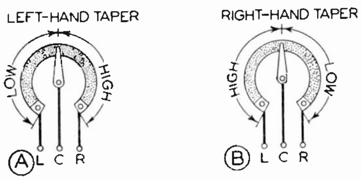


FIG. 19. Different resistances between the two halves of a volume control indicate a tapered control.

Taper. The manner in which the resistance of a volume control is distributed is of vital importance, even though the exact resistance of the unit can vary over wide ranges; this distribution of resistance is called the *taper* of the unit. If the resistance is uniformly distributed, so that varying the movable contact a definite amount causes a uniform change in resistance between points *R* and *C*, we say that the volume control has a *linear taper* and is therefore a *linear control.* Thus a linear control set at ¼ of its total rotation would give ¼ of the total resistance; similarly, at ½ of the total rotation there would be ½ of the total resistance.

Volume controls are usually expected to increase the receiver output volume when the knob is turned in a clockwise direction (making the top of the knob move from left to right). The volume control is usually mounted on the radio chassis in such a way that the shaft, on which the knob is fastened, always points toward the person adjusting the control.

The diagrams in Fig. *19* show the essential elements of a volume control as they are when the shaft points toward you. If the resistance between terminals *C* and *L* increases uniformly as the contact arm is moved away from *L* and toward *R*, we have a linear control and curve *1* in Fig. *20* will represent its variation of resistance with control knob movement or rotation.

Left-Hand Taper. If, in moving contact arm *C* of a volume control unit from *L* to *R*, the resistance between *L* and *C* increases slowly at first and then more rapidly and uniformly after the half-way position is passed, we have what is known as a *left-hand taper* (represented by curve *2* in Fig. *20*). The taper or gradual change in resistance is here at the left-hand side of the control.

Right-Hand Taper. If the resistance between *L* and *C* in the above case increases more or less uniformly and rapidly at first, and then increases less rapidly as the contact arm approaches terminal *R*, we have what is known as a *right-hand taper* (represented by curve *3* in Fig. *20*). The taper or gradual change in resistance is here at the right-hand side of the control.

There is a simple way of telling whether a particular control has a right-hand or left-hand taper. With the shaft of the control pointed toward you, set the contact arm at its mid-position, as indicated in the diagrams in Fig. *19*, and then measure the resistance first between terminals *C* and *L* and then between terminals *C* and *R* with an ohmeter. If the lower resistance exists between *C* and *L*, you have a left-hand taper control, as in Fig. *19A*; if the lower resistance exists between *C* and *R*, you have a right-hand taper control, as in Fig. *19B*. If the resistances of the two halves are equal, you either have a linear taper or, in very rare cases, a combination right- and left-hand taper like that represented by curve *4* in Fig. *20*.

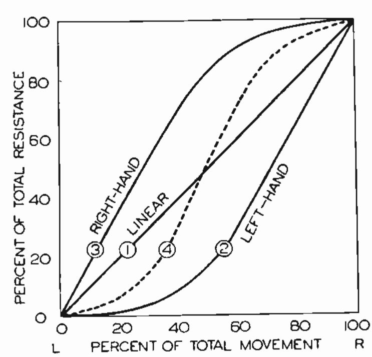


FIG. 20. Curves showing variation of resistance between terminals *L* and *C* with movement for three types of tapered volume controls and for a linear volume control.

Why Tapered Volume Controls Are Needed. The main purpose of a tapered manual volume control is to give changes in volume which sound uniform to the human ear for equal changes in volume control position. This means that the receiver designer must take into account the peculiar characteristics of the human ear, which prevent it from detecting changes of less than 3 db in the level of a complex sound. Two representative circuits which use tapered volume controls will now be studied.

A conventional diode detector circuit in which is incorporated A.V.C. and a manual volume control *V.C.* is shown in Fig. *21A*. A study of this circuit will show you that as the movable contact on the volume control is moved from the cathode end to the diode plate end, the A.F. voltage fed to the triode section of the tube increases; this means that increased volume is secured when the contact arm is moved towards point *R*. If a conventional volume control unit is used, it should be so connected that terminal *L* on it connects to the cathode and terminal *R* to the tuned input circuit as indicated. This is done to make clockwise movement of the control knob give increased volume.

Supposing that a linear volume control were used for the circuit in Fig. *21A*, let us see how it would act. We know that when movable contact *C* is at *R* the maximum available A.F. voltage will be applied to the grid of the triode section and full output volume will be obtained; likewise there will be zero A.F. voltage on the grid when *C* is at *L*, and volume will be zero.

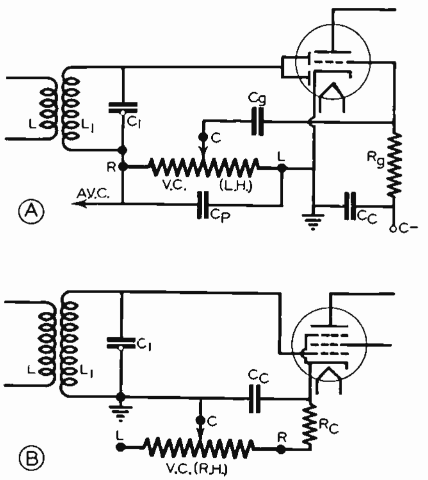


FIG. 21. Two examples of circuits which require tapered manual volume controls.

It is a known fact that a reduction of one-half in A.F. voltage corresponds to a 6 db change in sound level; since the average human ear can just barely detect a 3 db change in the level of a complex sound, the 6 db change would be equivalent to two noticeable changes in sound.

With these facts in mind, let us reduce the volume from maximum to zero by rotating contact arm *C* gradually from *R* to *L*. We listen carefully as we turn; at first we can detect no change in volume—our ear catches one change or reduction—we keep on turning until we can detect another reduction—now we check the volume control knob and find it is at the half-way position, so that half of the maximum A.F. voltage is being used.

We cut the voltage in half again by moving *C* from the ½ to the ¼ position, and again get two noticeable changes in volume or a 6 db change in sound level. Moving *C* from the ¼ to the ⅛ position again cuts the voltage in half, with two more detectable changes in sound. Thus as we move *C* from *R* to *L*, we get two noticeable changes in volume while moving the control knob first ½, then ¼, ⅛, 1/16, 1/32, etc. of its total movement. Clearly a linear control gives extremely non-uniform changes in volume in this circuit, with the changes in volume being most apparent as the contact arm approaches *L*.

To overcome this non-uniform change in volume with control setting, the radio engineer uses a volume control which reduces the voltage rapidly as *C* is first moved away from *R*, then produces less change in voltage with change in setting, or allows the voltage to taper off slowly. This type of volume control would have a left-hand taper. *As a general rule, when the current through the entire volume control resistance is constant regardless of the setting of the movable contact, the left-hand taper is required.*

Another widely used manual volume control circuit is shown in Fig. *21B*. Here resistor R_C sets the minimum C bias for the tube; increasing the resistance of manual volume control resistor *V.C.* increases this C bias and hence reduces the amplification and receiver volume. To make the volume increase with clockwise rotation of the control, the right-hand terminal of the volume control must be connected to resistor R_o as indicated.

Maximum volume is, of course, obtained when contact arm *C* is at *R*. As *C* is moved away from *R*, the increase in C bias voltage is at first quite rapid, but increases less and less rapidly after that because advancing this volume control reduces the plate current of the tube. It therefore takes larger and larger series resistances in the cathode lead to get appreciable increases in C bias; what we need is a resistor which changes its resistance rapidly at first, and then more slowly. A right-hand tapered resistance, represented by curve *3* in Fig. *20*, does this and is therefore used in a circuit like this.

In general, when the current through the volume control resistance changes in value as the movable contact is adjusted, a right-hand tapered volume control unit is used. In the C bias type of manual volume control such as this, the gain of the tube does not change uniformly with changes in C bias. To compensate for this deviation, special tapers are oftentimes used for the volume control. An ordinary right-hand taper control will generally suffice as a replacement in cases like these, however.

You have undoubtedly noticed that the terminals of the manual volume controls in the circuits of Figs. *2, 3, 4, 5, 6* and *7* are marked *L, C* and *R*; these markings indicate how the volume control should be connected so as to get increased volume when the control knob is turned in the conventional clockwise direction. In addition, the ohmic values of the controls are given, and each volume control is marked either *L.H.* to indicate left-hand taper or *R.H.* to indicate right-hand taper. This extra information will be of practical help to any one who is called upon to service volume control circuits.

TEST QUESTIONS

Be sure to number your Answer Sheet 19FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Do receivers which employ automatic volume control also have manual volume controls?
2. Give three reasons why automatic volume control is desirable in a radio receiver.
3. Name three types of manual volume controls which are found in radio receivers.
4. What is the most effective way of varying the mutual conductance of a tube in order to control volume?
5. What is meant by the threshold voltage in a receiver having delayed A.V.C.?
6. What signal voltage (developed by the A.V.C. tube in a radio receiver) is kept *out of* the A.V.C-controlled stages by A.V.C. filters?
7. What determines the time constant of the A.V.C. filter system?
8. What sections of a superheterodyne receiver are usually A.V.C.-controlled?
9. Which type of taper (left-hand or right-hand) does a volume control unit have if, in moving contact arm *C* from *L* to *R*, the resistance between *L* and *C* increases slowly at first and then more rapidly after the half-way position is passed?
10. What is the general rule for using a volume control unit which has a right-hand taper?

HOW SIGNAL CURRENTS ARE KEPT IN CORRECT PATHS

20FR-3

PIONEER HOME STUDY RADIO SCHOOL

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YOUR HEALTH

At any particular time, there is a definite relationship between a man's mental ability and his physical condition; in fact, these two conditions are linked together far more closely than people care to admit even to themselves.

Overeating or unwise eating is generally followed by a lazy feeling and a desire to sleep. The mind becomes less active during this period. If the food proves particularly indigestible, a headache may develop in a few hours, along with a gloomy, crabby, or disgusted-with-life-in-general feeling. Certainly a man cannot do his best work when feeling this way.

Blue Mondays are not myths—they are quite real, and are caused by too much food and too little mental and physical exercise on Sunday, combined with a troubled sleep or too little sleep Sunday night. It takes several days for the human system to get back to normal after a week-end of excesses, so it may not be until Wednesday that you are able to tackle your work with a clear mind. Then you find it easy to concentrate; work actually becomes a pleasure, and the day seems only a fraction as long as Monday or Tuesday. Life really becomes worth while, and you say to yourself: "How much happier I would be if every day were like this!"

But every day *can be like this*—if you take the proper care of yourself, if you observe the simple rules of health which every one should follow, if you take a brisk walk or secure some other physical exercise each day in the open air, and above all, if you get a good sound sleep *and enough of it* each night. Sleep is all-important, and for many people is quite elusive; drastic changes in living conditions or the advices of a doctor are often necessary in order to remove factors which prevent restful sleep.

Give your health the attention it deserves, and you will be rewarded many times by increased happiness and increased success in your work.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

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How Signal Currents Are Kept in Correct Paths

Introduction

UNDESIRED signal currents can enter a circuit in three different ways: *1,* through a *conductive path* such as a wire or a metal chassis; *2,* by *electrostatic induction,* where the electric field set up by one circuit repels and attracts electrons in another circuit; *3,* by *electromagnetic induction,* where the magnetic field set up by one circuit induces interfering currents in another circuit.

Undesired signal currents are kept out of circuits and desired signal currents are kept in their correct paths by many different methods; although these are generally applied to radio apparatus by design engineers, a knowledge of how each method works is needed by the radio operator or serviceman who is called upon to locate and remedy a defect in some circuit.

The most important of these methods for controlling signal current paths are listed below; many of these have been covered in previous lessons, but this entire subject is of such great practical importance that a more detailed study is entirely justified.

By-Pass Condensers

The importance of by-pass condensers can best be understood by considering the behavior of an amplifier stage which has no by-pass condensers. Such a stage is shown in Fig. *1A,* where the input device R_S (across which the input signal voltage e_S appears) and the plate load R_L are shown as resistors. Although tuned circuits and transformers could be used at these locations in practical circuits, under ideal conditions they have the effect of resistors and will therefore be considered as such here.

When the input signal voltage e_S in Fig. *1A* is zero, the control grid of the tube is at a fixed potential, the value of

METHODS OF KEEPING SIGNAL CURRENTS IN CORRECT PATHS

1. **Using by-pass condensers.**
2. **Using R.F., I.F. and A.F. signal current filters made up of resistors, coils and condensers.**
3. **Using D.C. blocking condensers.**
4. **Making proper circuit connections, in order to prevent stray coupling between leads and parts and to eliminate stray currents.**
5. **Shielding signal circuit parts against the effects of stray electric fields.**
6. **Shielding circuit parts against the effects of stray magnetic fields.**
7. **Positioning of power pack and signal circuit parts in such a way that magnetic and electric fields cannot cause interference.**
8. **Twisting filament leads and power supply leads which carry A.C., or running such leads parallel to each other and close together.**
9. **Using center-tapped filament connections for grid and plate return leads.**
10. **Using neutralizing circuits to counteract the effects of R.F. and I.F. feed-back currents. (This last method is covered elsewhere in the Course and will not be repeated here.)**

which determines how much D.C. plate current and D.C. screen grid current will flow. The directions of electron flow in various parts of the amplifier under this condition are indicated by arrows directly on the circuit lines in Fig. *1A;* you can easily verify these directions by remembering that electrons leave the minus terminal of the B battery (the only D.C. source in the circuit) and travel from cathode to plate or from cathode to screen grid in the tube. The D.C. screen grid and plate currents both flow through resistor R_C, developing across it a D.C. voltage drop which serves as the normal C bias for the tube and which therefore serves to determine the values of these D.C. electrode currents.

When an input A.C. signal voltage e_S is applied across R_S, it makes the control grid alternately more and less negative than the normal negative C bias value; when this input signal swings the control grid less negative (more positive), D.C. plate and screen grid currents both increase a certain amount, and when the input signal swings the control grid more negative, the D.C. plate and screen grid currents decrease. The application of an input signal on the control grid is thus causing the D.C. plate and screen grid currents to vary continually above and below their normal no-signal values, and we actually have pulsating D.C. currents in these two circuits.

We know definitely that the vacuum tube, when acted upon by the input signal, causes these variations in the electron current which is sent through the screen grid and plate circuits by the B battery; it is quite permissible, therefore, to think of the vacuum tube as simply a variable resistance acting in the plate circuit (and also in the screen grid circuit) and thereby producing these variations or pulsations in plate and screen grid currents. If we say that this tube resistance is varying at exactly the same rate and in the same manner as the grid input A.C. signal, we can neglect the grid circuit entirely and concentrate our attention upon the plate and screen grid circuits, through which the B battery is forcing the pulsating currents.

In an amplifier circuit we are primarily interested in the pulsations or variations in plate current, for these develop across load resistor R_L the desired amplified signal voltage. We could consider only this A.C. or signal component of the plate current, and think of it as acting in a circuit made up of the B battery and a varying cathode-to-plate resistance in the tube, but experience has shown that an analysis or study of the circuit under this condition becomes quite complicated.

There is a much easier way of dealing with A.C. or signal currents in the plate and screen grid circuits of an amplifier—a method which is almost universally used by engineers because of its simplicity. This method involves neglecting the D.C. electrode currents entirely, and considering the *vacuum tube* as our source for A.C. or signal currents. (The battery is neglected as a voltage source and considered simply as a resistor equal to the internal battery resistance R_B in Fig. *1A*). In other words, we replace the entire grid circuit and the cathode-plate path of the tube with an A.C. generator having a given internal resistance (the A.C. plate resistance) when we deal with the plate circuit, and we likewise consider an A.C. generator in place of the cathode-screen grid path of the tube when dealing with the screen grid circuit. (You will recall that this is exactly what was done in the equivalent tube circuits studied in a previous lesson.)

The tracing of signal currents (A.C. components of electrode currents) in Fig. *1A* is quite simple now that we can consider the tube as the A.C. source. A.C. plate current i_p flows through the cathode-plate path of the tube (its source) to the plate, flows through load R_L, flows to point *2* (the chassis) either through the B battery or through voltage divider R_1-R_2, and then returns to the cathode through R_C; arrows labeled i_p indicate these paths. A.C. screen grid current flows through the cathode-screen grid path of the tube (its source) to the screen grid electrode, flows to point *2* (the chassis) either through R_1, or through R_2 and the B battery, and then returns to the cathode through R_C; arrows labeled i_{sg} in Fig. *1A* indicate these paths.

Cathode Circuit. Both the plate and screen grid signal currents flow through C bias resistor R_C, producing A.C. voltage drops across it. Since the control grid voltage is applied through R_C, these A.C. voltage drops act on the control grid along with the input signal voltage e_S, and *degeneration* occurs. What actually happens is this: When the input signal e_S is increasing in a positive direction, making point *3* more positive with respect to point *2*, the plate and screen grid signal currents through R_C will be increasing. Since electron flow for these currents is from point *2* to point *1*, point *2* will be made increasingly more negative with respect to point *1*. We thus have acting on the control grid of the tube (applied to the grid and cathode terminals of the tube) the positively increasing input signal voltage and the negatively increasing A.C. voltage developed across the C bias resistor. These A.C. voltages oppose each other (are out of phase with each other) and hence the net A.C. voltage on the grid is reduced, with *degeneration* or reduction of signal current as a result.

Cathode C Bias Resistor By-Pass Condenser. The method commonly used to keep signal currents out of the

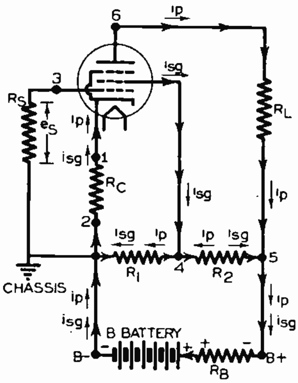

FIG. 1A. Simplified pentode amplifier circuit, with all by-pass condensers omitted. Arrows on circuit lines indicate D.C. electron flow, while other arrows indicate paths taken by signal currents.

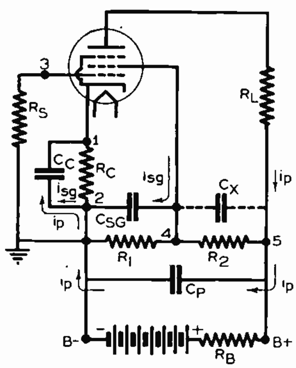

FIG. 1B. Three by-pass condensers inserted in the amplifier circuit of Fig. *1A*, as shown above, effectively serve to keep signal currents in their proper paths, eliminating interfering effects.

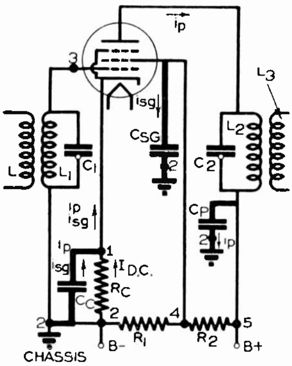

FIG. 1C. Pentode R.F. amplifier circuit of Fig. *1A* with suitable by-pass condensers to provide low-reactance paths for signal currents. Actual tuned input and output circuits are shown instead of resistors.

C bias resistor and thus prevent degeneration from occuring in the cathode circuit involves placing a by-pass condenser across the C bias resistor, making the reactance of this condenser low enough at the lowest signal frequencies so that the signal currents will take the path through the condenser rather than through the C bias resistor. This is done in Fig.*1B*, where C_C is the cathode by-pass condenser which is connected across C bias resistor R_C. The A.C. voltage drop across this condenser will be negligibly low because the by-pass condenser has practically no reactance at signal current frequencies, and hence the only A.C. voltage acting on the grid will be the input signal voltage. The D.C. components of screen grid and plate current will continue to flow through R_C, producing across it the desired C bias voltage.

Screen Grid Circuit. Now let us see what undesirable effects are produced by A.C. screen grid current in the amplifier circuit of Fig. *1A*. We note that the screen grid gets its D.C. voltage from a tap at point *4* on the voltage divider network made up of R_1 and R_2. The voltage of this point with respect to point *2* (B-) depends upon the ohmic values of R_1 and R_2 and upon the current which flows through each resistor to produce across it a voltage drop. From Kirchhoff's voltage law we know that the sum of the voltage drops across R_1 and R_2 must equal the B battery voltage; stated in another way, the screen grid supply voltage (the drop across R_1) will be equal to the B battery voltage minus the voltage drop across R_2.

Consider the A.C. screen grid current path through R_2. When a positively increasing control grid voltage causes screen grid current through R_2 to increase, the voltage drop across R_2 will increase and consequently the voltage drop across R_1 (the screen grid voltage) will *decrease.* A decreasing screen grid voltage means a decreasing A.C. plate current, and consequently we have *degeneration,* a reduction in signal output, as an undesirable effect of A.C. screen grid current in this circuit.

Screen Grid By-Pass Condenser. A.C. screen grid current could be kept out of R_2 by placing across it a by-pass condenser (C_X in Fig. *1B*) which provided a low-reactance path around this resistor for this current, but a more practical solution is one which places a by-pass condenser between the screen grid lead (point *4*) and the cathode lead (point *2*); condenser C_{SG} in Fig. *1B* is connected in this way. Now A.C. screen grid currents have a direct low-reactance path from point *4* to point *2* and then through C_C to the cathode, and consequently there will be no degeneration. This practical solution keeps A.C. grid current i_{sg} out of the source as well as out of R_2.

Plate Circuit. We still have the effects of *A.C. plate current* to consider in the circuit in Fig. *1A*. This current (i_p) flows through the B battery along with the A.C. screen grid current i_{sg}. Any voltage source has a certain amount of internal resistance; this resistance can be considered as acting in series with the source in Fig. *1A*, and resistor R_B therefore represents the battery resistance through which these signal currents must flow.

We have seen how screen grid signal current can be made to take a proper path, but we still have plate signal current flowing through this battery resistance and producing a voltage drop across it. By considering the directions of electron flow (indicated by arrows in Fig. *1A* for the case where the grid signal is positively increasing) you can see that this voltage drop causes the potential of point *5* (the supply voltage) to decrease with respect to point *2* when the grid input voltage increases. The flow of signal current through the battery thus reduces the plate supply voltage and the plate current, and again we have *degeneration.* Furthermore, any A.C. plate currents which take the R_1-R_2 path from point *5* to point *2* instead of going through the battery may also cause undesirable effects.

Radio apparatus today generally contains a number of vacuum tube stages all connected to a common supply source. Any other tubes connected to the battery in Fig. *1A* would consequently be affected by the signal voltage drops across the battery resistance and would undergo either regeneration or degeneration, depending upon whether the undesired voltage drops aided or opposed changes in plate current in a particular stage. Clearly it is undesirable to allow signal currents to flow through the plate supply or the voltage divider.

Plate Supply By-Pass Condenser. A by-pass condenser connected directly across the plate supply, like C_P in Fig. *1B*, will offer a low-reactance path for signal currents to point *2* (the chassis), thereby keeping them out of the higher-resistance paths through the plate supply and voltage divider and eliminating undesirable degeneration or regeneration effects.

The plate by-pass condenser also lowers the impedance of the A.C. plate current path, allowing more A.C. plate current to flow through load resistor R_L and thereby developing across it a higher output signal voltage. No useful A.C. plate voltage is wasted now in the internal battery resistance R_B.

Practical Amplifier Circuit. One example of a practical circuit which requires by-pass condensers is that shown in Fig. *1C*, representing a pentode I.F. amplifier stage of a superheterodyne receiver. The connections to the three by-pass condensers are shown by heavy lines to make them easy for you to locate. In this circuit, bypass condensers C_P and C_{SG} are both connected to point *2* on the chassis, to which R_C is also connected, and low-reactance by-pass condenser C_C is relied upon to provide a path from the chassis to the cathode for the signal currents. Oftentimes, however, these by-pass condensers are connected directly from the plate and screen grid circuits to the *cathode.* Design engineers choose whichever method gives the shortest leads, for long leads result in electric and magnetic fields which produce undesirable coupling between circuits.

BY-PASS CONDENSER RULE

In a vacuum tube circuit, all signal currents are by-passed through condensers to the cathode after they leave the electrodes or circuit parts through which they must flow to give the desired circuit action. **Signal currents will take the path through a by-pass condenser in preference to other possible paths between two points in a receiver circuit because *the by-pass condenser has practically no reactance at signal current frequencies;* in fact, a by-pass condenser is the equivalent of a direct wire connection for these currents.**

Occasionally a design engineer omits a by-pass condenser specifically to secure regeneration or degeneration, or uses a single C bias resistor and by-pass condenser for two or more tubes.

A few typical examples will fix in your mind the general rule for applying by-pass condensers. A simple triode vacuum tube circuit like that shown in Fig. *2A* requires two by-pass condensers. A simple tetrode circuit like that in Fig. *2B* requires three by-pass condensers. A circuit containing a pentode tube in which the suppressor grid is tied directly to the cathode will likewise need three by-pass condensers. In a pentode tube circuit where the suppressor grid is not at cathode potential, as in Fig. *2C*, four by-pass condensers are needed to keep signal currents in their correct paths. Occasionally a vacuum tube is used in a circuit where the control grid is at cathode potential (zero C bias); in cases like this the cathode resistor and the cathode by-pass condenser in the circuits of Fig. *2* would be omitted and the cathode would be grounded.

Simple Signal Current Filters

Simple Condenser Filter. When A.C. or signal currents are to be kept entirely out of some part of a circuit, better by-passing of the undesired signal than can be obtained with a simple by-pass condenser is often required. As an example, consider the circuit in Fig. *3A*, where the source provides both D.C. and A.C. voltages and the load R_L is to be affected only by the D.C. component of the source voltage. True enough, we can provide a low-reactance path for the A.C. current by shunting load R_L with by-pass condenser C_F, but a very large value of capacity is required to secure completely effective filtering with a simple arrangement such as this. If the reactance of the by-pass condenser to A.C. is one-thousandth of the resistance of R_L, the A.C. current through the load will be reduced about one thousand times.

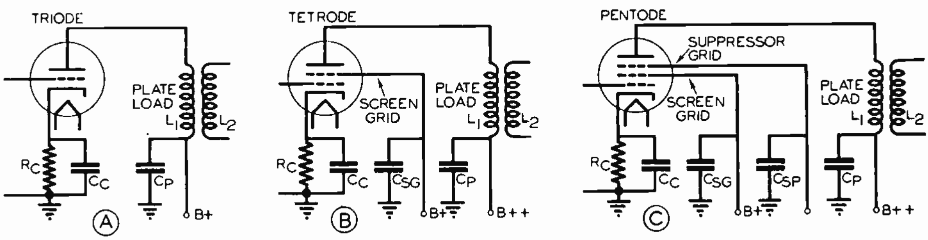

FIG. 2. Here are three applications of the general by-pass condenser rule. Observe that signal currents in the plate circuit are by-passed to the chassis after they leave the plate load, while screen and suppressor grid signal currents are by-passed to chassis after leaving their respective electrodes. In each case the cathode by-pass condenser provides a low-reactance path from chassis to cathode for signal currents.

Coil-Condenser and Resistor-Condenser Filters. Alternating current can be kept out of the load more effectively by inserting a resistor R_F in series with the load, in addition to using a load by-pass condenser, as shown in Fig. *3B*. This resistor increases the opposition which the load path offers to alternating current, making the impedance of the load path much greater than that of the path through condenser C_F. Since currents always favor the lowest-impedance path, most of the alternating current will flow through the condenser and very little will flow through the load. To be sure, series resistor R_F reduces the flow of direct current through the load, but in many cases this reduction in current is unimportant or is even desirable. When no appreciable reduction in direct current through the load can be allowed, choke coil *CH* in Fig. *3B* is used in place of series resistor R_F; a coil is chosen which has a low D.C. resistance and a high reactance at the frequency of the A.C. source. When the load resistor is high in ohmic value, better filtering may be obtained by inserting the choke coil at position *x* in Fig. *3B* instead of the position indicated. In this new position it will reduce the value of alternating current *before* it is by-passed around the load by the condenser.

Dual-Condenser Filters. An even better filter circuit arrangement is that shown in Fig *3C,* where in addition to the series resistor or choke coil, an additional by-pass condenser is shunted directly across the load. By-pass condenser C_{F1} takes the greatest part of the signal current, and whatever signal current gets through R_F or *CH* is almost entirely by-passed around the load by condenser C_{F2}.

Pi or Low-Pass Filters. When the choke coil is used in the circuit of Fig. *3C,* we have a *pi filter* (so-called because on a circuit diagram it resembles the Greek letter π, which is pronounced "pie") or *low-pass filter* which can separate low frequency signals from high frequency signals. This filter has a resonant action at a definite frequency known as the *cut-off frequency;* signals below this cut-off frequency pass through the filter readily and enter the load, for the choke coil then has very little reactance and the condensers have such high reactances that there is little shunting effect on signals. At frequencies slightly above the cut-off value, resonant action prevents transfer of signals through the filter. Signals considerably above the cut-off frequency are blocked by the choke coil and passed by the condensers, and hence cannot reach the load.

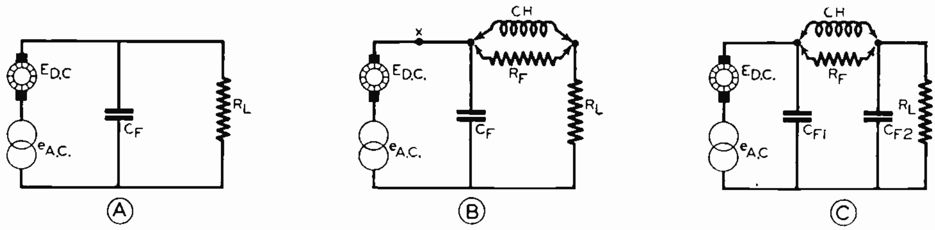

FIG. 3. The actions of the signal current filters commonly used in radio circuits are readily understood by studying these basic filter arrangements. Note the two-circle symbol for an A.C. generator; this symbol is widely used by radio and electrical men.

The cut-off frequency value depends upon the inductance of the choke and the capacities of the condensers (which are usually of equal size). The cut-off frequency is easily found by considering the filter as a resonant circuit made up of an inductance equal to one-half the inductance of the choke coil and a capacity equal to that of one of the condensers in the filter, then determining the resonant frequency by the usual procedure for resonant circuits.

Practical Examples of Signal Current Filter Circuits. The tuned radio frequency amplifier circuit in Fig. *4A* contains two examples of the resistor-condenser filter shown in Fig. *3B*. Condenser C_{F1} provides a direct path to cathode for grid circuit R.F. currents, while the C_{F1}-R_{F1} filter combination prevents any A.C. voltages which may exist across R_C from affecting the grid of the tube (there may be small amounts of A.C. plate current and power pack ripple current flowing through R_C and developing A.C. components of voltage across it). What happens is this: C_{F1}, having a very low reactance, is in series with R_{F1}, a very high resistance, across R_C, so what little D.C. plate voltage a certain amount; if this reduction in voltage is undesirable, this resistor may be replaced by an R.F. choke coil. Unfortunately, this substitution of a choke coil only serves to prevent plate circuit signal currents from getting into the power supply; the choke coil is not effective in keeping low frequency power pack ripple currents out of the plate circuit unless an additional iron-core choke designed for this particular purpose is used in series with the R.F. coil. For effective two-way filter action, R_{F2} should be replaced by R.F. and A.F.

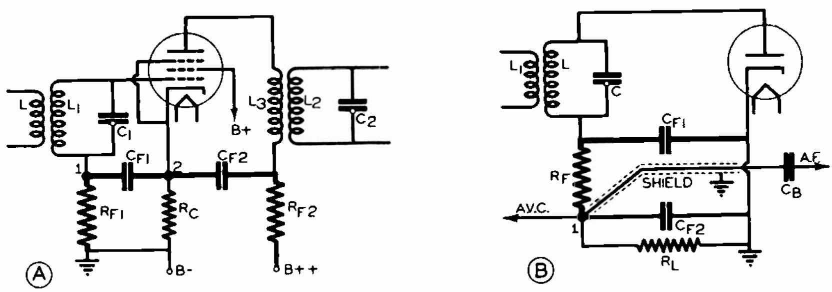

FIG. 4. The signal current filter is shown by heavy lines in each of these radio circuits.

alternating current gets through R_{F1} produces only a negligible A.C. voltage drop between points *1* and *2* as it flows through C_{F1}. Only the desired steady D.C. voltage across R_C can act on the grid through R_{F1}. Remember this important fact: A signal current filter *will act both ways,* preventing signal currents which are in one circuit from getting out and preventing other alternating currents from getting in.

In the same manner, signal current filter C_{F2}-R_{F2} prevents plate circuit signal current from getting into the power supply and prevents any alternating current in the power supply from getting into the plate circuit. Filter resistor R_{F2} naturally lowers the choke coils in series. Because of the relatively high cost of choke coils, it is more economical to use a filter resistor and either increase the D.C. supply voltage or adjust the circuit to operate satisfactorily at a reduced value of plate voltage.

The diode detector circuit shown in Fig. *4B* contains a practical example of the dual-condenser filter represented by Fig. *3C*. The path taken by the *rectified* signal current is through the diode tube, input coil *L,* filter resistor R_F, and diode load resistor R_L. R.F. current is kept out of the diode load by the filter combination made up of C_{F1}, R_F and C_{F2}. In some circuits you will find that C_{F2} is omitted, and the wire going from point *1* to the A.F. stage through blocking condenser C_B is surrounded by a grounded metal shield. This shield acts as a capacity to the chassis, and thus serves the double duty of substituting for condenser C_{F2} and shielding this lead from stray electrostatic and magnetic fields.

I have already pointed out that choke coils may be used in place of filter resistors. One important objection to the use of choke coils is the fact that their characteristics change greatly with the frequency. Wherever possible, non-inductive carbon or

C_{F3} and C_C. The cut-off frequency for this filter can be any value lower than the I.F. value but higher than the highest modulation signal frequency being handled. The signal current filter made up of C_{F3} and R_F in Fig. *5A* serves to keep signal currents in the plate signal circuit and to keep power pack ripple current out of the plate signal circuit.

An I.F. amplifier circuit using a pentode tube and two resistor-condenser signal current filters is shown in Fig. *5B*. You can readily identify condenser C_C as the by-pass condenser for

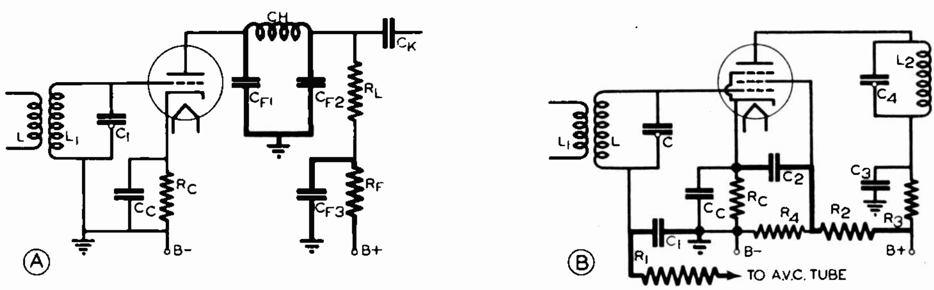

FIG. 5. Triode second detector circuit (*A*) and I.F. amplifier circuit (*B*) containing examples of signal current filters (shown in heavy lines).

metallized resistors are therefore used as filter resistors, particularly in high-fidelity audio amplifiers and in the preselector stages of all-wave superheterodyne receivers, for their effects are the same at any frequency.

The second detector circuit in Fig. *5A* is an example of a superheterodyne receiver stage where a pi or low-pass filter is used. The combination of C_{F1}, *CH* and C_{F2} forms a filter like that in Fig. *3C*, which definitely suppresses the I.F. signals while allowing direct current and low or audio frequency current to pass through. The desired modulation signal currents thus pass through load R_L and return to the cathode through by-pass condensers

automatic C bias resistor R_C; this condenser also provides a low-reactance path from ground to cathode for all signal currents. You will also recognize combination R_1-C_1 as the A.V.C. filter for this stage; this filter has a two-way action, providing a path to ground for R.F. grid currents (thus keeping them out of the A.V.C. system) and preventing the A.C. components of A.V.C. voltage from entering the grid circuit. Filter R_3-C_3 forces the A.C. plate current to go to the chassis and then through C_C to the cathode instead of entering the power pack. Resistors R_2 and R_4 serve primarily as a voltage divider which provides the screen grid with the correct portion of the supply voltage, but R_2 also serves with C_2 as a filter which prevents screen grid signal currents from flowing through the supply lead and the power pack to the cathode. C_2 provides a direct path from screen grid to cathode for these currents.

D.C. Blocking Condensers

When the plate circuit of one stage is to be coupled to the grid circuit of a following stage and both stages have common supply terminals, the coupling device must be of such a nature that it keeps D.C. supply current out of the grid circuit of the following stage. (This discussion does not apply to direct-coupled amplifiers.) If this precaution were not observed, the grid would become positively charged with respect to its cathode, and correct operation would not be secured. When radio or audio frequency transformers are used as plate loads, the signal is transferred from one stage to another by induction and the D.C. component of plate current can flow only in the primary of the transformer, effectively solving this problem. When resistors or choke coils are used as plate loads, however, special means must be used to prevent D.C. supply current from entering the following grid circuit.

A universally used solution to this coupling problem is that shown in Fig. *6A*, where coupling condenser C_B provides a low-reactance path for signal currents between the two stages and effectively blocks any flow of direct current. The currents flowing through each part in this circuit are indicated. You can readily see that if there were a D.C. conductive path for electrons from point *2* to point *1*, electrons starting from point *3* (which is at ground or B— potential) would pass through grid resistor R_{g2} to point *2*, and then to point *1* and through resistors R_P and R_F to the B+ terminal of the power pack, making point *2* positive with respect to ground (point *3*) and thereby placing a high positive bias on the grid of the following tube.

Quite often an external D.C. voltage is to be applied to a tube electrode which is already connected to ground by a D.C. conductive path. The R.F. amplifier circuit in Fig. *6B* is an example; oftentimes an A.V.C. voltage must be applied to the grid of the tube, yet because the rotor of the tuning condenser is premanently grounded to the chassis and at the same time connected to one side of low-resistance coil L_1, an A.V.C. voltage applied directly to the grid would be shorted to ground through L_1.

One solution to this problem appears in Fig. *6C*. The A.V.C. voltage is applied to the grid of the tube through an A.V.C. filter in the usual manner, with resistor R_g inserted as shown to prevent the A.V.C. circuit from shunting to ground (through A.V.C. filter condenser C_F) the R.F. signal voltages produced across tuning circuit L_1-C_1. The value of R_g may be several hundred-thousand ohms; since the grid of the tube is negative at all times, it draws no current, and any current-limiting effects of resistors in the grid circuit are unimportant. In addition, D.C. blocking condenser C_B is required to prevent shorting out of the A.V.C. voltages by coil L_1. This is known as the *shunt feed* method of applying an A.V.C. voltage, for the A.V.C. voltage acts in parallel or in shunt with the signal input voltage.

Another solution to this same problem, used when the coil can be disconnected from the chassis, is the *series feed* method of applying the A.V.C.

voltage, shown in Fig *6D*. The A.V.C. lead is connected to the lower end of coil, L_1, through resistor R_F of the A.V.C. filter. A.V.C. filter condenser C_F serves as a D.C. blocking condenser in preventing the A.V.C. voltage from being shorted to ground, and at the same time provides the required low-reactance path from the coil to ground for R.F. signals.

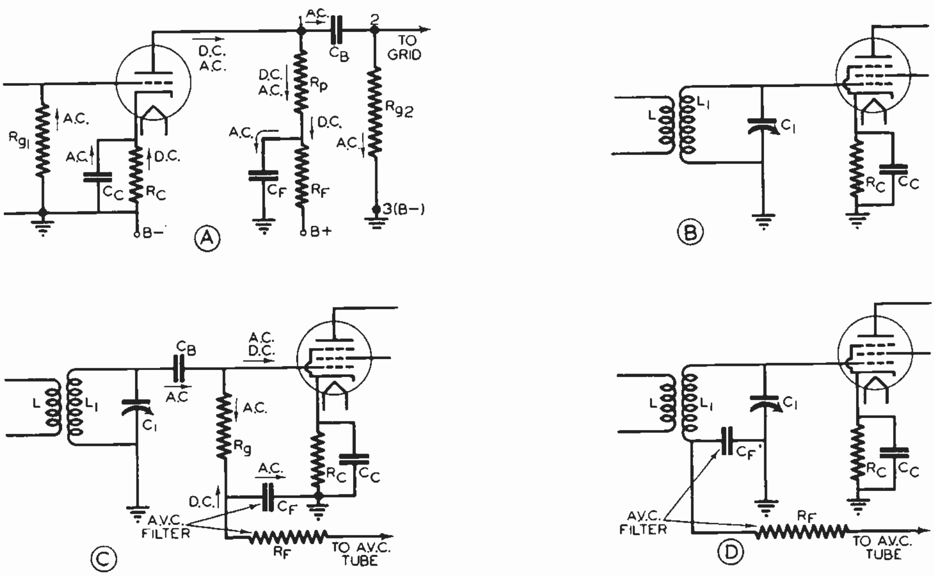

FIG. 6. Examples of circuits which require and use D.C. blocking condensers.

Importance of Proper Connections

The use of filter circuits to keep R.F., I.F. and A.F. currents out of the power supply is in itself no assurance that regeneration or degeneration effects will disappear. We still have to consider the problems of stray coupling between leads, common coupling between different circuits due to stray currents in the metal chassis, and common coupling between circuits due to stray currents in ganged variable condensers, for each of these defects can cause either regeneration or degeneration under certain conditions.

An engineer can sit down at a drawing board and, after making certain engineering calculations, design a radio receiver or an amplifier which has certain desired characteristics. It is quite another matter, however, to convert this design into an actual model which has these same characteristics. Regeneration and degeneration effects generally give the most trouble, making necessary considerable experimentation in order to determine the best locations for the various parts and connecting wires.

Long connecting wires from the grid to the grid input circuit, from the plate of a tube to the plate load, or from the screen grid electrode of a tube to its power supply terminal are to be avoided, for they can give trouble in the form of capacitive or inductive coupling between each other.

Quite often a receiver manufacturer will allow a certain amount of regeneration or degeneration to exist because it does not appear to be objectionable at the time, but will later be compelled to modify certain sections of the receiver because the undesired effects become too objectionable after the receiver has been in use for some time. This is why you will occasionally find receivers of the same model, but made at different times, with minor changes in connections and parts values. Furthermore, since Radiotricians are called upon to make these corrections on earlier receivers which have developed trouble, the practical importance of this problem of making proper connections is quite evident.

Proper Connections in a Single R.F. Stage. As a practical example, let us consider how connections should be made in a typical pentode R.F. amplifier stage, such as that represented by the schematic circuit diagram in Fig. *7A*. This diagram tells us that A.V.C. filter R_1-C_3 is used to keep A.F. signals out of the grid circuit, to delay the A.V.C. action, and to provide a low-reactance path from the grid circuit to the chassis for R.F. signals. By-pass condenser C_4 provides a low-reactance path for signal currents around C bias resistor R_C, while screen grid filter R_2-C_5 keeps screen grid signal current out of the power supply; plate supply filter R_3-C_6 does the same thing for plate circuit signal currents. This diagram does not show, however, how these signal currents actually travel between points *1*, *2* and *3* through the chassis to point *4*. The paths taken by these currents are quite important, for degeneration or regeneration may occur if the signals from the screen grid, plate and control grid get a chance to produce appreciable voltages and mix before they reach the cathode. (Although the signals mix in passing through C_4, the reactance of this condenser is so low that the undesirable voltages produce negligible regeneration or degeneration effects.)

The production design engineer, who must decide beforehand the best location for each connecting lead and for each part, might redraw the schematic circuit diagram of Fig. *7A* in the manner shown in Fig. *7B* in order to indicate that points *1*, *2* and *3* be connected directly to point *4*. Doing this prevents the screen grid, control grid and plate signal currents from wandering through the chassis and mixing together before reaching point *4*. All by-pass condensers in a single R.F. stage should be connected to a common point in the stage in order to prevent undesirable direct coupling between the different circuits in the stage.

The arrangement of connections shown in Fig. *7B* may insure freedom from troubles due to improper direct connections, but we can still have trouble due to capacitive or inductive coupling between leads. Grid and plate leads in an R.F. stage must be kept as short and as far apart as possible in order to prevent capacitive and inductive feedback of signals from the plate circuit to the grid circuit. Suppose that, through faulty chassis layout, plate lead *z* is placed close to control grid lead *x;* this would allow signal feedback from the plate circuit to the grid circuit, causing either regeneration or degeneration. Keeping the input and output leads in their proper places, as far away from each other as possible, is a highly important duty of the radio apparatus manufacturer; since the exact positions of connecting wires are seldom shown in radio receiver service manuals, it is essential that you be familiar with approved methods of making actual connections.

Actual chassis connections for the pentode R.F. amplifier stage of Fig. 7A

point; in fact, one is above the chassis and the other is below.

Effects of Stray Chassis Currents. Suppose that instead of making connections as shown in Fig. 7C, points *1*, *3* and *4* were simply connected to the nearest convenient points on the chassis, as indicated in Fig. 7D. Now we would expect the grid circuit signal

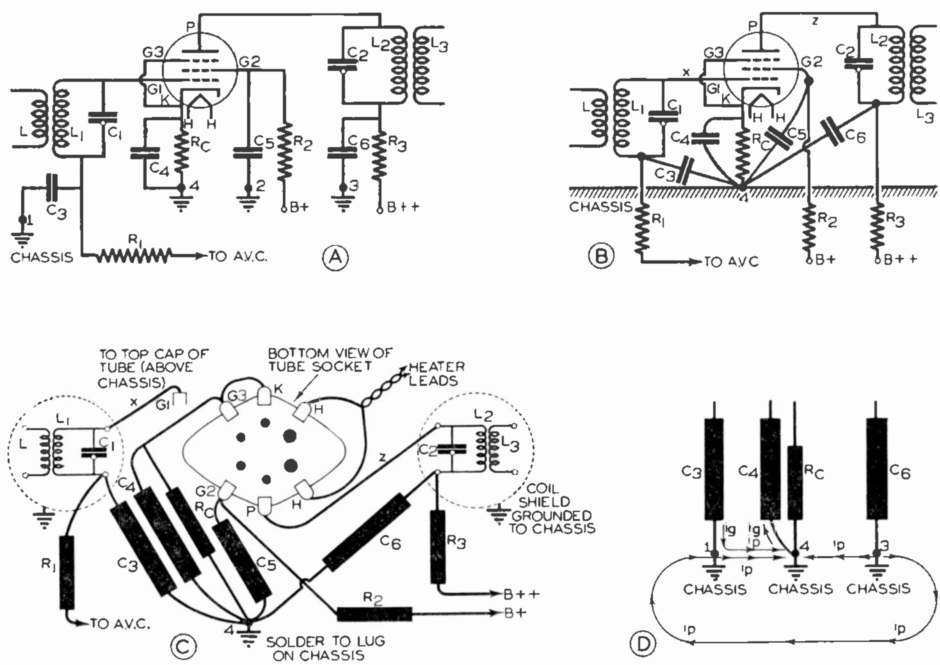

Fig. 7. An ordinary pentode I.F. amplifier circuit appears in its simplest form in the schematic diagram at *A*. Diagram *B* shows actual connections of by-pass condensers to a common point, but still in schematic form. Diagram *C* shows actual connections of parts on the chassis, while *D* shows how improper grounding of by-pass condensers to the chassis can result in interfering currents.

are shown in Fig. 7C, as they would appear when looking at the bottom of the chassis. The input and output coils with their trimmer condensers are, of course, on the top of the chassis, as also is the connection from the input tuned circuit to the top cap of the tube. Take particular notice of the fact that the control grid lead *x* and plate lead *z* do not run close to each other at any

current i_g to flow from point *1* through the chassis to point *4*, and A.C. plate current i_p to flow from point *3* through the chassis to point *4*. This is what actually takes place, but the A.C. plate current, which is many times greater than the grid current, spreads out over a wide path through the chassis in traveling from point *3* to point *4*. One possible curved path is indicated in

Fig. *7D;* notice that now some of the A.C. plate current i_p is flowing over the same path as the grid circuit signal current i_g. The A.C. plate current which takes the curved path causes an additional A.C. voltage drop between points *1* and *4* in the grid circuit, and this may cause undesirable regeneration or degeneration, depending upon the phase relationship between the signal currents involved.

If the grid by-pass condenser in a following stage is connected by mistake to a convenient point on the chassis, this signal current can likewise wander through the chassis, with one of its many possible paths being from point *1* to point *4* in Fig. *7D*. This current can likewise cause undesirable regeneration or degeneration, depending upon the phase relationships of the currents.

Courtesy Solar Mfg. Corp.

Although you ordinarily think of power pack filter circuits whenever electrolytic condensers are mentioned, here is an electrolytic condenser which is widely used to keep audio signal currents in correct paths. It is a low-voltage, high-capacity tubular dry electrolytic, and is used to by-pass a.f. currents around cathode resistors in the a.f. amplifier stages of radio receivers.

If it is desirable from a production viewpoint to connect points *1* and *3* directly to the chassis, as indicated in Fig. *7D*, a length of heavy copper wire running from point *1* to point *4* and then to point *3* will provide a single path for all these A.C. currents, keeping them from straying through the chassis. Since this heavy wire will have low resistance, the current will take this path in preference to the high-resistance path through the metal chassis. You will occasionally find this practice followed in radio receivers; a single heavy bus wire (copper wire having a square cross-section) is run from point *1* to point *4* to point *3* of one tube to point *1* to point *4* to point *3* of the following tube and in turn to each following tube. The connection must be made in this logical order if interference between currents is to be prevented.

Stray Currents in Ganged Variable Condensers. The ganged variable condenser in a sensitive modern all-wave receiver will generally have three tuning sections, with the rotors grounded (theoretically, at least) to the chassis through the frame of the condenser, as shown schematically in Fig. *8A*. There will be a connection from each stator section to the grid of a tube and to a tuning coil.

With the stator sections so close to each other on the condenser unit, you can readily see how signals in one section might affect an adjacent stator section, causing feed-back effects. To eliminate this possibility, shielding plates are usually placed between the stator sections, these plates being grounded to the frame of the condenser and therefore to the chassis. (Electrostatic shielding of this type will be taken up later in this lesson.)

The average technician fails to realize that the current in each resonant circuit must flow through the rotor shaft in order to get to the condenser frame and then to the chassis. The construction of the rotor plate assembly is such that this path has appreciable resistance, and a certain amount of regeneration or degeneration occurs when different signal currents flow through the same section of the rotor.

In the circuit of Fig. *8B*, for example, signal currents through condenser section C_2 can either flow through the apparent rotor resistance R_2 of this condenser and then through rotor resistance R_3 of condenser C_3 to ground, or can simply flow through the rotor resistance R_1 of condenser C_1 to ground; in either case there will be interference between signal currents. In order to eliminate this trouble, it is necessary to provide low-resistance paths to ground for the signal currents of each making the stray currents appreciable in relation to desired signal currents. Rather elaborate precautions must often be taken to eliminate these stray currents; a study of the gang tuning condensers in a few modern all-wave receivers will reveal the exact manner in which low-resistance paths to ground are provided for each rotor section.

Shields for Electric Fields

Having seen how interfering currents can get into circuits by actually

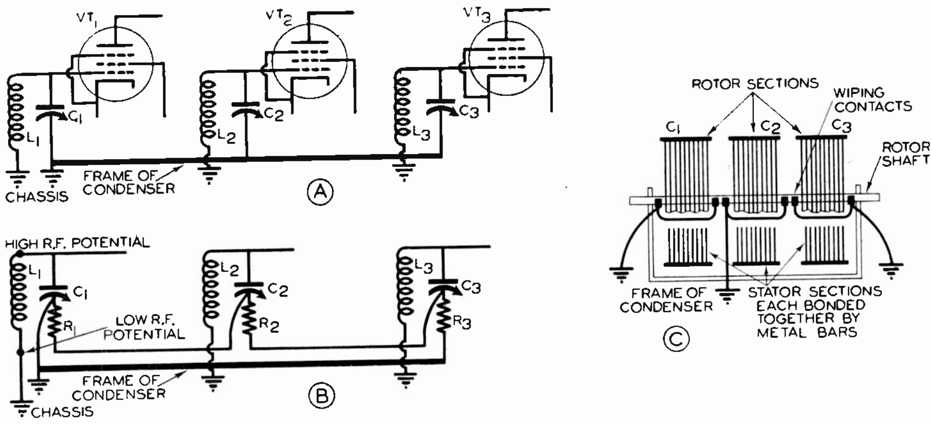

Fig. 8. Connections for a typical three-section ganged variable condenser appear at *A*. The effective locations of rotor shaft resistances are shown at *B* (curved arrows represent rotors), while one method used to offset the effects of rotor resistance and eliminate stray currents is shown at *C*. R_1, R_2 and R_3 are not actual resistors, but represent resistances existing in each rotor section because of its mechanical construction.

rotor section. Thus you will often find wiping contacts on each side of a rotor section, with each pair of contacts connected together and also connected directly to the chassis, as shown in Fig. *8C*. A better connection is from the rotor wiping contacts directly to the low or grounded R.F. terminal of the tuning coil associated with a rotor section.

Since the currents flowing in the rotor sections are resonant stepped-up currents, they may often be quite large, flowing over undesired conductive paths, we are ready to consider how interfering currents can invade a circuit even when there are no direct wire connections. When the medium by which the interfering signals enter is an electric field, we call the action *electrostatic induction*, and when a magnetic field is to blame, we call it *electromagnetic induction*. We will consider electric fields first.

How Electric Fields Affect Grid Circuits. The grid or grid lead of a vacuum tube is particularly susceptible to stray electric fields, for extremely small induced A.C. grid voltages can produce strong A.C. plate currents. The action is as follows: When the grid lead of a vacuum tube is located in the electric field which surrounds a highly charged object, variations in the electric charge (potential) of the object will cause the electric field to vary correspondingly, and this varying electric field will influence the free electrons in the grid circuit. When the object is negatively charged, it will repel the grid electrons; when the object is positively charged, it will attract the grid electrons (like charges repel, and unlike charges attract). If the object is being charged by an A.C. potential, the free electrons in the grid circuit will move back and forth to produce an alternating current of the same frequency.

Sources of Electric Fields. The plate of a vacuum tube is one object which can have a varying potential and produce an electric field which affects other circuits. The electric field associated with a power transformer or audio transformer can also induce currents in nearby tubes and in conductors. The stator plates of one section of a variable condenser can produce varying electric fields which induce interfering currents in another stator section or in connecting leads. There will also be an interaction of electric fields when plate leads run near grid leads. These are just a few typical examples of how interfering currents are produced by stray electric fields. These interfering currents can result in regeneration, in degeneration or even in undesirable modulation of an R.F. signal, depending upon circuit conditions. Excessive regeneration, which results in a hissing noise in the loudspeaker or even in squeals due to oscillation, is easily recognized as being due to undesired coupling between circuits. Likewise, a 60 or 120 cycle hum modulation can be recognized and often traced to undesirable coupling between a power supply part and some signal circuit.

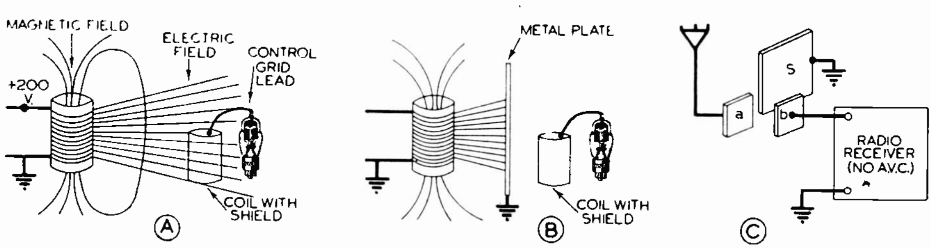

FIG. 9. These diagrams show how an electric field can affect electrons in the grid circuit of a tube, and how a metal plate serves as a shield for electric fields or electric lines of force.

Shielding of Coils. The electric field around a coil which is carrying a current can be represented as shown in Fig. *9A*. When this electric field passes near the control grid lead of a vacuum tube, the electrons in this lead will move back and forth in accordance with variations in the current through the coil, and consequently an interfering current will be induced in the control grid lead.

If a metal plate is inserted between the coil and the exposed grid lead of the tube, as indicated in Fig. *9B*, this metal plate will serve as a shield which prevents the electric fields (lines of force) from going any farther. Only materials which are good conductors of electricity will serve as shields for electric fields; insulating materials have little or no blocking effect upon an electric field.

The effectiveness of a shield in suppressing an electric field is easily demonstrated if you have access to a radio receiver which does not have A.V.C. Couple the receiver to the antenna system in the manner shown in Fig. *9C*, so that the only connection to the antenna is by capacity coupling between metal plates *a* and *b*. With plate *a* removed, tune the receiver to a station which can just barely be heard. Now as you bring plate *a* near plate *b*, the volume will increase. Inserting a third metal plate *S*, larger in size, between plates *a* and *b* without touching them will have no effect on volume, for plate *S* merely relays the electric charges from plate *a* to plate *b*. When plate *S* is grounded, however, the electric field set up by plate *a* is grounded through *S*, and the volume will drop to the point where it is just barely audible. *This little demonstration shows clearly the importance of grounding an electric shield* in radio apparatus.

Practical Data on Electric Shields. The use of metal plates as shields between interfering parts is an old idea in radio, and this practice is followed even today in isolating the sections of many ganged variable condensers. Metal plates are entirely impractical, however, for shielding other parts in a receiver, as an electric field radiates in all directions and can affect many parts simultaneously.

The solution to the problem of suppressing electric fields lies in surrounding with a metal case the coil or other part which produces the field in order to prevent spreading of the field. Parts which may be affected by electric fields are surrounded with metal shields in much the same manner. Thus, grid leads are surrounded by flexible metal sleeves (with insulation between the sleeve and the grid wire to prevent a short circuit), metal shields are used over glass tubes, or tubes which have all-metal envelopes are used to overcome the effects of electric fields.

Typical metallic shields which have been found effective in preventing interference by electric fields are shown in Fig. *10*. The metal plates used between sections of a ganged variable

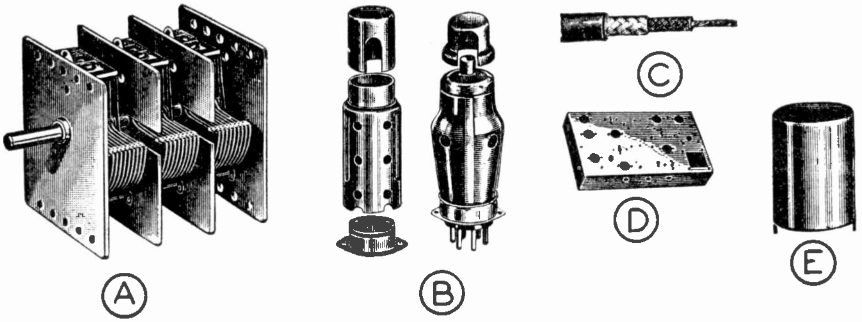

FIG. 10. Examples of electric shields used for radio apparatus.

condenser are illustrated at *A*. Two types of metal shields for glass tubes appear at *B*. At *C* is shown a shielded wire; an ordinary insulated wire is covered by a flexible metallic braid or metallic loom, and the metal is in turn covered by a layer of insulation. Sometimes this outer layer of insulation is omitted, and sometimes there may be two or more insulated wires inside the metallic loom.

In addition to supporting the various parts, the chassis of a radio receiver also serves as a shield which is effective in preventing interference between parts above the chassis and those below the chassis; a typical chassis made of heavy gauge sheet metal is shown at *D*.

An example of an aluminum shield used for R.F. coils and R.F. transformers appears at *E*. In all cases it is essential that the shield be grounded to the metal chassis of the receiver at several points.

Shielding is so important to the operation of a high-gain, high-quality radio receiver that totally exposed parts (except resistors) are becoming quite rare. Paper condensers are automatically shielded if that lead marked "outer foil," "grounded end," or "ground" is connected to the chassis; a great many types of electrolytic condensers are made with metal shields, these being automatically grounded by bolting the unit to the chassis. The envelopes of all-metal tubes are likewise grounded automatically by inserting the tube in its socket, for one prong of the tube is always connected to the metal envelope, and the socket terminal for this prong is usually grounded.

Electromagnetic Shields

Stray magnetic fields, which are produced by coils or wires carrying varying electric currents, can induce interfering voltages in other coils or wires. These induced voltages are especially troublesome in grid circuits.

Two distinct electromagnetic shielding problems arise in the construction of radio equipment: *1*, the elimination of interference due to parts which carry low-frequency power supply currents or A.F. signal currents; *2*, the elimination of interference produced by parts which carry R.F. or I.F. currents.

Shields for Low-Frequency Magnetic Fields. In the case of magnetic fields which vary at a low frequency, the solution is simple. The part in question, usually an A.F. or power line frequency choke or transformer, is placed in an iron or steel housing which is so designed that leakage magnetic fields will flow through this housing and return to their correct paths instead of straying through the receiver and making trouble. Surrounding a coil with iron or steel lessens the temptation for lines of force to take high-opposition paths through air; iron or steel housings or shields are therefore widely used for low frequency coils and transformers.

Shields for High-Frequency Magnetic Fields. At frequencies above about 50 kc., it is not necessary to use an iron or steel housing for shielding purposes; in fact, *materials with good conductivity,* such as aluminum and copper will give better shielding effects than poor-conductivity iron and steel.

You can perform a simple experiment which will show how R.F. magnetic fields are affected by shields. Two coils, L_1 and L_2, are connected as shown in Fig. *11*. Any air-core coils will do; the numbers of turns are not important; Coil L_2 is connected to the antenna and ground terminals of a radio receiver which does not have A.V.C. and which is tuned to a strong local station. Coil L_1 is connected to the antenna and ground, as indicated. Antenna current flowing through L_1 sets up a varying R.F. magnetic field which induces an R.F. voltage in coil L_2, and signals are therefore transferred to the receiver input.

Now insert between coils L_1 and L_2 a reasonably large copper, brass or aluminum plate, or place an ordinary aluminum cooking pot or frying pan between the two coils. You will find that this prevents transfer of the magnetic field from one coil to the other, and therefore prevents the local station from being heard. If this metal plate is grounded, it will also act as a shield for electric fields.

The action of the metal shield in Fig. *11* can be explained as follows: In attempting to pass through the conductive metal plate, the varying magnetic flux sets up very small circulating currents in the metal plate. You can consider this plate as being made up of many small circular metal rings, each of which is a complete closed circuit for electrons. The varying magnetic flux induces a voltage in each of these closed circuits in such a manner that the currents flowing through the circuits produce magnetic fields to oppose the original magnetic fields; this is simply Lenz' Law, with which you are already familiar. The opposing magnetic flux repels the original flux, sending it back and thus preventing the original flux from penetrating the metal shield. The circulating currents produced in the metal shields are called *eddy currents*. Of course, a certain amount of power is wasted when eddy currents flow in a conductor, but if the shield is not placed too close to the strongest part of the magnetic field, the loss will be negligible.

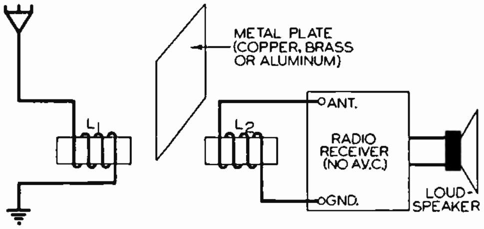

FIG. 11. In this experiment, a conductive metal plate inserted between the two coils prevents R.F. signals from reaching the receiver.

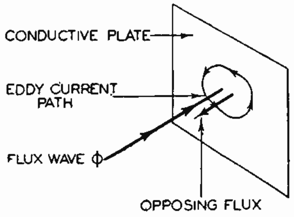

FIG. 12. How eddy currents in a metal plate can set up an opposing flux.

High-grade R.F. and I.F. coils are usually placed in aluminum or copper cans, but copper-plated steel housings are also used as shields for coils. Aluminum and copper are good conductors of electricity, and therefore allow larger eddy currents to flow; these currents in turn produce stronger opposing magnetic fields to keep the original flux from passing out of the can. By placing the shield a reasonable distance away from the coil (at least one-half the diameter of the coil), little loss of signal power is incurred. Since the shield in effect acts as a larger number of short-circuited secondary windings on the coil, the main flux of the coil is reduced and the inductance of a shielded coil is therefore lower than that of an unshielded coil. The relationship of the original flux, the eddy current rings and the opposing flux are indicated in Fig. *12*. Typical shielded coils are illustrated in Fig. *13*.

Positioning of Parts for Minimum Interference

When shielding of parts is impractical or is not completely effective, interfering effects can be kept at a minimum by proper positioning of those parts and wires which are most affected. A review of the nature of magnetic fields and their voltage-inducing characteristics will reveal the best positions for various parts and wires.

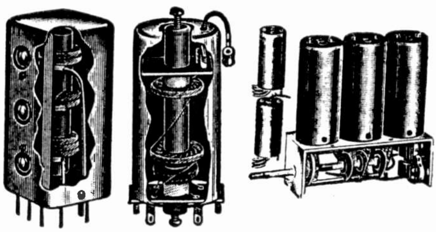

FIG. 13. Examples of shielded R. F. coils.

The nature of the magnetic field in the vicinity of a coil is indicated in Fig. *14*. For purposes of simplicity, an iron-core choke coil having open core ends was chosen. When a wire which is a part of a closed electrical circuit is placed in this magnetic field in such a way that the field cuts across the wire (or loops through the closed circuit formed by the wire), as is the case for wire *a* in Fig. *14*, a voltage will be induced in the wire. When the wire is placed in position *b* (Fig. *14*), the magnetic field will be parallel to the wire instead of cutting it or linking through the closed circuit, and no voltage will be induced. Thus you can see that for minimum interference, a wire should be parallel to the magnetic lines of force in its vicinity.

When a coil is placed in the magnetic field produced by the iron-core choke in Fig. *14*, the relative positions of the two coils will determine whether or not a voltage is induced. For example, coil *A* in Fig. *14* is placed with its axis parallel to that of the choke coil, and hence the magnetic field links through coil *A*, producing an induced voltage. Observe that the magnetic lines of force which pass through coil *A* are parallel to the axis of the coil. The axis of coil *B*, however, is at right angles to the mag-

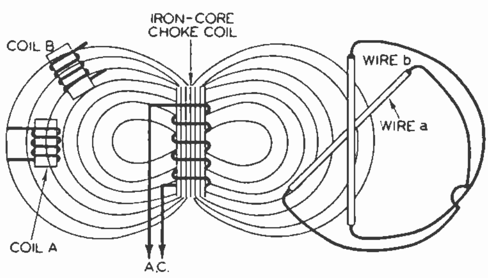

FIG. 14. The position of a coil or wire in a magnetic field determines whether or not a voltage will be induced.

netic lines of force; in this case no flux flows through the turns of the coil and consequently there is no voltage induced.

Positioning of Wires. When it is necessary to place two wires close together, and one of the wires carries a varying current which can produce a varying magnetic field and in turn induce an interfering current in the other wire, the two wires should be placed at right angles to each other in the manner shown in Fig. *15A*. Doing this makes the magnetic lines of force produced by wire x cut across wire y twice in opposite directions, with the result that the two voltages induced in y cancel each other and have no effect upon the circuit of which wire y is a part. For example, one line of force produced by wire x may cut wire y at point *1* at a certain instant, producing in y an induced voltage having a certain polarity, but at the same instant this line of force will be cutting wire y in the opposite direction at point *2*, producing a voltage of opposite polarity at *2*. Placing wires at right angles to each other in this way also reduces interaction of electric fields.

Positioning of Coils. Coils and transformers should be positioned in such a way that their main magnetic field paths are at right angles to each other, as indicated in Figs. *15B* and *15C*, and should be as far apart as possible from circuits which are most affected. This rule is, of course, only approximate, for the fields produced by these devices may be considerably distorted. Final positions for minimum interaction can be determined by experimentation; in the case of audio and power transformers, this can be done by feeding an A.F. or power line voltage to one coil and connecting a pair of headphones either directly across the other coil or through a separate audio amplifier which boosts the voltage and gives more positive results. Adjust the position of either transformer until minimum hum is heard in the headphones. In actual radio receivers you can, of course, adjust the position of the transformer until minimum hum is heard.

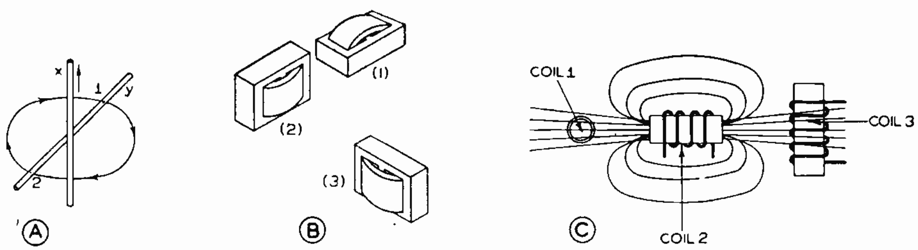

Fig. 15. Interfering currents due to electromagnetic induction are a minimum when wires, iron-core devices and coils are positioned at right angles to each other, as shown here.

Twisting of Power Supply Leads

Having seen how the low-frequency magnetic fields which are produced by power transformers and power pack filter chokes can be prevented from straying, we are ready to consider how the connecting leads to these parts can be prevented from setting up interfering magnetic fields. The power line leads which pass through the OFF-ON power switch to the power transformer are one possible source of trouble, and the low voltage, high current A.C. leads to the filaments of all tubes are another common cause of trouble. A study of the magnetic fields produced when two wires are close together will show how these magnetic fields can be suppressed.

Figure *16A* shows two parallel wires, W_1 and W_2. Alternating current flows out over one wire and back to its source over the other, but at any instant of

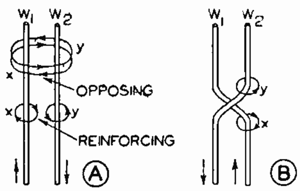

Fig. 16. Magnetic fields produced by two wires which carry the same current in opposite directions.

time the electron flow is in opposite directions as indicated. The magnetic lines of force produced by these currents have circular loops as indicated, with loops x produced by W_1 and loops y produced by W_2.

Some of the magnetic loops will enclose both wires; notice that when this occurs, the magnetic lines of force will be in opposite directions and will cancel. Some of the magnetic loops will surround only their own wires, and in these cases the magnetic lines of force produced between the wires will all be in the same direction, and will reenforce each other.

Separating the wires allows more of these magnetic lines of force to pass between the wires and reenforce each other, and consequently the external magnetic field in the vicinity of the two wires becomes stronger. Placing the wires closer together, on the other hand, forces more of the magnetic lines of force to encircle both wires and cancel each other, thus reducing the strength of the external field. Twin conducting leads should therefore be very close together if interfering magnetic fields are to be reduced to a minimum.

Even greater reduction in the external magnetic field produced by two current-carrying wires is possible when the wires are twisted together. The wires must, of course, be insulated in this case in order to prevent shorting them together. Figure *16B* shows how twisting or transposing leads W_1, and W_2 makes the individual flux paths x and y take opposite directions. In the vicinity of the wires these lines of force do not entirely interlock and cancel, but at a distance from the leads they actually do cancel and greatly reduce the external magnetic fields.

The more twists or transpositions there are in a given distance for two wires, the more reduction there is in external or stray magnetic fields. Incidentally, this reduction in the external magnetic field actually reduces the inductance of the conductors (any two wires which are close to each other and in the same circuit have a certain amount of inductance due to the fact that they form a single-turn coil).

Now you can understand why filament leads in radio apparatus are often twisted together or run very close together, and you can likewise understand why the power line leads to the power transformer primary are also twisted or placed close together. In some receivers, particularly those having low A.C. filament currents, manufacturers have found it unnecessary to twist filament wires or run them close together; elaborate precautions are needed only when trouble is actually encountered.

You will usually find that the power transformer is located at a point on the chassis very close to the place where the power line cord enters. The power switch, however, is usually located at the front of the chassis; the two leads running to it are usually quite long, and hence should be twisted together for minimum magnetic effects.

There is still a certain amount of leakage magnetic flux even when leads are twisted, and therefore filament and power supply leads should be kept as far as possible from the grid leads in the first stages of a receiver or amplifier. Even extremely weak interfering signals entering these stages may become appreciably strong after amplification by the entire system.

Center-Tapped Filament Connections

The importance of preventing alternating current in filament leads from affecting signal circuits by magnetic induction has already been pointed out; it is just as important to prevent alternating current in the filament itself from affecting the signal circuits and to prevent filament leads from providing conductive paths for signal currents.

With the heater-type tubes which are so widely used in radio receivers at the present time, there is no direct connection between the filament and the cathode; if there is no leakage between these two elements, there will be no chance for signal currents to get to the filament circuit and for power line A.C. to get out of the filament circuit into signal circuits.

In the audio stages of radio receivers (particularly the power stages) and in the R.F. stages of radio transmitters, filament type tubes are still widely used; here the filament serves also as cathode, and hence preventive measures must be taken.

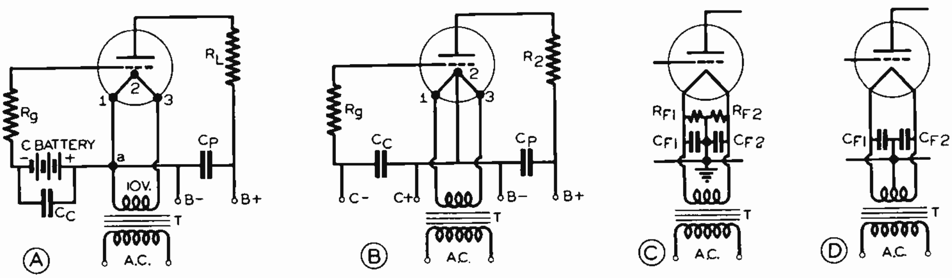

FIG. 17. When a filament type tube is being supplied with an A.C. filament voltage, as at *A*, the method shown at *B*, *C* or *D* is used to prevent the A.C. filament voltage from affecting the grid or plate circuits.

Let us first see what happens when we connect a filament-type tube as indicated in Fig. *17A*. Consider a simple circuit like that in Fig. *17A*, where a C bias battery provides the normal negative bias voltage for the grid of the tube and the filament is fed with an A.C. voltage of, let us say, 10 volts. The grid and plate return leads for signal currents go to point *a* on one filament lead. Point *2*, at the electrical center of the tube filament, can be considered as the cathode of the tube, even though all points on the filament are emitting electrons. (For each point on the filament which is more negative than point *2* at any instant, there will be another point which is an equal amount more positive than point *2*, regardless of the direction of current flow; as a result, the average of the voltage values between the grid and each point on the filament will equal the voltage between the grid and point *2*, and likewise the average of all filament-to-plate voltages will equal the voltage between the plate and point *2*.) The plate current will, therefore, be determined by the potential between point *2* and the grid (the grid bias voltage) and by the potential between point *2* and the plate (the D.C. plate voltage).

We can readily see, now, that the effective grid voltage will be the C battery voltage plus the voltage drop between points *1* and *2* on the filament. With 10 volts A.C. applied between points *1* and *3*, there will be a 5 volt A.C. drop between points *1* and *2*. This voltage drop will act in series with the C battery voltage insofar as the grid is concerned, making the grid bias voltage alternately 5 volts greater and 5 volts less than the battery voltage. Naturally this A.C. voltage of 5 volts applied to the grid will cause the plate current to vary correspondingly. The A.C. voltage drop will likewise act in series with the B battery voltage in determining the effective plate voltage, but the variations in voltage will obviously be more serious in the grid circuit because of the high amplification of the tube. Clearly the arrangement in Fig. *17A* will result in excessive A.C. hum interference.

A theoretical solution to this problem is indicated in Fig. *17B*, where the A.C. filament voltage is eliminated from the signal circuits simply by connecting the plate and grid return leads directly to point *2* by means of a tap on the filament. Since few if any tube filaments are made with center-tap connections, this solution cannot be utilized in practice.

The practical solutions to this problem, indicated in Figs. *17C* and *17D*, involve the use of external electrical mid-taps between the two filament leads. These mid-taps can be provided by a center-tapped resistor, as in Fig. *17C*, or by a center-tapped filament winding, as in Fig. *17D*. Often the mid-tap on the resistor is made variable, so it can be adjusted to compensate for unbalanced filaments and other conditions. When filament-type tubes are used in radio frequency amplifiers, by-pass condensers are generally connected between the mid-tap and each filament lead to provide low-reactance paths to either filament terminal of the tube for signal currents; in the case of Fig. *17D*, these condensers also serve to prevent signal currents from taking the path through the filament winding of the power transformer.

Analysis of Signal Current Circuits in a Typical Radio Receiver

The complete schematic circuit diagram of a typical 5-tube superheterodyne receiver is shown in Fig. *18* just as you might find it in the service manual for the set. We will study this diagram in detail, first tracing the paths of signal currents, then locating and identifying the various extra parts used by the designer to keep signal currents in their correct paths. Having done this, we will analyze the chassis layout of the receiver to see how the effects of stray electric and magnetic fields are minimized by proper placement of parts. This analysis will not only serve to summarize for you the many practical facts covered in this lesson, but will also give you additional experience in reading circuit diagrams.

A practical radio man is able to read a circuit diagram like that in Fig. *18* almost at a glance simply because he has learned to consider only the important fundamental signal circuit parts, neglecting the various resistors and condensers which keep signal currents in their correct paths, and neglecting the power supply leads. In Fig. *19* are shown only those parts which serve to identify the various stages of this receiver circuit; we will study this at first, in preference to the complete diagram in Fig. *18*, for you are not as yet expected to be able to eliminate the less-important parts mentally.

We start at the upper left in Fig. *19*, since the upper part of a radio circuit diagram is invariably arranged to read from left to right. The R.F. signals picked up by the antenna are transferred to a grid of the first tube by T_1, which we recognize as a tuned-secondary antenna transformer. The first tube has five grids and is therefore a pentagrid converter serving as mixer, first detector and oscilllator. The first two grids of the tube act with parts C_3, L_3 and L_4 as an oscillating circuit which produces the desired local R.F. carrier to mix with the incoming R.F. signal and produce in the plate circuit of this 6A7 tube the desired I.F. signal.

Adjustable condensers C_6 and C_8 identify T_3 as an I.F. transformer which passes on this I. F. signal to the 6D6 first I.F. tube for amplification, while I.F. transformer T_4 transfers the amplified I.F. signal to the diode section of the type 75 tube. Here you will recognize the conventional second detector-A.V.C. arrangement, with diode

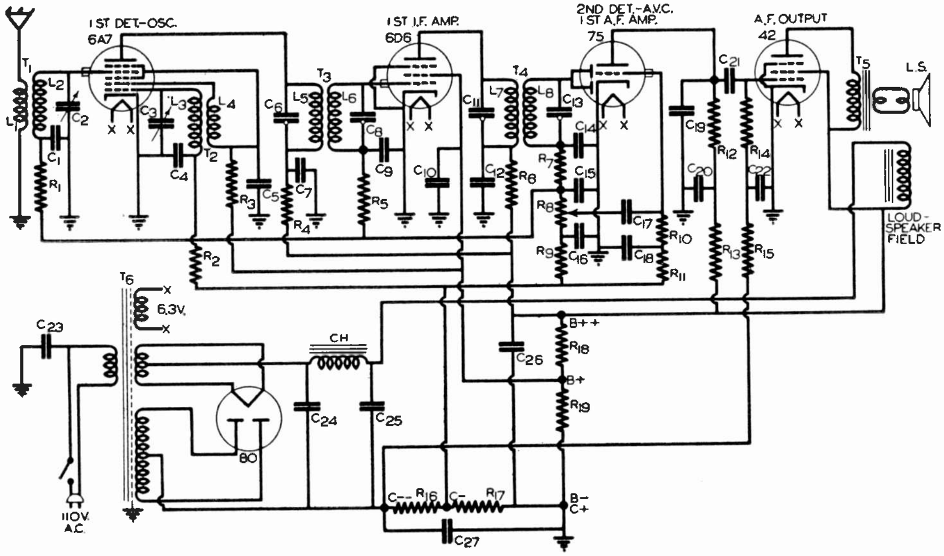

Fig. 18. Complete schematic circuit diagram of a representative 5-tube superheterodyne receiver. This circuit is presented here only to show circuit functions and illustrate the filtering and by-passing methods described in this book; it is not intended for constructional purposes, and does not represent any one particular manufactured receiver.

current developing across the detector load the desired A.F. component and a D.C. component of voltage for A.V.C. purposes. The first detector and the I.F. amplifier are A.V.C.-controlled for their control grid leads do not return directly to their respective cathodes.

The A.F. signal is fed through coupling condenser C_{17} to the grid of the triode section of the 75 tube, which consequently acts as an A.F. amplifier stage. The value of the A.F. voltage which is fed to this first A.F. stage is controlled by the setting of manual volume control potentiometer R_8. The amplified A.F. signal is transferred to the type 42 output tube through resistance—capacitance coupling, and the A.F. output of this tube is fed to the voice coil of the dynamic loudspeaker through output transformer T_5.

D.C. voltages for the various tube electrodes are supplied by the power pack, made up of power transformer T_6, a type 80 full-wave rectifier tube, a filter system containing C_{24}, filter choke *CH*, C_{25}, the loudspeaker field (which serves also as a filter choke) and C_{26}. Voltage divider resistors R_{16}, R_{17}, R_{18} and R_{19} then provide the required values of B and C voltages, with C_{27} providing additional filtering for the C voltages.

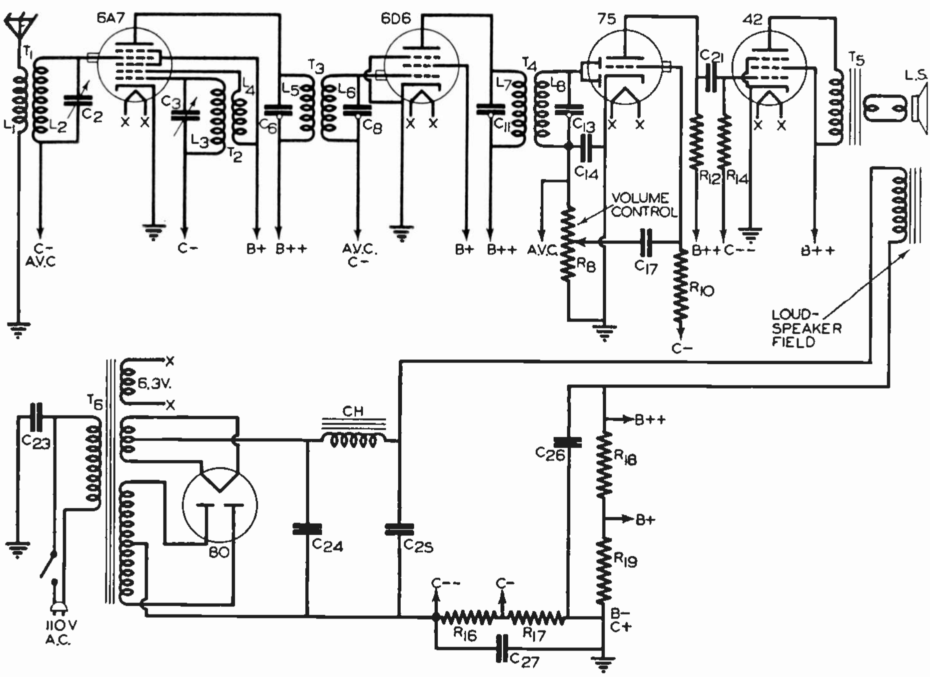

FIG. 19. Simplified version of the 5-tube superheterodyne receiver circuit shown in Fig. *18*.

Now that we are familiar with the general function of each stage in our receiver circuit, we can return to Fig. *18* and try our skill at identifying the various by-pass condensers and signal current filters which must be added to the basic circuit of Fig. *19* in order to secure satisfactory performance. We see immediately that C_1 and R_1 act as the A.V.C. filter for the first detector, for R_1 connects to a point in the load circuit of the diode second detector. C_1 also serves to provide a path to ground and cathode for grid circuit R.F. signals, and to prevent shorting to ground of the D.C. A.V.C. voltage.

Next we come to the R_2-C_4 combination. Since R_2 connects to the C— point of the power pack voltage divider, we know this is not an A.V.C. filter; it is therefore a simple resistor-condenser signal current filter, which keeps oscillator R.F. signal out of the power pack. C_4 also permits application of the C bias voltage to the grid without interrupting the continuity of the oscillator tank circuit C_3-L_3 for R.F. signals.

R_3-C_5 is likewise a signal current filter, serving to keep screen grid (grids 3 and 5) and oscillator plate (grid 2) R.F. currents out of the power pack and at the same time by-pass these signal currents to the cathode of the 6A7 tube.

R_4-C_7 is a signal current filter which by-passes plate signal currents of the 6A7 tube to its cathode and at the same time keeps these currents out of the power pack.

R_5-C_9 are readily recognized as another A.V.C. filter once you trace connections from R_5 to the second detector.

C_{10} is clearly the screen grid by-pass condenser for the first I.F. amplifier.

R_6-C_{12} form a signal current filter which by-passes plate signal currents of the first I.F. tube to cathode and keeps them out of the power pack.

Dual-condenser filter combination C_{14}-R_7-C_{15} serves to keep R.F. current out of diode detector load R_8 by providing low-reactance paths to cathode for this current. C_{16} and R_9 together serve as a signal current filter which permits application of normal C bias (developed across R_{17}) to the 6A7 and 6D6 A.V.C.-controlled tubes while preventing power pack hum currents from reaching these tubes and at the same time keeping signal currents out of the power pack.

C_{17} is simply an A.F. coupling condenser and D.C. blocking condenser. R_{11} and C_{18} act as a signal current filter in providing a return path to cathode for A.F. grid currents of the first A.F. amplifier, keeping these currents out of the C bias supply circuit, and also serve to keep power pack ripple currents out of signal circuits. R_{10} provides a conductive path for the D.C. bias voltage, since it is high in ohmic value, the entire A.F. voltage fed through C_{17} by potentiometer R_8 is developed across it.

C_{19} is an R.F. by-pass condenser which shunts to ground any R.F. currents which may reach the plate of the type 75 tube. R_{12} is the load resistor for this tube, with signal current filter R_{13}-C_{20} providing a path to ground and the cathode of the 75 tube for A.F. currents after they leave the load, thereby keeping these currents out of the power pack; R_{13} and C_{20} also prevent power pack ripple currents from entering the plate circuit.

C_{21} is a D.C. blocking and A.F. coupling condenser, while R_{15} and C_{22} act as a signal current filter for the grid of the type 42 output tube. R_{14} is a grid resistor which permits application of the bias voltage to the grid.

Filament current for the four signal circuit tubes is provided by a separate winding (marked XX) on the power transformer. Since heater-type tubes are used, there is no electrical connection between filament and signal circuits, and no filter or by-pass condensers are required. The filament leads will, of course, be twisted or run close together under the chassis to lessen their magnetic effects on adjacent wires and parts. Notice the dotted line in the core of power transformer T_6; this represents an electrostatic shield made of a layer of metal foil actually placed between the primary and secondary windings to eliminate electrostatic coupling which might, under certain conditions, transfer undesirable power line disturbances to the secondary winding and the receiver circuits.

We have thus made a thorough analysis of the receiver circuit. Very seldom does a practical radio man have to study a circuit as thoroughly as this, but since he may have to analyze a particular section of the circuit in which trouble has developed, it is well for you to go over complete circuits like this occasionally during your training period.

A common and widely-used arrangement of parts for a 5-tube receiver like that just studied is given in Fig. *20*, which represents the top view of the chassis. In a receiver of this type, only the parts shown in Fig. *20* are mounted above the chassis; all the other parts are located underneath, with the chassis serving as an effective shield. Notice how parts which are connected together are placed close together; for example, the oscillator tuning condenser is alongside the oscillator coil, and the antenna transformer and tuning condenser are likewise near each other. The signal circuit tubes and transformers are arranged in the same order as on the circuit diagram, as indicated by the arrow line in Fig. *20*. In any radio receiver you will find the parts so arranged on the chassis that the path taken by signal currents from tube to tube *does not cross itself anywhere, with the end of the path* (the output circuit) *as far as possible from the starting point* (the antenna circuit); *this lessens the chances for feed-back and simplifies the shielding problem.*

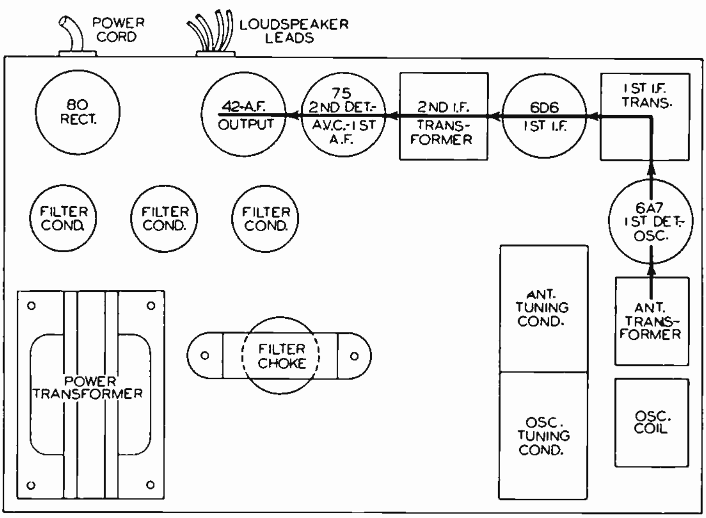

Fig. 20. Logical chassis layout (top view) for the 5-tube superheterodyne receiver circuit of Fig. *18*.

Notice also that the power pack components—the power transformer, filter choke, filter condensers and the type 80 rectifier tube—are all grouped at one end of the chassis, as far as possible from the antenna input circuit, with the power cord entering the chassis just behind the rectifier tube. This lessens the chances for A.C. power line hum to get into the input circuit and be amplified by the entire receiver along with signal currents. You will find that the power transformer is completely shielded by its steel housing. As a further precaution against magnetic interaction, the filter choke is located at right angles to the power transformer.

All signal circuit coils and transformers above the chassis are in copper or aluminum shields, which prevent interference effects of stray electric and magnetic fields. Since the tubes all have glass envelopes, they are likewise covered with metal shields.

Wiring and leads for all components under the chassis of this receiver will in general be as short as possible, with all chassis connections for any one stage being made to the same point to eliminate the effects of stray signal current in the chassis. If you encounter leads in a manufactured receiver which seem unnecessarily long, do not change them unless you know definitely that they are causing trouble; oftentimes it is necessary to use long leads in order to get around certain parts and eliminate interfering effects.

TEST QUESTIONS

Be sure to number your Answer Sheet 20FR-3.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In what three different ways can undesired signal currents enter a circuit?
2. Why is a by-pass condenser commonly placed across the C bias resistor in the cathode circuit?
3. How can signal currents be kept out of the high-resistance path through the plate supply of a radio circuit?
4. Why do signal currents take the path through a by-pass condenser in preference to other possible paths between two points in a receiver circuit?
5. Can a signal current filter act both ways, preventing signal currents from getting out of a signal circuit and preventing A.C. power supply currents from getting into the signal circuit?
6. Why should all by-pass condensers in a single R.F. stage be connected to a common point in the stage?
7. Why must grid and plate leads in an R.F. stage be kept as short and as far apart as possible?
8. Is it important to ground an electric shield?
9. What materials serve best as magnetic shields at high frequencies (above about 50 kc.)?
10. Why are chassis parts so arranged that the signal current path from tube to tube does not cross itself at any point, and its end (the output tube) is as far as possible from the starting point (the antenna circuit)?

THE VACUUM TUBE AS AN A.C. GENERATOR IN RADIO-TELEVISION CIRCUITS

21FR-2

PIONEER HOME STUDY RADIO SCHOOL

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NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

THOROUGHNESS

Whatever you do, do well if you would stay on the straight road to success. The habits of carelessness and slip-shod work are all too easy to acquire; beware of them as you would the plague. Men who are thorough in their work cannot remain undiscovered for long, because the demand for such men is greater than the supply.

Thoroughness is just as important in study as it is in work; what you get out of a lesson depends upon how completely you master the material presented in it. Some books, as fiction, are read hurriedly and only once, then cast away; the enduring works of literature are carefully read and reread many times, but always essentially for the pleasure they give; text-books, however, must be read quickly, to get the basic ideas, then carefully many times until every important principle has been mastered. Text-books are always saved for future reference; tomorrow you may have urgent need for the information given in a paragraph which today seems so insignificant.

Thoroughness in study habits leads to thoroughness in work habits, and eventually to a thorough success.

J. E. SMITH.

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The Vacuum Tube as an A. C. Generator in Radio-Television Circuits

PRACTICAL IMPORTANCE OF TUBE OSCILLATORS

RADIO, as a means of transmitting intelligence through space, depends upon the *production of high frequency A.C. currents,* and television requires the *production of ultra high frequency currents.* The operation, efficiency and stability of the super-heterodyne type of receiver depends upon the oscillator, *a generator of A.C. currents.* Some of the most successful electronic control systems are possible only because of the tube oscillator. Maintenance, testing and servicing of radio equipment can be satisfactorily carried out only with special oscillators called signal generators. Thus the very existence of sound and television broadcasting depends upon tube oscillators.

THE COIL AND CONDENSER AS AN OSCILLATOR

Long before radio was even considered as a public servant, scientists knew that an A.C. current would flow through a coil when it was connected to a charged condenser. The frequency of this current, as you already

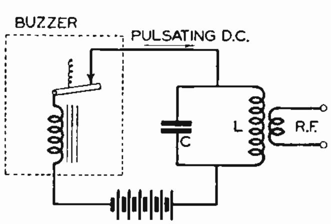

FIG. 1A. An early oscillator circuit; each closing of the buzzer contact recharges or primes condenser *C* in the coil-condenser circuit, and oscillations continue in the *L-C* tank circuit when the buzzer contact opens.

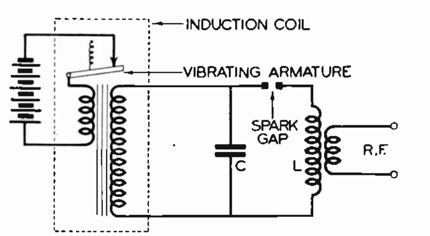

FIG. 1B. Early spark transmitter circuit. The induction coil charges condenser *C* with a high potential, the condenser voltage causes a spark to jump across the gap, and an oscillatory current flows through coil *L* and the spark gap as long as the condenser voltage is high enough to maintain the spark. Each closing of the induction coil contact recharges the condenser for another cycle of operation.

know, essentially depends upon the inductance and capacitance values. The duration of the current is fixed by the resistance in the circuit; as the energy travels back and forth between coil and condenser the losses in these two parts reduce the energy a little on each "trip," until finally the oscillations cease. Clearly it is necessary to have some means of "priming" the circuit, or feeding it with at least enough energy to overcome resistance losses; the first scheme utilized a buzzer which connected the oscillatory circuit intermittently to a battery, as in Fig. *1A,* so it would recharge the condenser regularly.

Spark Transmitter. In order to get greater power output, radio pioneers developed the high voltage oscillatory circuit of Fig. *1B;* a step-up transformer having a vibrator in series with its primary (the combination being called an *induction coil*) primes the oscillating coil-condenser circuit hundreds of times each second. *The frequency* of R.F. oscillation is determined essentially by the values of L and C.* Of course there were many later improvements on this early spark transmitter circuit, but these are now "ancient radio history," mentioned simply to show that the coil and condenser were *first* and *still are* the important frequency controlling units.

Damped Waves. Each time the condenser in an oscillating circuit is charged, the applied energy immediately starts to oscillate between condenser and coil; the resistance of the oscillatory circuit (essentially the resistance of the coil or of coil and spark gap together) causes the amplitudes of successive cycles to be reduced or damped, as in Fig. *2A*. Repeated priming of the oscillatory circuit (at points *1, 2* and *3*) give a series of such oscillation groups. Although this form of oscillation serves very well for code transmission, it has the very severe drawback that it creates excessive interference with adjacent-channel stations, often "riding in" with signals of other stations. Reducing the resistance of the oscillatory circuit improves matters by giving the wave form illustrated in Fig. *2B*, but still the damped oscillations are unsuited for the transmission of speech and music. The reason for this is simple; the damped wave form is in itself modulated at a frequency which depends upon the number of oscillatory groups per second, and this modulation note would interfere with the program being transmitted.

A continuous, constant-amplitude wave form like that shown in Fig. *2C*, free of modulation, is required as a carrier when transmitting voice, music or picture signals. This wave can be produced by a vacuum tube oscillator, a simplified circuit of which appears in Fig. *3*.

Vacuum Tube Oscillators. In a vacuum tube oscillator the power loss due to the resistance in the L-C oscillatory circuit is *constantly* being compensated for by power which is supplied by the tube acting as an amplifier, whereas in the spark gap transmitter the losses were compensated for *intermittently*.

Let us see how a vacuum tube oscillator operates. Only electrical changes in the circuit, such as connecting the tube to its power supply, will start this vacuum tube oscillator; once oscillation starts, there is produced across the condenser (or coil) terminals an A.C. voltage whose frequency is determined by the values of L and C. The vacuum tube, acting as an amplifier, will respond to this varying grid voltage and cause the plate current to vary at the same frequency. Coil L_T, carrying this A.C. plate current, will induce into coil L by mutual induction a voltage e. Coil L, condenser C and resistor R (an apparent resistance, representing the combined resistances of L, C, the grid-cathode path in the tube, and the resistance effects of a load, if used) act as a series resonant circuit. The reactance effects of L and C cancel each other, and the voltage e acting on R determines the amplitude of the oscillatory A.C. current. As in any simple generator-load

*The frequency of an oscillatory L and C circuit can be determined from the following formula: $f = 159{,}000 \div \sqrt{LC}$ where f = frequency of oscillation in cycles per second, L = coil inductance in microhenrys, and C = condenser capacity in microfarads.

circuit, the current assumes a value which will make the A.C. voltage drop in R equal to the induced A.C. voltage e.

Because of resonance, the voltage across either L or C is greater than the induced voltage; this resonance-amplified voltage, applied to the grid of the tube, drives the plate current through large swings, and the increased current through the tickler coil increases the induced voltage e. The plate current swing and consequently the induced voltage e continues to increase up to the limit of the amplifying ability of the tube; the tube thus introduces into the oscillatory circuit, through tickler coil L_T, enough power to overcome power losses in R and make the oscillatory current assume the constant amplitude shown in Fig. *2C*.

There are many ways of operating the oscillator tube, connecting the oscillatory circuit and producing the feed-back voltage in order to secure improved performance; these will now be studied. Remember, however, that it is essentially the values of coil L and condenser C in the oscillatory circuit which govern the frequency of a self-excited vacuum tube oscillator; these values can be adjusted to give frequencies ranging from one cycle to hundreds of kilocycles per second.

HOW A VACUUM TUBE OSCILLATOR CIRCUIT WORKS

Most tube oscillators work alike, even though the method of feed-back, the position of the oscillatory circuit containing C and L (also called the

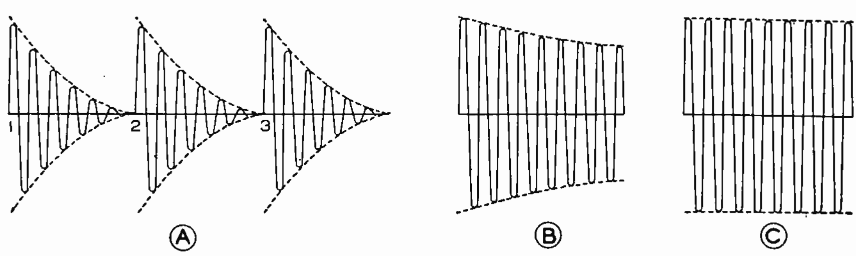

FIG. 2. Priming or recharging of an oscillator circuit gives the series or "trains" of damped oscillations shown at *A* and *B*, but present-day radio transmission calls for the constant amplitude oscillation shown at *C*, which can be obtained from a vacuum tube oscillator. For simplicity, only a few cycles of the oscillatory wave are shown here; actually there may be thousands of cycles of oscillations in each damped wave group, such as between points *1* and *2* in *A*.

tank circuit), the method of supplying the D.C. power, or the positions of the circuit components may vary. A typical oscillator circuit is shown in Fig. *4*; here, as in most oscillators, the plate feeds a part of its energy back to the grid to make the tube supply an A.C. plate current. All oscillators in which the grid takes a small part of the plate circuit power are said to be self-excited.

Power Input. Neglecting tube filament power, the total power fed to the oscillator is the D.C. plate voltage V multiplied by the D.C. plate current I. This input power is used in several ways: *1,* It overcomes resistance losses in the L-C tank circuit. If coil L is coupled to a load, the effective value of R is increased and the power consumed by the tank circuit also includes useful output power or useful work. *2,* The grid in an oscillator circuit is driven positive at times, causing grid current to flow, and the grid consequently draws power from the plate circuit; *3*, a part of the input plate power is used to overcome the A.C. plate resistance, thus heating the tube elements. In spite of all these power losses, from 50% to 85% of the input power can be converted into useful A.C. power in a good oscillator.

An oscillator circuit is unique in that changing any one thing in the circuit changes current and voltage conditions in the entire circuit; the reason for this is that the grid and plate circuits are linked together. A study of Fig. *4* will reveal a few outstanding facts which apply in general to all self-excited oscillators. The A.C. voltage across C or L can never have a peak voltage greater than the applied voltage V; in fact, the peak value of v_T will always be less than V because the charging voltage of C is equal to the applied voltage *minus* the tube voltage drop. Furthermore, as the A.C. plate current *increases* to furnish more power to the tank circuit, the A.C. voltage across C or L becomes less.

A.C. voltage v_T causes an A.C. current i_T to circulate in the tank circuit, and this current induces an A.C. voltage in the grid circuit. The amount of voltage induced in the grid circuit will, of course, depend upon the mutual inductance between coils L_G and L, upon the A.C. tank current i_T, and upon the frequency of oscillation. The mutual conductance of the oscillator tube must be such that the grid driving voltage causes enough A.C. plate current to flow to maintain oscillation; in other words, the mutual conductance (g_m) of the tube is of as much importance as the A.C. grid voltage. Oscillator action is a sort of "around the circle" affair; the grid must draw enough power from the tank circuit to swing the plate current enough to produce enough A.C. power in the tank circuit to supply the load with power and feed sufficient power back to the grid to maintain oscillation. The amount of output power can be controlled by changing the mutual conductance of the tube or by changing the mutual inductance between the plate and grid circuits.

Starting an Oscillator. Getting oscillations to start in a feed-back circuit like that in Fig. *4* is often explained as follows: When the tube is first connected to the power supply, the plate current starts to rise as soon as the cathode begins to emit electrons. A rising plate current flowing through coil L (see Fig. *4*) induces a voltage in coil L_G. This grid voltage, acting through the mutual conductance of the tube, causes the plate current to vary; *if the voltage to the grid is so phased that the original plate current change is aided,* the plate current will build up to the full capacity of the tube, as determined by the operating voltages. This primes the tank circuit with energy and it starts to oscillate, feeding A.C. voltage to the grid and causing the plate current to increase and decrease alternately; this is the desired condition for a tube oscillator. Tank current and grid voltage continue to increase until a balance is reached, this occurring when the A.C. current in the tank circuit produces (through coupling to the grid) sufficient A.C. grid voltage for the tube amplifier to supply the tank power required by the tank circuit load and to overcome the grid and plate circuit power losses. All power is obtained from the plate supply source.

Automatic C Bias. Now let us concentrate our attention on grid resistor R_C and grid condenser C_C in Fig. *4*. As you will shortly see, condenser

C_C has a double purpose. The A.C. grid voltage e_G acts directly upon the grid-cathode of the tube because C_C has a low reactance. Thus the tube is fed with an A.C. signal which makes the grid alternately positive and negative with respect to the cathode. When the grid is positively charged, it will draw electrons from the cathode, these electrons flowing through resistor R_C on their way back to the cathode since they cannot pass through condenser C_C; a D.C. voltage therefore appears across resistor R_C.

From the basic fact that electrons flow through a load from the negative to the positive terminal, point *1* of resistor R_C is negative with respect to point *2*. If condenser C_C were absent, the current flow through R_C would be of a pulsating nature since the grid is positive for only short periods of time; this condenser, however, is charged by the voltage drop across the resistor so that when the electron flow through R_C starts to decrease, condenser C_C begins feeding electrons into R_C. The result is a steady flow of electrons through R_C, and the voltage drop across it becomes constant. Thus, in addition to the A.C. voltage supplied by L_G, a steady D.C. bias voltage is automatically supplied to the grid by grid condenser C_C and grid resistor R_C; this voltage is called the *automatic C bias.* This makes the operating plate current set itself at a lower value.

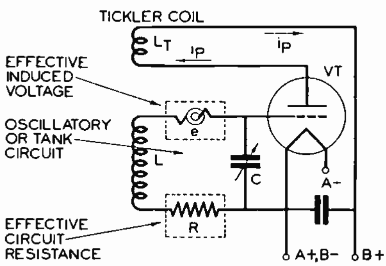

FIG. 3. Simple feed-back type vacuum tube oscillator circuit. *R* is not an actual resistor; it simply represents the resistance of coil *L* and all other resistances, apparent or otherwise, which may cause losses in the oscillatory circuit. Likewise *e* represents the voltage induced in coil *L* by the tickler coil.

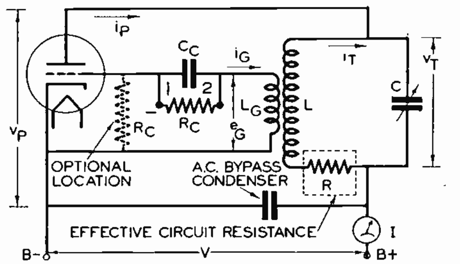

FIG. 4. An understanding of this basic self-excited oscillator circuit will simplify your study of other oscillators. *L* and *C* form the oscillatory tank circuit. *L* induces into L_G the required feed-back voltage; C_C and R_C provide automatic C bias for the tube.

You may consider the A.C. voltage and the automatic C bias voltage as acting independently on the tube, or you may consider both effects at the same time, as you prefer. The presence of the C bias lessens the effect of the A.C. grid voltage on the tube, actually reducing the time and the amount by which the grid is driven positive; the C bias cannot, however, completely prevent the grid from being positive, for if it could, there would be no grid current to produce the automatic C bias.

The automatic C bias can never be greater in value than the peak A.C. grid voltage. The average value of grid current multiplied by the ohmic resistance of R_C determines the C bias in the circuit. It should be pointed out that the grid bias resistor may be connected from grid to cathode (instead of across the condenser) without changing the automatic C bias.

Operating Efficiency. It is true that the circuit in Fig. *4* will oscillate without any form of C bias, but in this case the D.C. plate current will be so high that losses will be excessive, giving very poor tube efficiency at normal plate voltage, and the resulting heat may melt the tube elements. The use of an automatic C bias keeps D.C. plate current at a minimum and limits the effects of the A.C. grid voltage, allowing the tube to work more efficiently. The value of R_C and the feed-back voltage are so selected that the average C bias at least equals the value for plate current cut-off (this C bias approximately equals the plate voltage divided by μ, the amplification factor of the tube). This means that plate current flows for one-half of each cycle, and grid current flows during a much smaller part of the cycle.* The coil and condenser tank circuit stores up energy, and because of its oscillatory nature continues to oscillate during those parts of the cycle when there is no plate current; the resulting tube efficiency is at least 50%. By making the C bias even greater than cut-off value, the time of plate and grid current flow is reduced and greater efficiencies, which may be as high as 85%, are obtained. Although increasing the C bias does increase efficiency, it naturally reduces the power output; a compromise must therefore be made between maximum efficiency and maximum power, to suit a particular need.

A fixed C bias voltage (secured from a tap on the voltage divider of the D.C. power supply) could be introduced in place of R_C and C_C, but if it is made greater than the plate current cut-off value, the oscillator will not be self-starting (the original rise in plate current will not occur). Automatic C bias is a very practical solution, for the C bias generally sets itself automatically for best operation.

Blocking. The ohmic value of the grid resistor in a self-excited vacuum tube oscillator (such as R_C in Fig. *4*) is not critical, but if it is made too large, its D.C. voltage will build up to such a high value that the oscillator will *block* (stop oscillating momentarily) at regular intervals. Values of R_C above about one megohm cause the oscillator to block, producing a tone modulation whose frequency depends upon the time constant of the resistor-condenser combination; the value of R_C in megohms multiplied by the capacity of C_C in microfarads gives the approximate time of one blocking and starting cycle. When the value of R_C is low (5,000 to 250,000 ohms), the bias is never driven so far negative that intermittent oscillation is obtained. The grid condenser C_C can be any size sufficiently large to make its A.C. reactance in the grid circuit negligible.

In a properly adjusted oscillator, the C bias is zero at the instant of starting the oscillator, and a definite value of plate current flows. This plate current *decreases* quickly to the operating value I_P as automatic C bias comes into action, for the operating bias is now more negative. This means that if the oscillator is stopped by shorting one of the coils (or by an internal short in tank condenser C), the plate current will *increase;* in some low power oscillators this is actually done to determine if the circuit is operating, but in high power oscillators the high plate current resulting from such a procedure might damage the tube.

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*These pulsating grid and plate currents produce many harmonics, but the tank circuit accepts only the fundamental. Coil L suppresses and condenser C by-passes the harmonics; by using a large value for C and a small value for L, the ability of the tank circuit to reject harmonics will be improved even more.

To adjust an oscillator to best operating conditions once the load to the oscillator is fixed, it is customary to adjust the different circuit parts to the values which give minimum D.C. plate current at the desired frequency. When an oscillator is to be tuned over a wide range of frequencies by varying the tank circuit capacity, as is the usual procedure, an optimum (best) circuit adjustment for one frequency may be unsatisfactory at some other frequency. For example, if the circuit is adjusted for best operation at a high frequency in its range, the resetting of the tank circuit to a low frequency may result in too low output or no oscillation due to too low a feed-back voltage. When a wide range of frequencies is to be covered, it is best to make optimum adjustments at a mid-frequency; this should provide ample feed-back excitation at the lowest frequencies.

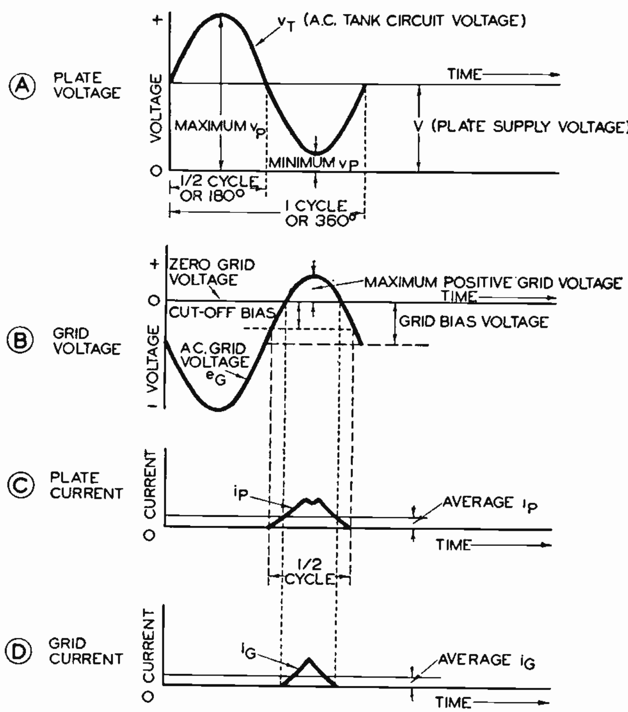

FIG. 5. These plate and grid currents and voltages represent operating conditions in the oscillator circuit of Fig. 4. Remember that graphs like these are always read from left to right. When comparing two voltages, that one which reaches a positive peak *closest* to the vertical reference line is said to *lead* the other; thus, v_T in *A* leads e_G in *B*.

Current and Voltage Relations. The curves in Fig. 5 present a picture of the grid and plate voltages and currents in the oscillator circuit of Fig. 4 during operating conditions; these curves are characteristic of all types of oscillators. Notice that although the applied plate voltage V in Fig. 4 is a D.C. voltage, the voltage v_T across the tank circuit (the plate-to-cathode A.C. voltage component) has essentially the sine wave form shown in Fig. 5*A*. Although the A.C. plate voltage swings above and below the D.C. plate supply voltage value, it never is driven to zero because of the A.C. plate resistance.

In Fig. *5B* is shown the A.C. grid voltage curve; you will notice that the A.C. grid voltage reaches its maximum positive value half a cycle (180 degrees) after the A.C. plate voltage reaches its maximum, or in other words, the A.C. grid voltage lags 180 degrees behind the A.C. plate voltage; coils L_G and L in Fig. *4* are so connected that this phase relation is produced. In this way the grid can be driven positive during the time when the plate-to-cathode voltage is low; current thus flows in the plate circuit when the grid swings positive, and the tank circuit absorbs or stores up energy. This energy is released because of the oscillatory action (also called the flywheel effect) of the tank circuit when plate current drops to zero, completing the A.C. cycle and producing the sinusoidal voltage wave shown in Fig. *5A*.

Looking at Fig. *5C*, note that plate current i_P begins to flow when the instantaneous A.C. grid voltage becomes more positive than the cut-off value of C bias. Grid current (Fig. *5D*) flows only when the A.C. grid voltage overcomes the effective C bias, and makes the grid positive with respect to its cathode. Thus plate current flows for a longer part of a cycle than grid current. Since the flow of grid current robs the plate circuit of current, a dip appears in the peak of the plate current curve; a dip will also appear in the grid current curve if a large amount of secondary emission takes place at the grid of the tube. The average value of plate current controls the amount of power taken from the supply; in the grid circuit the current through the grid resistor is averaged out by the smoothing condenser. By studying curves *A*, *B* and *C* together, you can see that the minimum plate voltage value is very important in controlling plate current; the larger this minimum voltage, the larger the plate current.

An Important Oscillator Requirement. Any self-excited oscillator *must have* the same phase relationship between grid and plate A.C. voltages that exist in an ordinary amplifier—the *A.C. grid voltage* must be 180 degrees out of phase with the *A.C. plate voltage.* For example, in an amplifier having a resistance load, a positive swing in grid voltage makes the plate current increase, increasing the IR drop in the load and therefore decreasing the plate-to-cathode voltage; the tank circuit of an oscillator is in effect a resistance load at resonance, and the same relation must therefore exist—grid voltage *increase* causes plate voltage *decrease.*

EFFECTS OF CIRCUIT CHANGES

Changes in the adjustments of various parts of an oscillator circuit will naturally affect the oscillatory condition; the following discussion of these changes will in general apply to all self-excited oscillators.

Static and Oscillating Plate Current. If the coupling between plate and grid in an oscillator is reduced or the grid excitation supply is shorted, the circuit will not oscillate, and the plate current will assume a *static* value which is governed essentially by the plate supply voltage and the D.C. plate resistance (the grid bias being zero for a self-excited circuit which is not oscillating). If the circuit was originally adjusted for optimum efficiency as an oscillator, an unusually high plate current will flow; in high power oscillators the tube will overheat and plate and filament will be destroyed by heat. In the case of low power oscillators such as those found in testing equipment and in superheterodyne receivers, the excessive plate current may weaken the cathode emission qualities of the tube. When the fault is remedied and oscillation starts again, the D.C. plate current will immediately drop. In the case of high powered oscillators, the plate current should immediately assume its normal value (much lower than the estimated static value) ; if plate current is above normal the circuit should be disconnected from the supply at once.

Effect of Plate-to-Grid Coupling. There can, of course, be no oscillation when plate-to-grid coupling is very loose; as coupling is gradually increased, oscillation will start at a definite point and the D.C. plate current will drop from the static value to the operating value. Further increases in coupling simply increase the grid excitation (increase the grid voltage swing), thus increasing the rectified grid current value and shifting the operating grid voltage more negative, but D.C. plate current remains practically constant for all values of coupling which maintain oscillation. When coupling is increased beyond a certain critical point, the time duration of the plate current pulses becomes such a small fraction of a cycle that the tank circuit can no longer supply sufficient energy to build up the voltage wave for the rest of the cycle, and oscillation stops; plate current then rises to the static value. Any change in coupling also changes the inductance and resistance of the tank circuit, thereby changing the frequency of oscillation slightly.

Effect of Loading the Tank Circuit. The tube circuit of an oscillator must supply a certain amount of power to the tank circuit in order to maintain oscillation; this power comes from the D.C. supply, for there is no other source of power in a self-excited oscillator. If a load is coupled (usually inductively) to the tank circuit, the tube must also supply the extra power demanded by the load, and this extra power must likewise come from the D.C. supply. This means that the D.C. plate current *increases* in value when a load is applied to the tank circuit of a self-excited oscillator (since power is equal to voltage multiplied by current, and the D.C. supply voltage is here essentially constant).

The A.C. plate current must increase either in amplitude or in the duration of a pulse in order to produce the increase in average or D.C. plate current; actually both factors increase, for the reduced tank current lowers the grid excitation, making the C bias more positive and allowing a current pulse of greater amplitude to flow for a slightly greater fraction of a cycle.

Effect of Plate Supply Voltage. Increasing the D.C. plate supply voltage of a self-excited vacuum tube oscillator increases the A.C. tank voltage, thereby raising the tank current and *increasing the power output.* The higher tank current also serves to increase the grid excitation, the rectified grid current, the automatic C bias and to a slight extent the D.C. plate current. If a self-excited oscillator will not start by itself, increasing the plate supply voltage will generally cure the trouble.

Effect of Increasing C Bias Resistor. Increasing the ohmic value of the C bias resistor makes the grid bias voltage more negative, with the result that grid and plate currents flow for smaller fractions of the cycle. Other effects are a lowering of the D.C. plate current, a decrease in the amount of energy supplied to the tank circuit and an increase in oscillator efficiency. These changes are not very great, for the increased efficiency tends to feed more grid A.C. voltage to the oscillator input, offsetting the increased bias. If the resistor value is increased too much, repeated blocking will take place, and stability (the tendency to remain in oscillation) will be reduced.

General Circuit Effects. It is desirable to have a high inductance-to-resistance ratio (high Q factor*) in the tank circuit of an oscillator in order to improve the flywheel action of the circuit and reduce the generation of harmonics in the tank circuit. On the other hand, a high Q factor gives a high tank current, increasing circuit losses unnecessarily. Circuits which are heavily loaded have a low Q factor and are very unstable, hence a compromise involving a mid-value of Q factor is usually required.

Changing the capacity in the oscillatory circuit naturally changes the frequency of oscillation; as the condenser capacity is reduced, the frequency goes up. The feed-back voltage or grid excitation depends upon the coupling (usually fixed), upon the tank current and upon frequency, hence tuning an oscillator to a higher frequency increases the feed-back voltage. Although the losses in the tank circuit increase with frequency, causing the tank current to reduce, this is more than overcome by increased feed-back. Increased feed-back makes the oscillator generate more power, but this effect is somewhat reduced by the resulting increased grid current and increased C bias voltage. By limiting feed-back, it is possible to secure an oscillator which can be tuned over a wide range of frequencies.

On the other hand, an oscillator set for optimum conditions at a high frequency may stop oscillating at the lower frequencies because of insufficient feed-back. In superheterodynes an oscillator may fail at lower frequencies because of poor tube emission, low plate voltage, or too high a C bias resistor value. Remedies include trying a new tube at normal voltage or adjusting the plate voltage and C bias resistor values to give oscillation at the lowest frequency desired with a given tank circuit coil and condenser.

TYPES OF SELF-EXCITED OSCILLATORS

As I pointed out before, the basic oscillator ideas which you have been studying apply in general to all types of self-excited oscillators. Now we will take up the common variations of the self-excited oscillator circuit.

Tuned Grid Oscillator. This is of the form shown in Fig. *6A*. The tank circuit is in the grid circuit, plate A.C. power being fed to it by inductive coupling. The circuit as shown here is for low power oscillators, such as those found in superheterodynes and in test oscillators. To prevent over-excitation and to permit greater tank current, the grid is often connected to a tap on the tank coil; in this way the tank circuit can be inductively loaded, and the grid excitation can be adjusted to a satisfactory minimum value.

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*A parallel resonant circuit acts as a large resistance, even though the circuit parts themselves have comparatively low resistances. The number of times the resistance of a parallel resonant circuit has been increased by tuning is called the *Q factor* of the circuit; this Q factor is equal to $\omega L \div R$, where ω is 6.28 times the frequency in cycles, L is the inductance of the coil in henrys and R is the resistance of the resonant circuit in ohms.

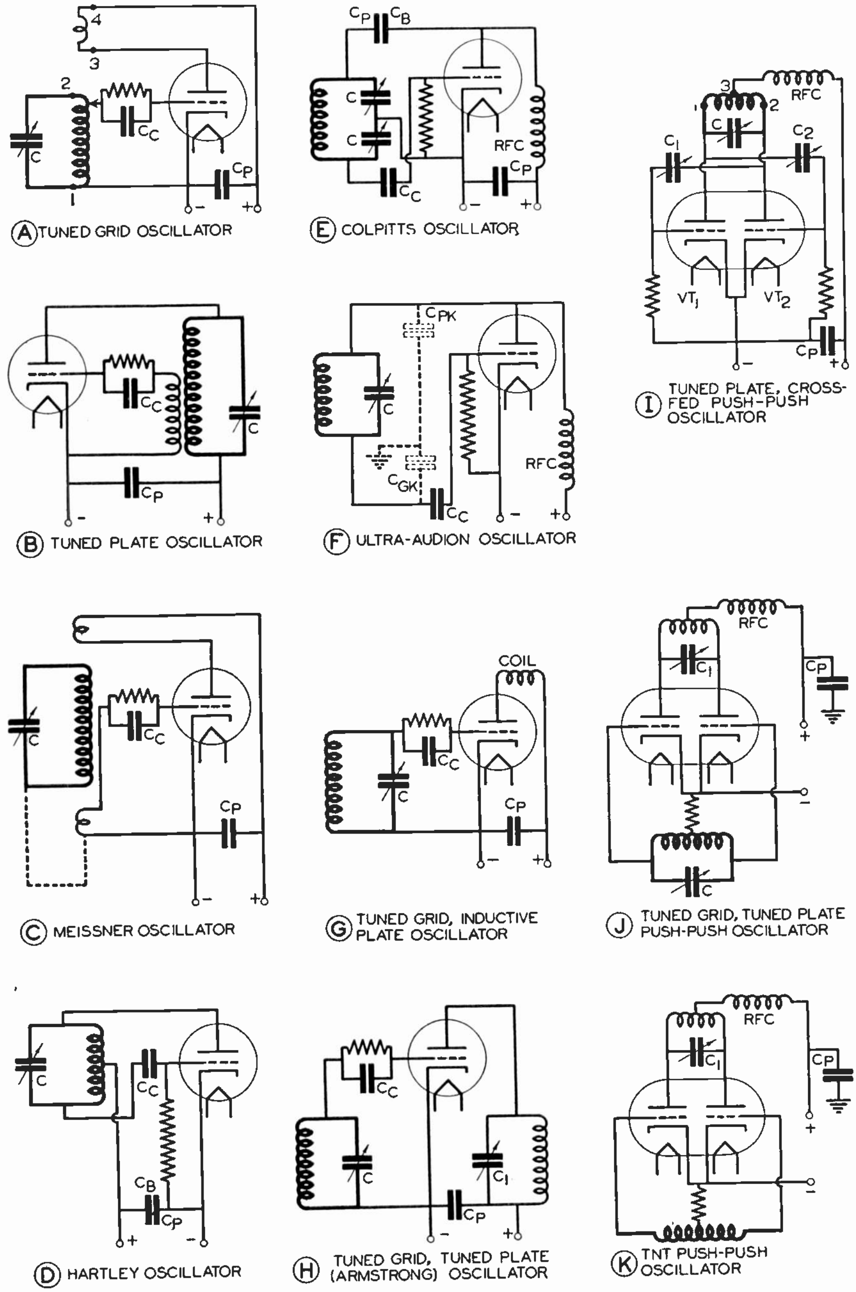

FIG. 6. Simplified schematic circuit diagrams of eleven different types of self-excited vacuum tube oscillators. Heavy lines indicate the coil and condenser tank circuit combination which controls the frequency of the oscillator. Although there are many possible variations of each of these circuits, you can identify a particular oscillator by the way in which its frequency-controlling tank circuit is connected to the grid and plate electrodes of the tube. Condensers marked *C* are frequency-controlling condensers; C_1 and C_2 are oscillation-controlling condensers; C_C is the low A.C. reactance condenser, which also smooths the rectified grid current; C_P is a low reactance A.C. by-pass condenser; C_B is a D. C. blocking condenser. When a condenser is double-marked, as C_B and C_P, it acts as a blocking condenser for D.C. and as a low reactance condenser for A.C.

Tuned Plate Oscillator. You are already quite familiar with this simple but effective oscillator circuit, shown in Fig. *6B* and also in Fig. *4*. The tank tuning condenser is in the plate circuit; changing the mutual inductance between grid and plate coils changes the grid excitation. This circuit is better than that in Fig. *6A* for high frequency power generation. Often the plate is connected to a tap on the tank coil to get a better impedance match between the tank circuit and the A.C. plate resistance of the tube;* this gives greater efficiency.

Meissner Oscillator. This circuit, named after its inventor, is shown in Fig. *6C*; the fact that feed-back and grid excitation are essentially independent of each other is an outstanding feature. Though not intended for high power requirements, the circuit is easily adjusted for optimum conditions, and gives highly stable operation. The tank circuit is usually coupled loosely to the grid and plate coils, giving the tank coil and condenser practically perfect control of the oscillating frequency. The isolation of the tank circuit also permits grounding of the condenser without affecting the supply circuits or R.F. circulating currents.

Hartley Oscillator. Also named after its inventor, the Hartley is perhaps the most widely used oscillator in the radio field. The basic circuit is given in Fig. *6D*. The Hartley oscillator can always be identified by the fact that *the tank circuit is in both the grid and plate circuits, the division of voltages being made by a tap on the tank coil.* This tank coil tap, which connects through an R.F. by-pass condenser to cathode and ground, divides the relative plate and grid R.F. voltages without disturbing the frequency of oscillation. Moving the tap away from the plate reduces the grid excitation. The optimum condition, when D.C. plate current is at a minimum value, is easily obtained. Additional improvement in efficiency is often realized by connecting the plate to a movable tap on the tank coil, especially when low plate impedance tubes are used.

Colpitts Oscillator. Where highly stable oscillators are needed, this circuit (shown in Fig. *6E* and named after its originator) is widely used. A unique feature is the use of two tuning condensers to divide the R.F. voltages between plate and grid circuits; individually the condensers determine the plate and grid A.C. voltages, but together in series they determine the frequency of oscillation. Decreasing the grid to cathode capacity increases the grid excitation, but the plate to cathode capacity must then be increased to maintain the frequency of oscillation. These adjustments are usually carried out until minimum D.C. plate current is obtained. A low-capacity variable condenser is often connected in parallel with the tank coil to make the final frequency adjustment. Because the division of A.C. plate and grid voltages is independent of frequency, the inductance can be changed from one frequency band to another without affecting the adjustment for best operating conditions. In a few of the low powered Colpitts oscillators the correct distribution of plate and grid capacity is determined beforehand and the two units ganged (their rotors mounted on the same shaft) for quick variation of frequency in a given band.

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*With this connection the peak amplitude of the tank voltage will be greater than the applied D.C. plate voltage.

Ultra-Audion Oscillator. As one of the oldest of oscillator circuits, this seems to have been used long before the reason why it worked was known. The tank circuit is connected between grid and plate, the D.C. plate current being kept out of the grid by a blocking (grid) condenser, as shown in Fig. *6F*. This circuit oscillates because the plate-to-cathode and grid-to-cathode tube capacities (indicated as C_{PK} and C_{GK}) form an A.C. voltage divider which makes the circuit a variation of the Colpitts oscillator. At very high R.F. values the tank tuning condenser may be eliminated, the tube capacities serving both for voltage division and for tank tuning. The circuit may be adjusted for the optimum operating condition by varying the plate voltage and the grid resistor value. A midget type variable condenser is often connected between the grid end of the tank circuit and the cathode, to give control of the intensity of oscillation.

Tuned Grid, Inductive Plate Oscillator. This circuit, shown in Fig. *6G*, is on the whole an undesirable (parasitic) oscillator, more often eliminated from than introduced into a system; it is one of the reasons for oscillations in amplifying stages. The operation of the circuit is such that when the plate load is an inductance, the A.C. voltage which is fed back to the grid circuit through the grid-to-plate capacity of the tube is *in phase* with the A.C. grid voltage. This feed-back voltage thus *aids* the A.C. grid voltage, resulting in large sustained plate current swings and a transfer of power from the plate circuit to the grid circuit. If the plate inductance is large (high reactance), sufficient voltage will be fed back to overcome grid circuit losses and sustain oscillation. The frequency is, of course, controlled by the oscillatory circuit connected to the grid. The oscillations can be reduced by shunting the plate coil with a resistor, by introducing a resistor into the grid lead, by reducing the plate voltage, by introducing plate-to-grid capacity-bucking components (so called neutralizing circuits), and by using screen grid tubes. However, the tuned grid, inductive plate oscillator does serve a highly useful purpose, when the tank circuit is replaced with a crystal oscillator.

Tuned Grid, Tuned Plate Armstrong Oscillator. The so-called Armstrong (the inventor) tuned grid, tuned plate oscillator is shown in Fig. *6H*. This circuit is essentially like that shown in Fig. *6G*, except that a parallel resonant plate circuit is used to create the inductive plate load which is necessary for oscillation. When a parallel resonant circuit is tuned slightly above the frequency of the R.F. source, its impedance becomes highly inductive. In this circuit the grid is tuned to the desired frequency and the plate tuned for minimum D.C. plate current, which automatically sets the plate tank circuit at a high inductive value. The grid tank circuit is often replaced with a crystal oscillator and the plate circuit adjusted approximately to minimum plate current; this gives a widely used and very important crystal circuit, to which we will return shortly.

Tuned Plate, Cross-Fed, Push-Push Oscillator. In Fig. *6I* you have a circuit which is often used where both high efficiency and stability are desirable. Although a double triode tube is shown, two similar triode tubes are more often used. Each tube is automatically biased to cut-off value and each grid is fed 180 degrees out of phase with the other, so that when one tube is drawing plate current, the other tube is idle. In this way the tank circuit, which is connected directly to the two plates, is receiving energy for both halves of the cycle. If during one-half of the cycle point *1* is positive with respect to point *2*, then point *2* will be positive with respect to point *1* for the next half cycle. Point *1* being coupled to the grid of tube VT_2 through a small variable condenser C_2, this tube receives an A.C. grid voltage which is *in phase with* its normal excitation. Point *3* and the cathode are at the same R.F. potential. Another way of looking at this circuit is to remove one tube; now we have in effect an ultra-audion circuit. Increasing the capacity of feed-back condensers C_1 and C_2 increases grid excitation; both condensers are usually adjusted for minimum D.C. plate current. This circuit is widely used at high and ultra-high frequencies, because the tank circuit is shunted by only one-half the plate-to-cathode capacity; this allows operation at higher frequencies without encountering undesirable tube capacity shunting effects.

Tuned Grid, Tuned Plate Push-Push Oscillator. Here is another favorite dual tube circuit, relying on grid-to-plate tube capacity for feed-back; its circuit appears in Fig. *6J*. This circuit is essentially like the Armstrong circuit, except that the plate tank circuit is being fed with energy on both halves of the A.C. cycle, giving greater efficiency. Like all twin tube oscillators, it is a valuable circuit at high frequencies where tube capacities become important. The circuit frequency depends upon the grid tank circuit; the plate tank circuit is adjusted for minimum plate D.C. current, which sets the plate load to an inductive condition.

TNT Push-Push Oscillator. This circuit, shown in Fig. *6K*, uses a coil alone in the grid circuit, relying on distributed coil capacity for grid resonance; the frequency of oscillation is therefore limited to a narrow band. This gives a high L/C ratio for the tuning circuit in the grid, which is excited to large A.C. voltage values by the limited tube capacity feed-back. The plate tank circuit is tuned to an inductive value.

Direction of Plate and Grid Coil Windings. When the plate is inductively coupled to the grid, the feed-back voltage may be either in or out of phase. If out of phase, the oscillator will not work; in this case, reversing connections to one of the coils will make the oscillator start. A good rule to follow in connecting oscillator coils (assuming that the two coils are wound in the same direction) is to make the two outer coil terminals or leads (*1* and *4* in Fig. *6A*) the cathode and B+ terminals, leaving the grid and plate connections for the inner two coil ends, *2* and *3*.

APPLYING OSCILLATOR LOADS

Oscillator loads must be applied in such a manner that load changes have a minimum effect on frequency change, and do not destroy the stability of the oscillator. As you know, the tank circuit current and voltage are sinusoidal in wave form, and therefore are of the fundamental oscillator frequency. To feed the fundamental oscillator signal to the load, then, it is best to couple the load to a *tank circuit inductance;* several different methods are used.

Inductive Coupling to Load. This method, shown in Fig. *7A*, is very commonly used when the effective load resistance is low (is 500 ohms or less). The effect of inductive coupling is that of a resistance in series with the tank coil and condenser, the resistance increasing in value as the mutual inductance is increased. Of course, this method of coupling affects the resonance of the tank circuit, shifting the frequency of oscillation slightly when load is applied or varied.

Capacity Coupling to Load. To be sure, high resistance loads can be coupled inductively to the oscillator if a large mutual inductance is provided; in cases like this, however, the capacity coupling method shown in Fig. *7B* is more often employed. The effect of capacity coupling is that of a high resistance placed in parallel with all or a part of the tank circuit. Any parallel resonant circuit acts as a pure resistance at resonance; connecting a resistance load in parallel merely decreases the net value of resistance. This loading may be increased (by reducing the resistance of the load) nearly to the point where the circuit will no longer maintain its self-excitation. The electrical value of coupling condenser C is such that its reactance is negligible with respect to the reactance of the load, and hence C does not affect the loading on the oscillator. The loading can be increased very effectively, in cases where the value of the load is fixed, by moving the load tap on the tank coil *away from* the R.F. ground.

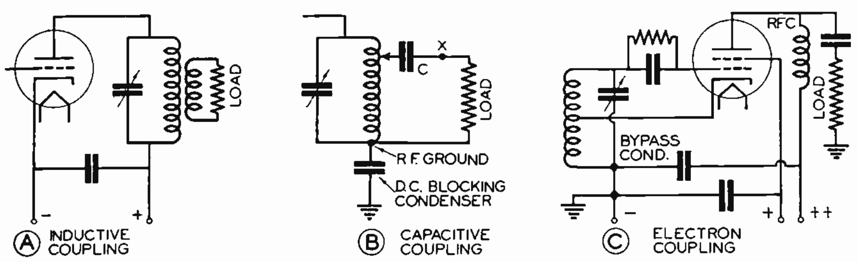


FIG. 7. Three common methods of coupling a load to an oscillator; as a rule it is best to apply the load to a circuit which has a minimum of effect upon oscillator stability and frequency.

After an oscillator is loaded, it must be adjusted for optimum operation by changing the grid bias resistor value and by adjusting the grid excitation until minimum D.C. plate current is obtained, making sure that the expected power output is obtained at all times. Where the effects of the load are to be minimized, as when the oscillator is being tuned over a given band, a series resistor of high value is placed at point X in Fig. *7B,* or the inductive coupling to the load is reduced. Of course, this cuts down the available output power, but stability is far more important than high power in the superheterodyne receiver and the test oscillator, where capacity coupling is often used.

Electron Coupling to Load. Practical electron coupled oscillator circuits like that shown in Fig. *7C* were first introduced by Dow, and hence are sometimes called *Dow oscillators.* These circuits are readily identified by their use of a multi-element tube in which the cathode, first and second grids are the basic oscillator elements (acting as the oscillator cathode, control grid and anode); these oscillator elements produce, just beyond the second grid, a pulsating space charge which acts as a virtual cathode. The plate of the tube, which is at a high positive potential and connects to the load through a coupling condenser, attracts electrons from the virtual cathode and passes them on to the load. The term "electron coupling" comes from the fact that a stream of electrons is the only coupling between the anode (second grid) of the oscillator circuit and the plate in the load circuit. The circuit in Fig. *7C* is that of a Hartley oscillator with the second grid placed at an R.F. ground potential so it acts as a shield between the plate (or load) and the oscillator. Electron coupling gives a high stability with a minimum of load reaction on the oscillator. Although the Hartley oscillator is shown in Fig. *7C*, any of the other oscillator circuits may just as well be used.

Best Position for Load. In loading one of the standard oscillator circuits, load that tank circuit which least affects the oscillator. In Figs. *6A* to *6G*, of course, the load is applied to the only tank circuit present; in Fig. *6G*, however, the load might be coupled to the plate coil if this did not reduce the reactance of the coil too much. In Figs. *6H* to *6K* inclusive, the plate coil would be loaded, the plate tank being retuned for minimum D.C. plate current.

OSCILLATOR POWER SUPPLY CONNECTIONS

Oscillator power supplies can be considered to be essentially at ground potential, for batteries or A.C. power packs have a fairly high capacity with respect to ground. If the oscillator is not "tied down" (connected) to the same ground as the power supply, anything coming near the oscillator chassis and any slight circuit change may cause undesirable changes in frequency and power output. The power supply circuits for the various tube electrodes may introduce undesirable paths for the A.C. currents; filters and chokes are therefore used extensively to keep A.C. power where it belongs. Each type of oscillator can be fed with power from the power supply either through some signal component (known as the series feed method) or directly through a choke which keeps signal currents out of the supply (known as the shunt or parallel feed method). To get definite phase relationships the plate, the cathode or the grid may be tied to ground.

Oscillators shown in Figs. *6A, 6B, 6C, 6D, 6G, 6H, 6I, 6J, 6K, 8A, 8C* and *8D* have series fed plate supplies; note that in each case the D.C. plate current flows through a circuit part which is essential for oscillation. Oscillators shown in Figs. *6E, 6F* and *8B* are parallel or shunt fed, the D.C. plate current being fed through an R.F. choke for high frequencies, and through an A.F. choke for low frequencies. The choke allows the plate to assume an A.C. potential without feeding A.C. into the plate supply.

A study of the power supply connections in the various forms of the widely used Hartley oscillator will bring out some important principles which apply to all oscillators. Although the circuits shown in Figs. *8A, 8B, 8C* and *8D* may at first glance appear different, they are all Hartley oscillators because the tank coil is in both grid and plate circuits in each case, with the mid-tap of the tank coil connected to the cathode either directly or through a condenser to divide the two circuits.

Plate Grounded. The Hartley circuit in Fig. *8A* contains a filament type tube with the plate connected directly to ground; the grid and cathode alternately acquire positive and negative potentials, which are always out of phase with each other, and oscillation is therefore maintained. Since the filament must receive D.C. power from its supply, a choke is introduced to make the filament assume an A.C. potential and to keep the A.C. signal from feeding into the supply. The use of a heater type tube would eliminate the need for the cathode choke, as then the cathode would definitely be isolated from the A supply.

Filament Grounded. Figure *8B* shows another filament type tube in which the filament is fed with A.C. and has its mid-point tied to ground. Feed-back condenser *C* provides an A.C. path between grid and plate circuits but blocks the flow of D.C. current to ground. The tank coil center tap is grounded directly to the mid-tap of the filament resistor; each section of this resistor is shunted by a condenser to allow signal currents to flow to the filament proper.

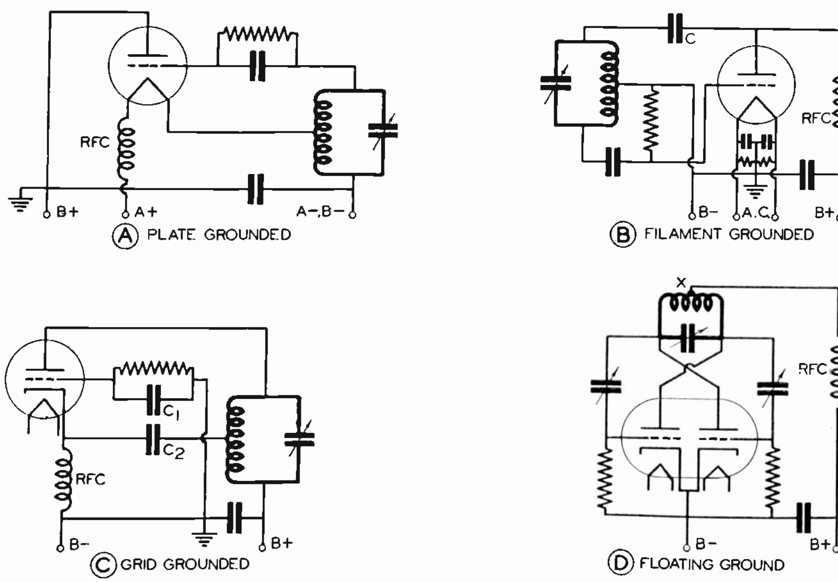


FIG. 8. Four methods of making ground connections in Hartley oscillator circuits are shown here. The frequency-controlling circuit is shown in heavy lines in each case.

Grid Grounded. Rarely is the grid grounded, but if it were necessary, the circuit shown in Fig. *8C* could be used. As far as A.C. signals are concerned, the grid is tied to ground through C_1 (shunting the grid resistor), and the mid-tap of the tank coil is connected to the cathode through condenser C_2, which prevents D.C. from flowing back to ground. The cathode circuit choke coil *RFC* allows the cathode to assume an A.C. potential without interfering with the flow of direct current from ground to cathode to plate to B+.

Floating Ground. Figure *8D* illustrates a rather well-known circuit, often called the *push-pull or push-push Hartley oscillator,* in which a floating R.F. ground connection to the tank coil is used. Tap *X* is placed as close as possible to the electrical center of its coil, making the voltages across each half of the coil practically equal at all times and opposite in polarity. But these voltages must be *exactly* equal, each section of the double triode tube getting equal excitation and equal plate currents, if the optimum operating condition is to be obtained; here is where choke *RFC* enters into the picture. Any slight difference in these tank coil voltages results in a small R.F. voltage drop across the choke, and this drop has the effect of swinging point *X* to the exact electrical mid-point of the tank coil.

FREQUENCY STABILITY

When an oscillator circuit is adjusted to a desired frequency shortly after it has been placed in operation, and a check of frequency is made an hour or so later, you will generally find that the frequency has changed or *drifted.* This is highly undesirable, for an oscillator should maintain as near constant frequency as possible. There are three causes for frequency drift in a self-excited oscillator: *1, Changes in the electrical values of parts in the oscillator circuit; 2, changes in load; 3, changes in tube constants,* due to power supply voltage changes or to the effects of causes *1* and *2.*

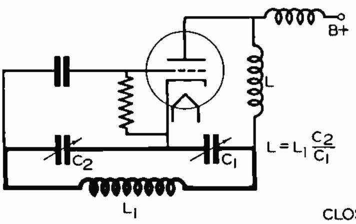


FIG. 9A. Coil *L* has been added to this Colpitts oscillator to minimize frequency drift which is caused by variations in the spacings between electrodes as tube temperature varies.

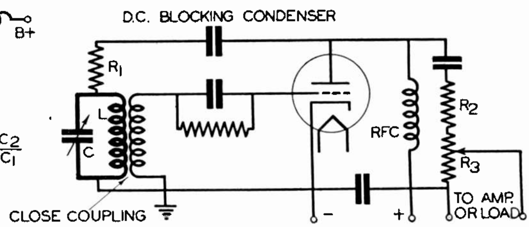


FIG. 9B. The insertion of resistor R_1 in this tuned plate oscillator improves the frequency stability of the circuit, although its use cuts down the output power.

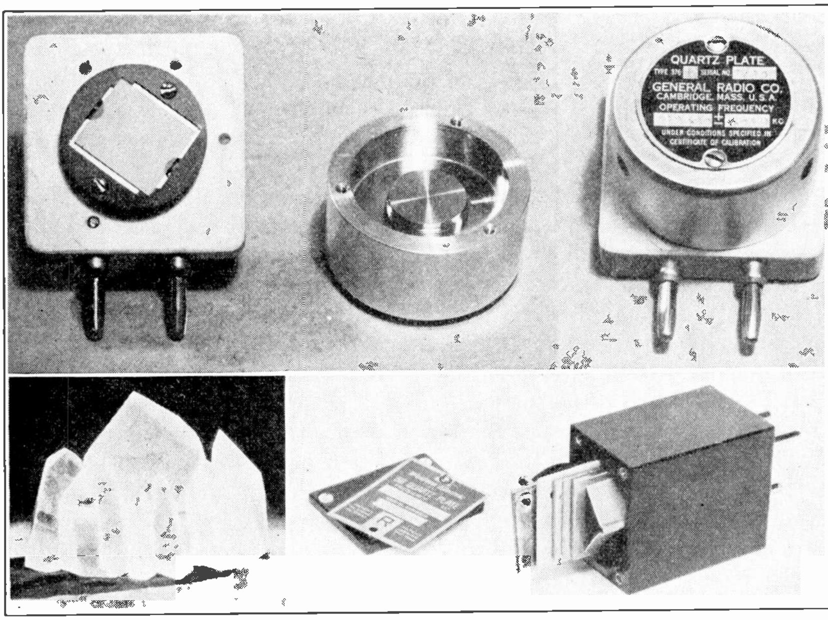
Assuming that sturdy, well designed coils, condensers and resistors which will not change in value of their own account are used, the greatest amount of frequency drift will be caused by *electrical changes* due to temperature changes; room temperature may fluctuate, and parts may heat up because of current passing through them. The solution lies in selecting parts on which temperature has little or no effect; if this proves insufficient, those parts which are most sensitive to temperature can be placed in a temperature-controlled oven.

Effects of *variations in load* can be reduced by keeping the coupling to the load as loose as possible or by using an ordinary amplifier, often called a *buffer* in this particular case, to separate the oscillator tube from its load.

Changes in tube constants are not so easily remedied; the A.C. grid-to-cathode resistance (R_g) and the A.C. plate-to-cathode resistance (R_p) have been mathematically proven to be the important factors. For a given oscillator tube and circuit the value of $R_g \div R_p$ is always a definite value regardless of the condition in the circuit; keeping the change in one as low as possible thus keeps the other one fixed and insures good stability. Frequency drift is further reduced by using a low loss tank circuit (with high Q), which in turn calls for a small load and a low loss coil and condenser.

The use of high values of grid bias resistors (but not so high that they block the circuit) makes R_g assume a high and practically constant value. If a series resistance of high value is connected between the plate and the B supply (or between the plate tank circuit, if used, and the B supply), this resistor will tend to absorb any changes in plate voltage, leaving R_p constant.

When high Q tank circuits are used, the frequency can be made practically independent of the values of R_p and R_g by inserting coils or condensers (or both) in series with the grid or plate leads (or both) of the tube. An example is shown in Fig. *9A* for a Colpitts oscillator; the electrical value required for the added coil L is determined by the values of C_1, C_2 and L_1.



Top row: **Three views of a *General Radio* type 376-L quartz plate (crystal) holder. The quartz plate itself can be seen inside its fiber mounting ring in the view at the left. This unit is of the plug-in type; one prong connects to a metal electrode beneath the quartz plate, while the other prong makes contact with the machined metal cover (top center) which serves as the upper electrode. *Lower left:* Natural crystals of Brazilian quartz, from which quartz plates used in crystal oscillators will be cut. (*Photo supplied through courtesy of Bliley Electric Co.*). *Lower right:* A *Western Electric* quartz plate in its holder; this unit is also of the plug-in type. The quartz plate is here held in position between the two metal electrodes by a spring-steel plate bent at a right angle.**

A more practical method, intended for use in cases where the tube capacities are relatively unimportant, is given in Fig. *9B;* there is a low loss (high Q) tank circuit (LC), a high resistance (R_1)* in the plate-to-tank circuit to minimize the effects of voltage and A.C. plate resistance fluctuations, and a small load. R_2 being much higher in ohmic value than R_3 and both being high with respect to the A.C. plate resistance, changes in the load have very little effect on circuit stability. This circuit sacrifices power for good frequency stability. In general, however, any oscillator

***R_1 should not be so large that it stops oscillation.**

should be allowed to heat up from one to two hours before use, where minimum frequency shift is essential.

CRYSTAL OSCILLATORS

Frequency Stability Requirements. In radio transmission, frequency stability becomes of extreme importance. Each year governmental agencies, such as the Federal Communications Commission in the U. S. A., are demanding that frequency drift be reduced and that the exact frequency be nearer to the assigned station value. The present permissible drift is 50 cycles in the broadcast band; if a certain station operates at 1,000,000 cycles, this means the transmitter carrier frequency drift must be less than .005 per cent. Frequency-monitoring equipment used in the station must have even greater stability than this. It is difficult to design self-excited oscillators which will hold their frequency this closely but fortunately the quartz crystal, when properly cut and ground to size, mounted in a holder located in a constant temperature oven and connected into a tube circuit, gives an oscillator which has acceptable frequency stability.

Types of Crystals. Crystals are solids and therefore have height, width and depth; lines parallel to these three dimensions of a crystal are called the crystal *axes.* There is the *X or electrical axis,* the *Y or mechanical axis* and the *Z or optical axis,* all at right angles to each other. By cutting a quartz crystal into small slabs across the *X* axis, a so-called *X-cut crystal* is obtained; by cutting across the *Y* axis a *Y-cut crystal* is obtained; *Z-cut crystals* are of little importance in radio. When one of these crystals is placed between two metal plates, one surface of the crystal being about .003 inch away from one of the plates to allow the crystal to vibrate freely, an A.C. voltage applied to the two plates will cause the crystal to vibrate at a frequency determined chiefly by the thickness of the cut crystal. For an X-cut crystal the frequency in cycles is approximately 3,000,000 divided by the crystal thickness in millimeters; for a Y-cut crystal the frequency in cycles is about 2,000,000 divided by the thickness in millimeters. Crystals which vibrate up to 5,000 kc. are quite easily made.

The really important feature of a crystal, as used in a crystal oscillator circuit, is that it acts *as a tank circuit which has a better frequency stability than any other practical device;* only changes in crystal temperature produce frequency drift, and temperature can be easily controlled.*

Study of a Crystal Oscillator Circuit. The simple crystal oscillator circuit given in Fig. *10A* is essentially the circuit of Fig. *6H* with a crystal in place of the grid tank circuit. This crystal is cut for a certain desired frequency, and will oscillate when the plate tank circuit is made inductive (by tuning *L-C* to a frequency slightly higher than the resonant frequency of the crystal). The plate tank circuit then has the effect of feeding back to the grid circuit, through the grid-to-plate capacity of the tube, a voltage which is in phase with the crystal voltage and which therefore serves to

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*When quartz is cut at an angle to both the *Y* and *Z* axes, giving what is known as a *V* or *A.T. cut crystal,* the resulting crystal is little affected by temperature changes. V-cut crystals are used where temperature-controlled ovens are not justified because of space or weight limitations.

maintain the vibrations of the crystal. Figure *10B* shows that as condenser *C* is varied from a low to a high value, oscillation starts at a certain value of *C* (point *1*) and plate current decreases to a minimum at point *3* as the value of *C* is further increased. As *C* is increased beyond point *3*, plate current suddenly rises to its original value, indicating that oscillation has stopped.

Operating Point. Although best efficiency is obtained when D.C. plate current is a minimum (at point *3*), the circuit is not stable at this operating point (slight increases in *C* will stop oscillation); point *2* is the most practical operating point, for here changes in load or plate voltage have less effect.

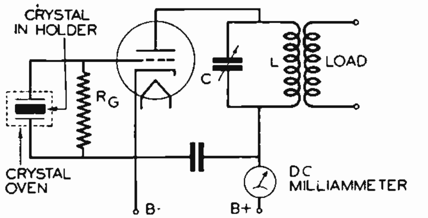


FIG. 10A. Simple crystal oscillator circuit. Rectified grid current flowing through grid resistor R_G provides the correct bias for the tube, while condenser *C* controls the starting, stopping and intensity of oscillation.

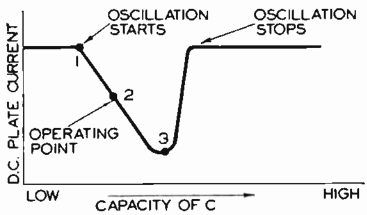


FIG. 10B. This graph illustrates how plate current in the crystal oscillator circuit at the left *changes* as *C* is tuned through the region of oscillation.

Crystal oscillator circuits are of many forms, the greatest variation being in the coupling to the load; electron coupling is widely used. Crystal oscillators have a very low output power, and R.F. amplifiers must therefore be used in practically every instance to get sufficient power output even for test equipment.

ULTRA HIGH FREQUENCY OSCILLATORS

Crystal Oscillators are Unsatisfactory for U.H.F. Work. Oscillators which must generate very high radio frequencies with very low frequency drift introduce many special problems. To be sure, crystal oscillators can be used with one or more special harmonic-producing R.F. amplifiers which are adjusted to double and redouble the oscillator frequency until the desired ultra high frequency (u.h.f.) is obtained. A single amplifier operated with a C bias greater than the plate current cut-off value will, if excited with a signal of some definite frequency, produce in its plate circuit the 2nd, 4th, 6th, 8th, etc. harmonics of this input frequency, the 2nd harmonic being the strongest. By using other similar amplifiers, each tuned to the 2nd harmonic of the preceding stage, the original frequency produced by a crystal oscillator can be doubled many times, but there are serious drawbacks to this doubling method. When the crystal frequency is 5,000 kc. (the practical maximum operating frequency of a quartz crystal), and frequencies of the order of 100,000 kc. are desired (such as for television purposes), it is expensive as well as difficult to build frequency doublers which will operate satisfactorily at such high frequencies.

Self-Excited U.H.F. Oscillators. Acorn type tubes are used extensively with very high Q tank circuits for *low power*, self-excited u.h.f. oscillators. The tank coils are wound with stiff, solid wire which requires no supporting form, thus keeping the distributed capacity and the losses of the coil at a minimum. Midget tuning condensers can be used, but often the required tank capacity is obtained by varying the spacing of the coil turns. This form of u.h.f. oscillator is used in television receivers.

Tank Coil Voltage Distribution. When the mid-tap of the tank coil in a self-excited u.h.f. oscillator is grounded as in Fig. *11A*, the coil ends are alternately positive and negative*; when one end of the coil is grounded, as in Fig. *11B*, the other end likewise changes in polarity. The distribution of voltage is sinusoidal, hence Fig. *11A* shows half-wave ($\lambda/2$) and Fig. *11B* shows quarter wave ($\lambda/4$) voltage distribution. This does not necessarily mean that the coil itself is a half or quarter wave length long in physical size; the physical and electrical lengths of the coil can be made the same, however, by using straight metal wires or pipes, as shown in

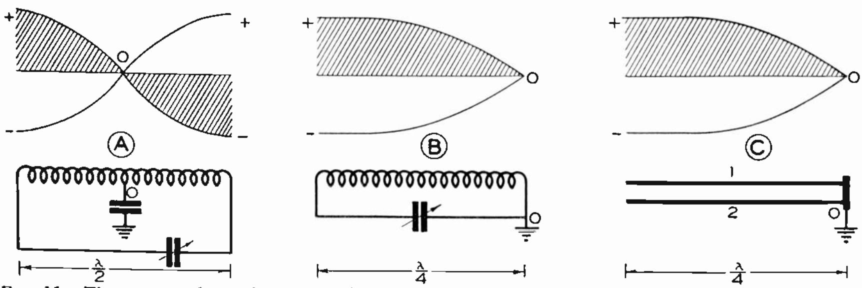


FIG. 11. The curves shown here give the voltage distribution across: *A*, the coil of an oscillator tank circuit when the coil mid-tap is grounded through an R.F. by-pass condenser; *B*, the coil of an oscillator tank circuit when one end of the coil is grounded; *C*, one of the pipes in a u.h.f. tank circuit using two parallel or concentric metal pipes. In each case the horizontal reference line represents ground potential or zero voltage; in each case the curve surrounding a shaded area represents conditions for that half of a cycle when the left-hand end of the tank coil is positive, and the other curve (the *minus* curve) portrays conditions for the other half of the cycle. The curves at *C* are for one pipe (No. 1) only; curves for the other pipe would have exactly the same shape but opposite polarity.

Fig. *11C*. Here pipes *1* and *2* are separated from one to four inches by air. When very high frequency, low wave length circuits are desired, simple pipes are used without tuning condensers.

High Power U.H.F. Oscillators. For high power u.h.f. oscillators, coils are made of copper tubing; sometimes two straight copper pipes side by side or one inside the other are used to provide the required inductance and capacitance. A single turn of tubing or even less is generally sufficient. Push-push tube circuits like that shown in Fig. *12A* are customarily used; to get close grid-to-plate coupling (unity coupling), the grid wire is run inside the length of copper tubing which connects the plates together. Notice how electrode voltages are fed to the mid-points of the plate and grid loops or coils.

The circuit shown in Fig. *12B* is a tuned grid, tuned plate oscillator (essentially the same as the fundamental Armstrong circuit shown in Fig. *6H*), but using parallel pipes which may or may not be concentric. So-called quarter wave length lines are used to tune the grid and plate circuits. Since the grid tank circuit governs the frequency, it should be mechanically designed so that temperature changes do not affect its physical length. The

*The coil tap can be grounded directly or through a condenser; either procedure places the coil tap at zero A.C. potential with respect to ground.

plate tuned line can be replaced with a coil and condenser (or coil alone) to conserve space, for it merely needs to be tuned slightly inductive.

Fig. *12C* is the ultra-audion circuit shown in Fig. *6F* with parallel lines substituted for a coil-condenser tank circuit; whereas the grid and plate in Fig. *12B* were tapped along the line and the filament was connected to the end of the line, in Fig. *12C* the grid and plate are tapped opposite each other along the line. The latter method gives twice the A.C. tank voltage. The taps are made variable so a better impedance match can be obtained, giving better circuit efficiency and stability. Points *1* and *2* in either circuit are load-coupling points and are usually variable as to position.

The three circuits in Fig. *12* are widely used in television transmitters, where high power and good frequency stability are required. They will operate at from 50 to 200 megacycles, the higher frequencies generally

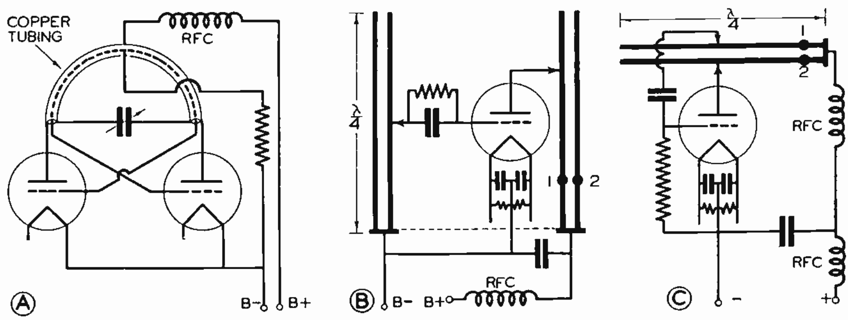


FIG. 12. Three high power ultra-high frequency oscillator circuits which are widely used in television transmitters.

being used to relay a program from a pick-up point to the main studio or from studio to transmitter. Amateurs use these circuits for communication in the 5 meter (56 megacycle) band. Air core coils and midget variable condensers are preferred in television receivers, although lines are occasionally used where space permits.

DYNATRON OSCILLATORS

When the voltage applied to a resistor is increased, we naturally expect the current through the resistor to increase. Likewise, when the plate voltage of a tube is increased (the grid bias being at less than cut-off), we expect that plate current will increase. But under certain circumstances, especially with vacuum tubes, it is found that the current actually *decreases* when the voltage is increased. This can mean only one thing, that somehow the vacuum tube is feeding energy back into the circuit. A circuit acting like this is said to have *negative resistance.** Naturally, when an

*By definition, resistance is voltage divided by current. A generator can be looked upon as a resistor whose ohmic value is equal to the generated voltage divided by the current flowing; since this voltage is equal and opposite to a real or positive voltage drop in a resistance, the generated voltage has a *negative resistance* effect; it cancels the effects of real resistance, supplying the power required by the real resistance.

oscillator tank circuit is connected to terminals which are acting as generator terminals and which have this negative resistance effect, the oscillator circuit will be fed with energy to overcome its resistance loss and oscillation will take place.

A Dynatron Oscillator Circuit. A screen grid tube is one device which can act as a negative resistance. When the plate is at a lower positive voltage than the screen grid, considerable secondary emission will take place at the plate, and these secondary electrons will be attracted to the screen. An increase in the plate supply voltage (but not above the screen grid voltage) increases the secondary emission, thus making the plate current decrease; the screen therefore gets more electrons than the plate. A typical oscillator circuit using a screen grid tube is shown in Fig. *13A;* this is known as a *dynatron* oscillator circuit. For a given C bias voltage (determined by the setting of P_2) a plate voltage-plate current characteristic like that in Fig. *13B* is obtained. Notice that after E_P reaches about

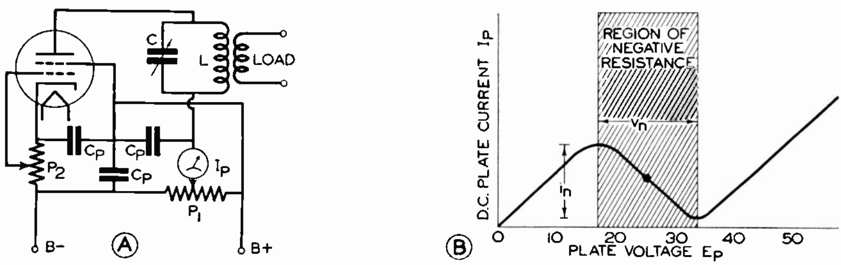


FIG. 13. A dynatron oscillator circuit (*A*) and its plate-voltage plate-current characteristic (*B*).

17 volts, further increases up to about 34 volts actually reduce I_P. This means that when the plate voltage of a screen grid tube varies within the shaded region in Fig. *13B,* the tube will behave as if it had a *negative resistance* equal in ohmic value to v_n divided by i_n.

In the dynatron circuit of Fig. *13A* this negative resistance characteristic makes the tube act as a generator which supplies energy to the *L-C* tank circuit to overcome resistance losses. *Oscillation will occur in a dynatron circuit whenever the resonant resistance of the L-C tank circuit is numerically greater than the negative resistance of the tube.* The minimum oscillator output voltage, v_n, is obtained when the two resistances are practically equal; increasing the resonant resistance makes the oscillator output voltage swing beyond the shaded area in Fig. *13B.* Oscillation is most stable when the D.C. plate voltage is in the middle of the region of negative resistance. A dynatron oscillator delivers a nearly pure sine wave voltage to a load which is inductively coupled to the tank circuit coil.

Oftentimes we get dynatron oscillator action in a vacuum tube circuit where it is not desired, resulting in squeals. The undesired oscillations are then known as *parasitic oscillations;* they can be stopped by increasing the D.C. plate voltage to get it beyond the region of negative resistance in Fig. *13B,* by adjusting the C bias to get this same result, or by inserting in the plate lead of the tube a resistor which will make the negative resistance of the tube too high for oscillation to occur.

RELAXATION OSCILLATORS

The cathode ray tubes used in television pick-up cameras, in television picture reconstructors and in cathode ray oscillographs used for testing purposes, require a special kind of oscillator, one which will produce a "saw tooth" voltage or current characteristic like that shown in Fig. *14A*. This saw tooth wave form is needed to sweep the electron beam at a uniform rate across the cathode ray tube screen, then return it almost instantly to the starting point for another sweep. Oscillators capable of producing a saw tooth wave form are known as sweep oscillators or as *saw tooth oscillators*. In radio circuit testing work, oscillators capable of producing the *square top* wave form shown in Fig. *14B* are required, for this wave form results in strong harmonics.

In general, circuits for these saw tooth and square top oscillators use a condenser which is alternately charged up by a D.C. voltage and discharged by an electrical device such as a gaseous glow tube. The output voltage drops to zero or *relaxes* for a definite fraction of each cycle, and such units are therefore called *relaxation oscillators*.

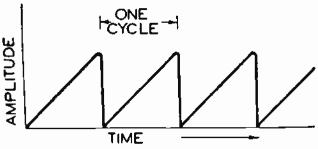


Fig. 14A. One type of relaxation oscillator produces this *saw-tooth* wave form, which gives the sweep voltage required for cathode ray tubes.

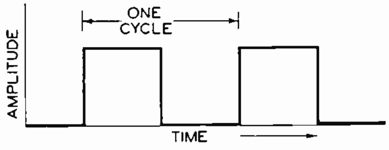


Fig. 14B. Another form of relaxation oscillator produces this *square-top* wave, used in laboratory oscillators because it produces very strong harmonics.

The simplest circuit for generating a saw tooth voltage is given in Fig. *15A*. In this circuit *N* is a neon glow tube consisting of two electrodes in a glass envelope filled with neon gas. This tube will not conduct electricity until a definite voltage, called its *firing* or *ignition* voltage, is applied; the tube resistance then becomes very low and a large current can flow unless it is limited by a resistance. Thus, when a condenser *C* is charged through resistor *R*, the condenser voltage gradually builds up (depending on the time constant; *R* in megohms times *C* in microfarads gives time in seconds), until the voltage across *C* is high enough to ignite the neon tube. The resulting flow of current through *N* lowers its resistance materially, thus shorting the condenser and dropping its voltage practically to zero (most of the line voltage being taken by *R*) ; the neon tube then stops glowing or firing and the action starts over again. The frequency is controlled by the characteristics of *N*, the values of *C* and *R*, and the value of the D.C. supply voltage.

Gaseous Triode Circuit. A gaseous triode tube is often used with a condenser-resistor charging circuit to produce a saw tooth wave, it being easier to control the firing voltage of this tube than of a diode. In Fig. *15B*, *T* is a Thyratron tube (mercury vapor-filled) or a grid glow tube (filled with neon gas). Conduction through the tube depends upon the ratio of plate to grid voltages; the more negative the C bias, the higher the plate voltage must be before the tube will conduct current. Once conduction starts, only the reduction of plate voltage to a very low value will stop current flow. In this circuit the condenser voltage builds up gradually through R until sufficiently high to fire the tube; the condenser is momentarily short-circuited by the tube as it discharges, the tube stops conducting and the charging of C starts over again. The frequency is essentially controlled by the values of C and R, for the plate and grid voltages are usually adjusted to correspond to the desired time constant. A controlling signal, such as the line or picture frequency of a television broadcast, can be introduced at point X, if the C bias is made sufficiently high so that the tube will discharge only when the controlling impulse is applied. The circuit can thus be made to produce a saw tooth signal output which is in synchronism with an input signal.

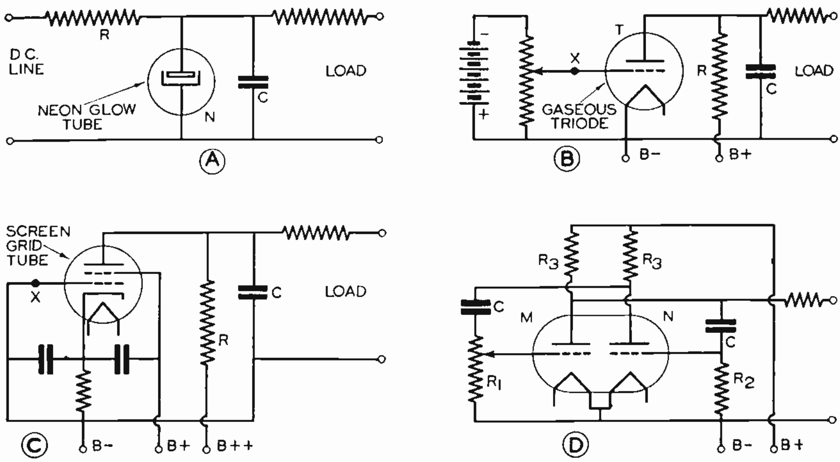


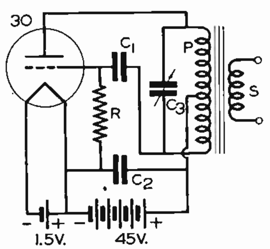
Fig. 15. Relaxation oscillator circuits.

An electron-coupled vacuum tube amplifier may be used instead of the gaseous tube signal circuit; a screen grid tube circuit is shown in Fig. *15C*. Space (cathode) current is made to flow by applying a positive voltage to the screen and a negative C bias voltage to the grid. Only a negligibly small current flows to the plate until it is placed at a very high voltage; at that point the plate-to-cathode resistance drops to a low value. Again a condenser charged through a resistor is used to build up a voltage which will break down the resistance of the tube (which is in parallel with the condenser).

In the circuits of Fig. *15A, 15B* and *15C,* the desired saw tooth voltage is obtained by connecting the load across condenser C. A resistor of high ohmic value (10 to 30 times the value of R) is placed in series with the load to insure a uniform build-up of voltage across C. Quite often, charging resistor R is replaced by a vacuum tube, the cathode-to-plate resistance of the tube serving as a self-regulating high resistance. The tube has the characteristic of making the condenser charge more evenly with time; in either case the presence of the charging resistor prevents the condenser from being charged to line voltage.

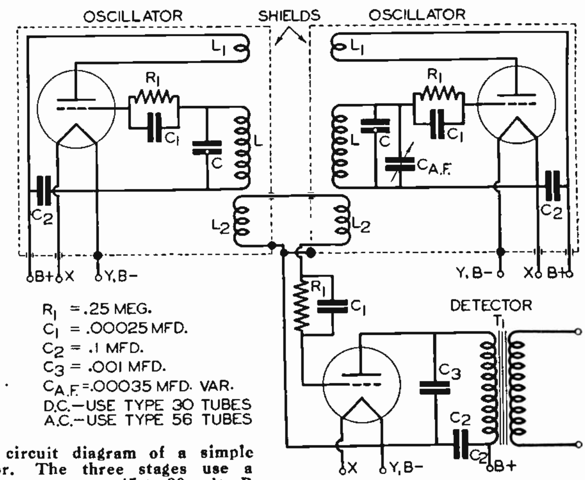
The Multivibrator. This important type of relaxation oscillator, which produces the square top wave form shown in Fig. *14B,* depends for its operation upon the fact that the input and output voltages of a resistance-coupled amplifier are 180 degrees out of phase. The multivibrator circuit consists of two amplifiers connected as in Fig. *15D*, each amplifier using one section of the double triode tube.

The operation of this circuit is a sort of "see-saw" affair in which first one tube and then the other passes plate current to produce the desired square top wave. When the circuit is first placed in operation, an increase in plate current in one tube causes a decrease in plate current in the other (because the two stages are out of phase with each other), and this initial increase is reamplified almost instantly to make the current in that tube rise to a maximum while the plate current in the other tube drops to



R = 50.000 OHMS
C1 = .005 TO .05 MFD.
C2 = 1.0 MFD., 200V.
C3 = .01 TO .1 MFD.

Fig. 16A (above). A typical audio frequency Hartley oscillator circuit.



R1 = .25 MEG.
C1 = .00025 MFD.
C2 = .1 MFD.
C3 = .001 MFD.
CA.F. = .00035 MFD. VAR.
D.C.—USE TYPE 30 TUBES
A.C.—USE TYPE 56 TUBES

Fig. 16B (right). Schematic circuit diagram of a simple beat frequency A.F. oscillator. The three stages use a common filament supply and a common 45-to-90-volt B supply battery. L, L_1 and C in each oscillator circuit comprise a tuned grid, low frequency I.F. transformer such as is used in inexpensive midget receivers; coil L_2 consists of 25 turns wound over coil L.

zero. Current continues to flow through the tube, forming one square-top portion of the wave, until such time as leakage through the resistor and condenser cause a slight plate current increase in the non-conducting tube; this increase is almost instantly amplified and reamplified, forcing current in the first tube down to zero. The time interval for which the current flows in each tube depends upon the values of R_1, R_2, R_3, and C, unless an A.C. control voltage is applied to one of the grids to set the rate of oscillation. This controlling signal may be the fundamental frequency or any harmonic of the natural frequency of the multivibrator; the input signal, which may come from a crystal oscillator, therefore controls the stability of the multivibrator.

AUDIO AND BEAT FREQUENCY OSCILLATORS

Oscillators which produce signals in the aural band (from about 30 to 16,000 cycles) differ in no way from R.F. oscillators; it is merely a matter of getting a sufficiently high inductance and capacity in the tank circuit. For a 100 cycle oscillator the inductance should be about 25 henrys if the capacity is .1 mfd., and 2.5 henrys if the capacity is 1 mfd. Air core coils with inductances of this order would be enormous. Saturation in iron core coils introduces distortion, but if an appreciable air gap exists in the magnetic path an A.F. signal which is entirely satisfactory for radio testing (defect isolation) purposes can be had.

A typical Hartley audio frequency oscillator circuit is shown in Fig. *16A*. The iron core coil can be the output transformer of a push-pull amplifier. Grid condenser C_1 must be rather high in value, for it must offer a low reactance to low frequency audio signals. Tuning is accomplished by varying C_3, the maximum frequency being governed by the distributed capacity of the transformer windings.

Beat Frequency A.F. Oscillators. Iron core coils having a low distributed capacity and operating below saturation are costly and even difficult to build in units which will cover satisfactorily the entire A.F. band with a single tuning condenser. For this reason audio oscillators generally employ the beat between two low R.F. signals. For example, if a 100 kc. and

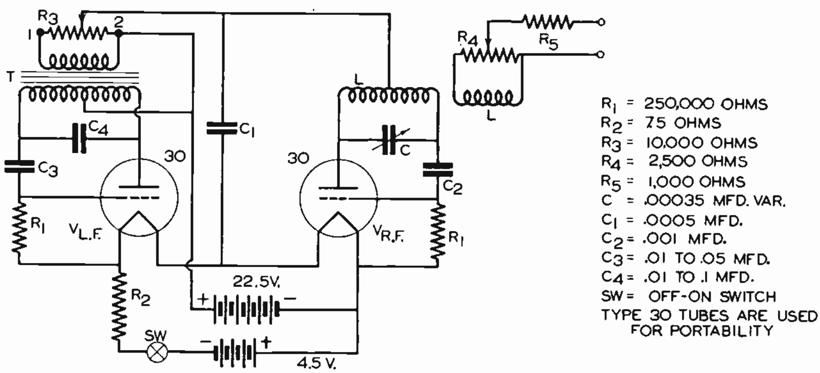


Fig. 17. Schematic circuit diagram of a typical modulated R.F. oscillator.

a 102 kc. signal are fed to a detector, the 2,000 cycle difference frequency will appear in the plate circuit. If the load is coupled to the detector plate circuit with an iron core transformer having a condenser shunted across its primary, the two fundamental frequencies and the 202 kc. sum frequency will automatically be shorted out or by-passed. Beat A.F. oscillators are widely used for testing and for precision checking work. The great difficulty lies in preventing the two R.F. oscillators from drifting in frequency.

The circuit of a beat frequency oscillator, built from parts found in the average radio shop, is given in Fig. *16B*. Each R.F. oscillator should be placed in an individual shielded compartment. With C_{AF} set at minimum capacity, adjust either of condensers C until the D.C. plate current in the detector is at its no-excitation value; this places both oscillators at the same frequency and there will therefore be no audio output.

Calibration of this oscillator is rather difficult with ordinary equipment, but a rough calibration can be obtained by comparing the audio beat output notes for various settings of C_{AF} with notes produced by tuning forks of known frequency. For precision results, it is far better to buy a commercial A.F. oscillator than to build your own.

A SERVICEMAN'S MODULATED TEST OSCILLATOR

All of the oscillators discussed so far produce constant amplitude A.C. signals. In testing radio receivers, however, the modulated radio signal ordinarily picked up must be replaced by an equivalent test signal. An R.F. oscillator which is modulated with an audio or video signal is, therefore, needed by a serviceman. There are many ways of producing this, but in a test oscillator (or signal generator) the easiest way to get this is to vary the D.C. plate voltage applied to the R.F. oscillator by introducing an A.C. voltage of an audio or video frequency. Figure *17* shows a typical modulated R.F. oscillator extensively used by servicemen; the low frequency or modulating signal is produced in the V_{LF} oscillator, the output from transformer *T* being connected in series with the D.C. plate supply to tube V_{RF} in the R.F. oscillator circuit. The degree or percentage of modulation is varied by varying R_3, which changes the amount of low frequency voltage.

The low frequency oscillator could just as well be replaced by an electric phonograph reproducer whose output was fed to points *1* and *2*. For testing all-wave receivers, coils *L-L* should be of the plug-in type; otherwise an arrangement whereby a switching mechanism inserts the proper coils must be used. Calibration of the oscillator is quite a tedious and exacting process, and since test oscillators are inexpensive, commercial equipment is always preferred.

TEST QUESTIONS

Be sure to number your Answer Sheet 21FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In a *vacuum tube* oscillator, are the power losses in the L-C oscillatory circuit compensated for *constantly* or *intermittently*?
2. What, in a self-excited vacuum tube oscillator, essentially governs the frequency?
3. Give another name for the oscillatory circuit.
4. In the oscillator circuit of Fig. *4*, what two parts automatically supply a steady D.C. bias voltage to the grid?
5. What happens if the ohmic value of the grid resistor in a self-excited vacuum tube oscillator (such as R_C in Fig. *4*) is made too high?
6. When a load is applied to the tank circuit of a self-excited vacuum tube oscillator, will the D.C. plate current *increase* or *decrease*?
7. Can the power output of a self-excited vacuum tube oscillator be increased by increasing the D.C. plate supply voltage?
8. How can the Hartley oscillator circuit be identified?
9. What is the purpose of the parallel resonant plate circuit in the tuned grid, tuned plate Armstrong oscillator?
10. To what part of a self-excited oscillator circuit should the load be coupled in order to feed it with the fundamental oscillator signal?

HOW SOUNDS AND SCENES ARE CONVERTED INTO AND REPRODUCED FROM ELECTRICAL SIGNALS

14FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

CONVERSATIONALLY SPEAKING

I enjoy conversation as well as any man, but I realize that there is danger in thoughtless conversation. Too many of us say things, unintentionally of course, which hurt, irritate or embarrass a friend—and a word once spoken can never be unspoken. "Think before you talk"—observe this rule if you would avoid conversational "boners."

Conversation is a give-and-take proposition, and listening is the "take" part. Talk only when you can say something of interest; otherwise remain silent. Let your silence be eloquent enough to show that you derive pleasure from listening—that you consider the words of your companion far more valuable than anything you could say; this kind of silence can make just as many friends as good conversation.

Talk about interesting incidents in your daily life—about interesting people you know, interesting places you have visited, anything which will please your listeners. If you are prone to "run dry," be on the lookout at all times for conversational topics; jot them down in an "ideas" notebook if you like.

Avoid expressing definite opinions on controversial subjects, for they often lead to unpleasant arguments. Ridicule of another is likewise taboo, regardless of whether or not that person is present. If you can't say pleasant things about others, keep quiet. Finally, reserve technical discussions for technically-minded listeners.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

How Sounds and Scenes Are Converted into and Reproduced from Electrical Signals

INTRODUCTION

RADIO, as you already know, is *a means of sending intelligence through space.* Radio, requiring no man-made paths between sending and receiving points, is obviously more desirable in many cases than communication systems which send the same intelligence over land wires or cables..

The three forms of intelligence which can be sent over either wire or radio communication systems are: *1, sound,* such as is used in radio broadcasting, in radiotelephone communication and in telephone systems; *2, pictures,* either still or moving, such as are transmitted by radio or land wire television and facsimile systems; *3, code,* such as the dots and dashes used in radio and wire telegraphy. Although land wire telephone, telegraph and picture-transmitting systems are not of particular importance to radio men, they differ from radio systems only in the method used for transmitting the intelligence from the sending to the receiving point; in fact, research work carried out by telegraph and telephone companies has contributed much to the improvement of radio apparatus and technique.

Sounds and scenes represent intelligence which must be converted into equivalent electrical forms before being sent over wires or given "rides" through space on radio carriers. At the receiving end, the intelligence signals pass through many electrical circuits before being converted back into the original sounds or scenes. Code transmission, on the other hand, is obtained simply by opening and closing a key in the transmitter circuit, which in the case of radio causes the carrier current to be fed intermittently to the antenna, and in the case of wire telegraphy sends pulses of current over the land wires. Let us first consider sound.

SOUND IS A WAVE MOTION

The great majority of people, if asked what sound is, would give an answer something like "sound is that which we hear." To the average person this answer is perfectly satisfactory, for only those sounds which he can hear are of importance to him. The technically-minded person wants a more basic definition, one which definitely tells the exact nature of sound; to him, *sound is a vibration in an elastic medium.* Air, water, steel, oil, glass and crystals are good elastic mediums; materials like putty, cork, asbestos, wood, wood pulp and soft rubber are rather poor elastic mediums. When an elastic medium vibrates we have sound, and this sound can be heard (is audible) *provided its frequency of vibration is neither too low nor too high to be detected by our ears.* A perfect vacuum (pure space) cannot transmit sound vibrations because a vacuum is not an elastic medium and therefore cannot vibrate. For example, if a comet exploded in inter-stellar space, which is a perfect vacuum, no sound would be produced because there would be no elastic medium.

We hear sounds because the vibrations which reach our ears through air (a good elastic medium) actuate the nerve centers in our aural "mechanism," and these nerve centers transmit impulses to the brain. Through years of experience from childhood on, our brain has acquired the ability to interpret these vibrations, with the result that we recognize and respond to them. Ordinarily, air is the conducting medium between a vibrating elastic material and our ears, but if the vibrating object is placed against the bony region surrounding the back of the ear, we can hear sound without air as a conducting medium. Take a long-bladed knife, set the blade into vibration by striking it, and bring the vibrating blade near your ear; you will hear a sound. Now hold the knife handle lightly between two

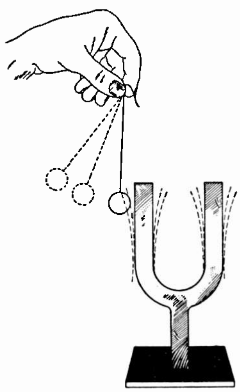


FIG. 1. Tuning fork experiment; the ball bounces away, proving that the fork is vibrating.

fingers and press the handle against the bone near your ear; again you will hear a sound, but now you have a direct conduction of the vibrations from the vibrating elastic material to your ear.

Producing Sound Waves. Striking metal objects together, rustling stiff paper, producing an explosion, plucking a stiff wire or spring, vibrating our vocal chords, and rubbing one object against another are just a few well-known ways of producing sound waves. The act of producing sound by impact causes some of the molecules in the object to move slightly; this movement is relayed to the ends of the object through the tightly-packed molecules and then reflected back and forth repeatedly, setting the entire object into vibration. Each object has its own definite *mass* (sometimes called mechanical inductance), *willingness to move* (sometimes called mechanical capacity) and *resistance to motion;* these three characteristics are different for various objects and materials, and therefore each produces its own peculiar vibration. If the vibrating object is surrounded by an elastic medium like air, water or steel, the vibrations are propagated (transmitted) along and through this medium until they die out because of the mechanical resistance of the medium.

Although we ordinarily think of air as an elastic medium which *transmits* sound vibrations, sound can also originate in air. A whistle is an example; a strong blast of air through the whistle sets the surrounding air into vibration, and we hear sounds.

Tuning Fork Experiment. The tuning fork used by piano tuners is illustrated in Fig. *1;* by holding the stem or handle of this fork in your hand and striking one of the prongs with some object, you can set the fork into vibration. You can feel this vibration and often actually see the prongs move; if a small ball suspended by a thread is brought against one of the prongs, the ball will be kicked away. Final proof that the fork is vibrating is the fact that you can actually hear the vibrations; the molecules in the surrounding air are set into motion, and energy moves away from the fork in straight lines in all directions.

Billiard Ball Experiment. If you play billiards, here is a simple experiment you can perform. Line up a number of ivory balls on the billiard table, close together but not necessarily touching, as illustrated at *A* in Fig. *2*. If, now, you direct ball *1* at ball *2*, (Fig. *2B*), the energy of ball *1* will be relayed from ball to ball, (Fig. *2C*), and finally imparted to ball *8* (Fig. *2D*), which will roll off just as if it had been hit directly. This is exactly how molecules in air, in steel, in water or in

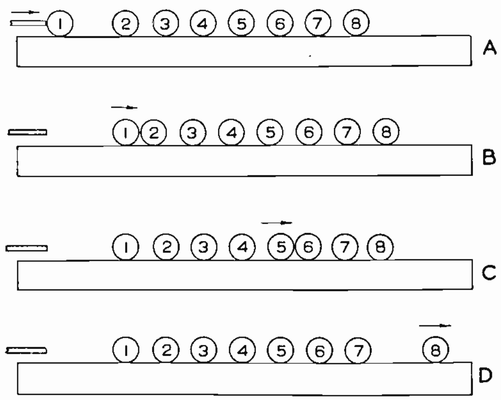


FIG. 2. Billiard ball experiment; the energy imparted to ball *1* by the cue at the left is relayed from ball to ball and finally transferred to ball *8*. Sound energy is transferred from molecule to molecule in much the same way.

any other elastic medium relay their original vibrations from one molecule to the next when transmitting a sound; the molecules in the transmitting medium vibrate to and fro *along the* path of sound wave movement in a manner which is sometimes spoken of as *longitudinal propagation.*

Piano Experiment. Sound waves ordinarily spread "fan-like" in many directions from the source (unless some means is taken to reflect them in certain directions). When a piano wire is struck by a hammer, the wire vibrates, alternately compressing and expanding the air near it on all sides, with the result that the sound waves which are produced travel out in many different directions. The wire continues to vibrate and produce sound waves for some time after the hammer is removed. Figure *3* illustrates the nature of the sound waves traveling out in one particular direction from the vibrating wire; it represents what would be seen if we could photograph conditions in the air at one instant. The air particles or molecules are *compressed* together at points *A* and are spread apart (*rarified*) at points *B*. These points of compression and rarefaction move away from the wire at a speed of about 1,089 feet per second (the speed of sound through air), so that at any one fixed point in space we have alternate compression and rarefaction as the sound wave moves past. This is why sound is called a wave motion. The billiard ball experiment showed how one pulse or wave was transmitted; this piano experiment illustrates how many pulses, produced one after another at a steady rate by the vibrating wire, are transmitted through an elastic medium in much the same manner.

A flexible metal diaphragm placed in the path of these sound waves would be moved back and forth according to the variations in air pressure; if the horizontal reference line of the sine wave curve in Fig. *3* represents the at-rest position of the diaphragm, then points on the curve represent positions of the diaphragm at different instants of time. (For simplicity here, we have assumed that the wire is vibrating in a simple sine wave manner; an actual piano wire produces many harmonics and therefore has a complicated wave form.)

"One-Wire Telephone" Experiment. Sound waves travel through water, metal and other sound conducting materials in the same way as they travel through air. Sound waves travel through long, thin objects, such as wires which are acting as sound-conductors. There is an interesting experiment which many youngsters perform; a length of wire or waxed cord is stretched tightly between the centers of the bottoms of two coffee cans as shown in Fig. *4*, the open ends of the cans serving as the combination mouthpieces and earpieces of this improvised telephone system. A person talking or whispering into one can is heard distinctly at the

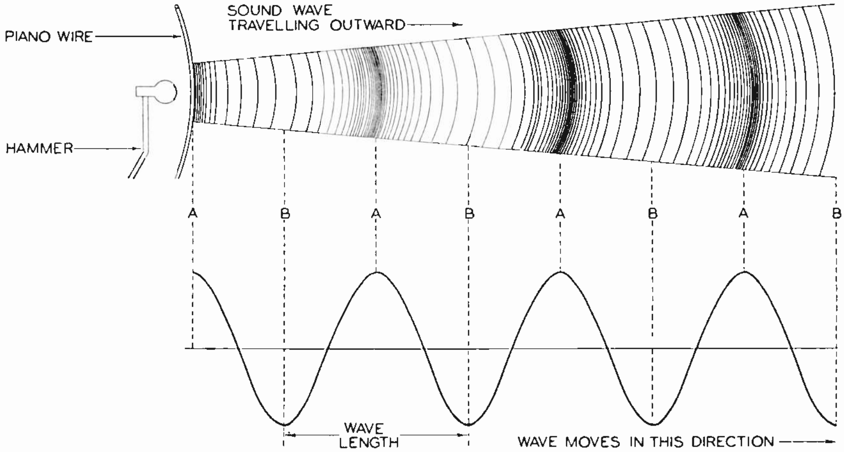


FIG. 3. Piano experiment; when a piano key is depressed, a hammer strikes a piano wire, setting it into vibration; these vibrations are transferred to the surrounding air (an elastic medium), alternately compressing (at A) and expanding (at B) the air, and the result is that sound waves travel out from the wire in many directions.

other can. If the bottom of can *A* is set into vibration by spoken sounds, these vibrations are conducted along the wire or cord, to set the bottom of can *B* into vibration in a similar manner, producing vibrations in air which the listener interprets as sound.

Speed of Sound Waves. The speed of sound waves in any solid or liquid material depends upon two things, the *elasticity* of the material and the *density* of the material. You know that a material can be made to stretch or compress by applying force; the amount of compressing or stretching (the increase or decrease in size) is called the strain. *The more force it takes to strain a material a given amount without permanently changing its shape, the greater is the elasticity or springiness of this material.* This is the scientific definition for elasticity; let me illustrate it with an example. Suppose you had two bracelets which were exactly the same size and shape, one being made of steel and the other of soft rubber. It takes much more force to squeeze the steel bracelet than the rubber one, and therefore steel is more elastic (according to the scientific definition) than rubber. As a general rule, the harder a material, the more elastic it is.

The density of a material is its weight per unit volume; if bricks of identical size are made up from various materials, the material in the heaviest brick will have the greatest density. The more elastic a sound-conducting material is, the faster can sound waves travel through it; the greater the density of a sound-conducting material, the slower will be the speed of sound waves through it. Both elasticity and density must therefore be considered when determining whether one material will transmit sound faster than another. Where objects have approximately equal densities, you can readily determine which will transmit sound waves the faster by comparing their elasticities; for example, sound waves travel faster through aluminum than through soft rubber, because aluminum has a higher elasticity.

Speed of Sound Waves Through Air. The speed of sound waves differs for various materials and even varies considerably with conditions in the same material. With air, for instance, the speed of sound waves increases with barometric pressure and with temperature; wind naturally affects the speed of sound and we must, therefore, consider only average conditions.

FIG. 4. One-wire telephone experiment; sound waves which are created when a person speaks into can *A* cause the bottom of the can to vibrate, and this vibrating motion is transmitted along the wire to can *B*, where it sets the bottom of the can into vibration and thus reproduces the words spoken into can *A*.

Careful laboratory experiments have shown that under normal conditions (and no wind) the speed of sound waves through air is about 1,089 feet per second.

Sound waves travel through water at the rate of 4,707 feet per second. Steel is about seven times as dense as water (which would tend to slow up sound waves), but its elasticity is so much greater than water that sound waves will travel through steel at 16,318 feet per second, almost four times the speed through water. Since the speed of electromagnetic waves (radio and light waves) is 186,000 miles per second, it is easy to understand why you can see lightning a long time before you hear the thunder which it produces.

Reflected, Transmitted and Absorbed Sounds. In radio and in the allied fields of public address and sound movies, we have a great deal to do with sounds produced in air. Ordinarily these sounds are produced in rooms or in confined places where walls, ceilings or floors prevent the sound from traveling out in all directions. When sound waves strike a material, they are either *reflected from the surface of the material, absorbed by the material* or *transmitted through the material;* these three factors which affect the movement of sound waves are illustrated in Fig. *5*.

Echoes. When sound waves are reflected by a flat surface which is quite far away from the source of sound, we may hear *echoes,* which are distinct but weaker reproductions of the original sound. Echoes are heard in many large rooms or in small rooms having curved walls which reflect the sound waves back to their source in a concentrated form. Echoes can be removed from a room by changing its shape or making it smaller; this clearly is a job for the architect.

Reverberation. When sound waves are repeatedly reflected back and forth between the walls of a room in a manner similar to that shown in Fig. *6*, the waves which reach the listener after reflection (over paths *2*, *3* and *4*) mix with the waves heard directly (over path *1*) to give "blurred" sound, or what is commonly called *reverberation.* The time required for a sound in a room to decrease to one-millionth of its original intensity is called the *reverberation period* of the room; auditoriums which have reverberation periods of between one and two seconds are considered to have good acoustic qualities. The reverberation period of a room can be reduced by placing sound-absorbing material on the walls and ceiling.

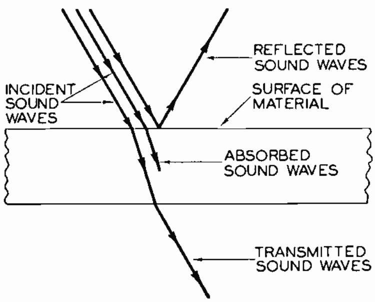


FIG. 5. The three things which can happen to a sound wave which hits the surface of a material are illustrated here. Sound waves behave much like rays of light.

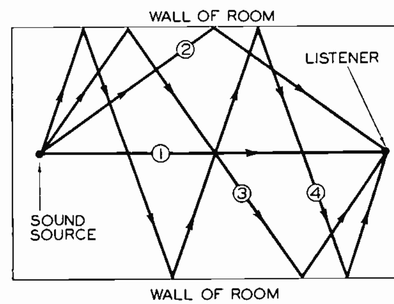


FIG. 6. Reverberations are produced in certain rooms because sounds come to the listener over many different paths. Sound waves which are reflected back and forth between the walls many times (curves *2*, *3* and *4*) must travel a greater distance, and consequently they arrive a little later than the direct wave (*1*).

Sound-Absorbing Materials. The better the sound-absorbing material used, the less sound will be reflected; an open window is actually an ideal sound "absorber," because it allows the sound to pass out of the room. Solid dense materials are good sound transmitters, and therefore poor absorbers; soft, pliable and porous materials like velvet, Celotex, rock wool, cotton, carpet and porous plaster are good sound-absorbing materials. The molecules in a good sound-absorbing material are able to move but cannot vibrate in step with the sound waves; they can, however, reflect sound waves internally in an irregular manner, changing the sound energy into heat. The thicker the material, the more absorption of sound there will be.

A sound-proof room must have good sound-absorbing surfaces if it is to keep out external sounds while absorbing sounds produced inside. The fact that an audience absorbs sound waves is recognized by public address technicians; they use directional loudspeakers which are directed at the audience rather than at the walls of the auditorium, in order to reduce reverberation and echo effects. The same thing is done in movie theatres; possibly you have noticed that the sound changes in quality as the size of the audience changes.

TECHNICAL FACTS ABOUT SOUND

Sound Waves Exert Pressure. A vibrating body, as you already know, produces sound waves. Since these sound waves consist of condensations and rarefactions of the particles in the transmitting medium, sound waves are best studied by measuring the pressure which they exert in the medium. Thus, in Fig. *3*, the pressure which the sound waves (produced by a vibrating piano wire) exert at any point varies in exactly the same manner as the motion of the wire. If the diaphragm mechanism shown in Fig. *7A* is placed in the path of a sound wave, the sound pressure will bend the diaphragm in and out and this motion will be traced on a moving strip of paper by the link and pencil mechanism. If the sound wave is of a simple sinusoidal form, the tracing on paper will resemble the sine wave shown in Fig. *7B*, and if the sound wave is of a complex form, the tracing will be somewhat like that shown in Fig. *7C*. By studying Fig. *7B* more closely, we can see that points *1* and *2* are conditions of normal air pressure, point *y* is a condition of high air pressure or compression, and points *x* represent conditions

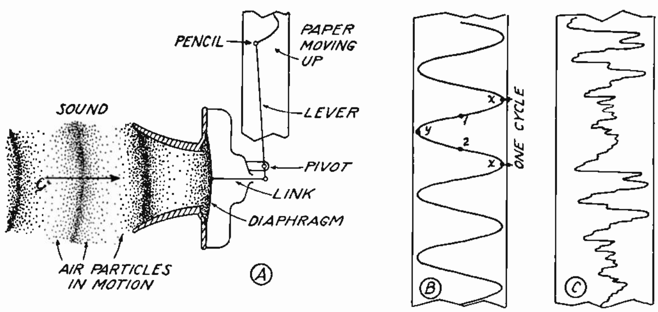


FIG. 7. The fact that sound waves exert a varying pressure on a diaphragm can be demonstrated with this simple apparatus.

of low air pressure or air rarefaction. Curve *x-1-y-2-x* represents one complete cycle, the time period for the cycle being given by the distance between points *x*. In actual practice, of course, the motion of the diaphragm would be converted into a varying electrical voltage which could be recorded by a cathode ray oscillograph, but the link mechanism shows us the form of the wave in a much simpler way.

A Sine Wave Has Two Characteristics. You will learn shortly that a complex sound wave, like that shown in Fig. *7C*, consists of a basic or fundamental frequency and many overtone or harmonic frequencies, each of which can be considered as a *simple sine wave*. Any sound having the form of a *simple sine wave* has two important characteristics: *1, amplitude* or *pressure; 2, frequency.* Just as we consider differences in voltage in electrical circuits, we consider differences in pressure here, for it is the *changes in pressure* which result in the movements of particles in a sound-conducting medium. The greater the change in pressure, the greater will be the response in our ears (loudness). Frequency is just as important as pressure, for frequency gives to sound a characteristic pitch and allows us to distinguish one sound from another even though they have the same loudness.

The Value of Harmonics. A loudspeaker connected to a simple sine wave electrical generator produces simple and pure sine wave sounds. Speech, music and noise, however, are never pure sine wave sounds; they always consist of a fundamental frequency and many higher frequencies which we call harmonics or overtones. The fundamental frequency gives to the sound its pitch, while the harmonics or overtones give certain characteristic qualities to a sound. Combinations of fundamental and harmonic frequencies give to speech and music distinguishing characteristics which, through experience, we are able to interpret. Thus we are able to distinguish between a harmonica, a trumpet, a violin, a flute and a tenor singer even though all may be producing the same fundamental frequency.

How Common Sounds "Look." The wave forms of a number of common sounds are illustrated in Fig. *8;* a cathode ray oscillograph would trace the wave shown at *A* if you were to say "ah" before a microphone which was suitably connected to the oscillograph. A greatly different wave form, that shown at *B,* results when the same sound "ah" is sung. The center key in a piano (known to musicians as "middle C") produces the wave form shown at *C,* while street noise gives the very jumbled wave form shown at *D.* You will note that with the exception of noise, wave forms of sound

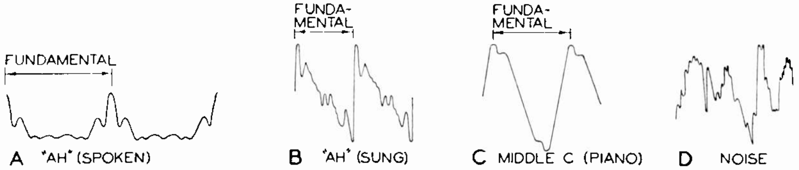


FIG. 8. Sounds can be seen as well as heard, if a cathode ray oscillograph is properly connected to a microphone; the curves shown here will actually be produced on the fluorescent screen of the cathode ray tube if the indicated sounds are produced within range of the microphone.

appear to repeat themselves at regular intervals; the time of one such interval determines the basic pitch or fundamental frequency of the sound. Experts have found the following facts about speech and music to be true.

1. Musical tones, whether produced by stringed instruments, wind instruments or the singing human voice, each consist of a fundamental frequency and a number of harmonics. For example, one of the C notes on a piano has a fundamental frequency of about 517 cycles per second; this note also contains a second harmonic of 1034 cycles, a third harmonic of 1551 cycles, a fourth harmonic of 2068 cycles and a fifth harmonic of 2585 cycles. Each harmonic can be considered as a pure sine wave tone, but the amplitudes of these harmonics differ greatly; the second harmonic in the above example is 20% of the amplitude of the fundamental, the third harmonic 25% of the fundamental, the fourth harmonic 10% and the fifth harmonic about 8% of the fundamental. In certain instruments some of the harmonics are missing, and in some cases a higher harmonic is stronger than a lower harmonic, or may be even stronger than the fundamental frequency. It is the harmonics which make musical tones pleasing.

2. Speech differs from music essentially in that the wave forms of music repeat themselves many times, while repetition of wave form in speech is almost negligible. Speech contains, besides a fundamental tone which distinguishes between the voices of children, women and men, many different higher frequencies with certain frequencies predominating to give the characteristic vowels and consonants of speech and the characteristic differences between the voices of different persons.

3. Noise signals have no basic frequencies and no clearly defined harmonic tones; the resulting sound is therefore not pleasing to the ear. Only skilled musicians and trained singers can produce acceptable music; others produce more or less noise.

4. The *octave* is a term commonly used by musicians and occasionally by radio men in speaking about the pitch of music. The word *octave* essentially means double frequency or one-half frequency; for example, when we say one note is an octave higher than the other, we mean that the first note is twice the frequency of the second (a 400 cycle note is one octave higher than a 200 cycle note); likewise a note which is one octave lower than another is half the frequency (a 100 cycle note is one octave lower than a 200 cycle note). In the accepted International Pitch Scale, the middle C note is 258.7 cycles per second; the next octave higher is 517.4 cycles, while the octave below middle C is 129.3 cycles.

Music. The piano, organ and harp produce the greatest ranges of *fundamental* frequencies, these musical instruments being capable of producing notes from about 16 to about 4,096 cycles. A baritone singer produces fundamental frequencies between 80 and about 400 cycles; a piccolo can "tweet" between 500 and about 5,000 cycles; a ukelele has the limited frequency range of between about 300 and 1,000 cycles. Thus each instrument has its own range of fundamental frequencies as well as harmonics or overtones of these fundamentals; radio apparatus must handle all of these fundamentals and the audible overtones if it is to give high fidelity reproduction.

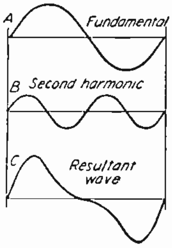


FIG. 9. The fact that odd-shaped wave forms contain harmonics is very easily proved graphically. By combining waves *A* and *B*, you get wave *C*.

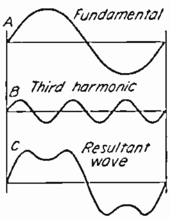


FIG. 10 (above). Here the double-humped curve (wave *C*) is produced by a fundamental sine wave and its third harmonic.

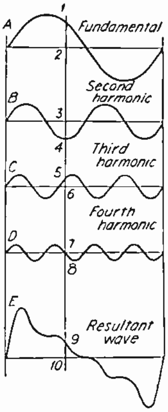


FIG. 11 (right). Many harmonics are present in wave *E*.

Practical Radio Aspects of Sound. From a practical point of view, we can limit our ideas on sound frequencies to a few simple facts. Radio apparatus is generally called upon to handle speech or music which may contain all frequencies between certain minimum and maximum values. Thus, the limits for ordinary speech are approximately 250 and 3,000 cycles; the frequency range for high quality speech and music extends from about 35 cycles to 8,500 cycles or even, in the opinion of some experts, up to 15,000 cycles. If the radio devices used are capable of handling all frequencies in the audible range (called audio frequencies), the fundamental and harmonic frequencies will be automatically taken care of. If all frequencies are handled equally well, there will be no distortion.

Harmonics in Odd-Shaped Wave Forms. Any wave form differing from a pure sine wave contains harmonics. You can prove this fact by introducing tuning circuits which will trap out the harmonic components. There is also a simple practical method, illustrated in Figs. *9, 10* and *11,* for proving that odd-shaped wave forms have harmonics. For example, wave form *C* in Fig. *9* can be obtained by combining fundamental frequency *A* with second harmonic *B;* wave form *C* in Fig. *10* consists of a fundamental frequency combined with a third harmonic, while wave form *E* in Fig. *11* is a combination of a fundamental, second harmonic, third harmonic and fourth harmonic, all added together. You can check this easily in Fig. *11* by measuring distance *1-2,* subtracting distance *3-4* from it, then adding distance *5-6;* the result will be distance *9-10,* a point on the resultant wave.

FREQUENCY AND AMPLITUDE DISTORTION

It should be clear to you now that speech and music is made up of a number of sine wave frequencies, each component having a definite frequency and a definite amplitude. The human ear readily detects *frequency* and *amplitude* changes, but cannot detect changes in phase between the components of sound waves. *Amplitude distortion* and *frequency* distortion are therefore the two objectionable types of distortion which can occur when a sound signal is passed through a radio vacuum tube stage.

Frequency Distortion. If one section or stage of a radio device *strengthens certain frequencies more than other frequencies,* or removes some frequencies entirely, the resulting sound will not be like the original and we will hear what is referred to as distorted reproduction or *frequency distortion* (sometimes called harmonic distortion because if the original sound wave is of a complex nature, its harmonics will not be properly amplified). Frequency distortion is produced essentially by the *circuit components* or *parts.*

Amplitude Distortion. On the other hand, when a signal passes through a radio stage which does not give the same proportional reproduction at each instant of time, *amplitude distortion* will result. A typical example of this, illustrated in Fig. *12A,* is that which occurs when the E_g-I_p curve of a tube is not linear in the operating range. As you can see, the sine wave input signal e_g has more control over plate current on its positive swing than on its negative swing, with the result that the plate current curve i_p is not a sine wave, and contains harmonics. This unequal control of plate current during positive and negative swings of the input voltage is known as amplitude distortion; mathematicians tell us that when wave forms are distorted in this way, harmonic frequencies which were not in the original signal are introduced. This fact can be partially explained by means of Fig. *12B;* when waves *2* and *3* are added to sine wave signal *1,* the result is the distorted wave at *4**. Amplitude distortion is objectionable, the odd harmonics being especially annoying to the ear. Amplitude distortion (also called wave form distortion) is produced almost entirely by vacuum *tubes.*

Testing for Distortion. We can test a circuit for amplitude distortion by introducing in it a pure sine wave signal of any frequency in the range for

* Waves *2* and *3* are half-wave rectified signals, and as you already know, each contains a fundamental and many even harmonics.

which the circuit is designed, and determining whether any harmonic frequencies are produced when the input signal is at the greatest voltage which will be encountered in actual practice. The presence of only one frequency, that which is fed into the circuit, in the output indicates that amplitude distortion is absent. To check for frequency distortion, we must feed various frequencies into the circuit and determine whether each frequency is amplified the same amount; only when amplitude and frequency distortion are absent can we be sure that true reproduction exists. Keep these two types of distortion in mind, for you will encounter them many times as you proceed with your studies and work.

THE HUMAN EAR

The human ear is by no means an ideal sound interpreting device, for it can hear certain desired sound frequencies while rejecting others. Human ears can actually become accustomed to frequency distortion and like it. A boomy radio receiver, sounding as if it were in a barrel, gives distorted reproduction but many persons like this; I have heard people say that modern high fidelity receivers do not sound as good as their 1930 model sets, and these people really meant what they said. Once the ear is trained

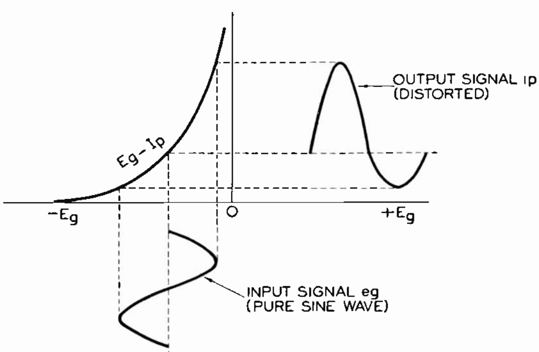


FIG. 12A. Amplitude distortion is produced because the E_g-I_p characteristic of the tube is not linear (straight) in the operating region; the output current wave is distorted.

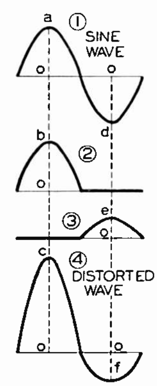


FIG. 12B. The addition of sine wave *1* to distorted waves *2* and *3* produces the resultant distorted output wave at *4*. (Note that adding *a o* to *b o* gives *c o*; subtracting *e o* from *d o* gives *f o*.)

to appreciate high fidelity, however, frequency distortion becomes very "sour"; as a rule, people with musical training can appreciate true high fidelity reproduction. Radio technicians should understand this queer behavior of the human ear; it is likewise of vital importance to the designer of radio apparatus. There is no need of spending time and money in reducing distortion when the improvement in high fidelity cannot be noticed by the average human ear; there is no need to make a receiver respond to frequencies which cannot be heard by the normal human ear.

By studying the responses of thousands of persons to sounds of various frequencies, the Bell Telephone Company has found that the average range of frequencies which can be heard extends from 20 cycles to 20,000 cycles; others claim that the average range is from 32 to 16,000 cycles. These tests also showed that the human ear is far more sensitive to sounds in the 1,000 to 4,000 cycle range than in sounds outside this range. Very high sound pressures are required before the ear can detect very low and very high frequencies in the audible range.

Sounds Can Cause Pain. When sound pressures are increased too high, a person stops hearing and actually begins to feel the sounds. At the lower frequencies the vibration of the air can be felt by all parts of the body, but at the high frequencies the action is more a sensation of pain in the ear. The response characteristic of the average human ear, obtained by noting when each frequency can just be heard and just felt, is given in Fig. *13*. A pure sine wave sound which could be varied in frequency from zero to 20,000 cycles was used in this test; the loudness of the sound was measured in terms of the pressure exerted on a flat surface. You will note that *at 2,000 cycles* it takes about .0005* bars of r.m.s. sound pressure to make the sound audible, and about 1,000 bars (2 r.m.s. pounds per square foot) before the sound can be felt; at this frequency, then, the pressure at the

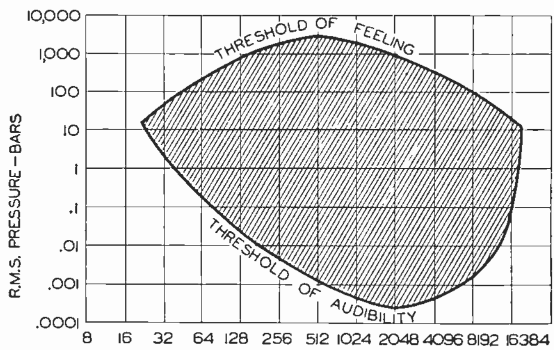


FIG. 13. The response of the average human ear to pure sine wave sounds of various frequencies is given here. Sounds in the shaded area can be heard. The effective or r.m.s. pressure of the sounds is here expressed in terms of "bars"; one bar equals .002 lb. per square foot.

threshold (the beginning) of feeling is about 2,000,000 times the pressure at the threshold of audibility. This difference in threshold values decreases for higher and lower frequencies, as you can see in Fig. *13*.

The Decibel. You might think that a 2,000 cycle sound at the threshold of feeling should seem 2,000,000 times louder to the human ear than a 2,000 cycle sound near the threshold of audibility, but this is not exactly the way in which the human ear responds. The amount by which a pure sine wave sound must be increased before the change in sound level can be distinguished by the average human ear is called a *decibel.* Doubling the pressure of a sound causes a 6 decibel increase in the ear's sensations. Increasing the pressure gradually to ten times its original value results in twenty sensations of increase in sound, or a 20 decibel (abbreviated 20 db) increase. Increasing the pressure one hundred times results in a 40 db increase; increasing the pressure one thousand times gives a 60 db increase,

* The bar is a metric term expressing *pressure per unit area;* one bar equals .002 pounds of pressure per square foot of surface. Since sound pressure on any material is varying continually, we must deal with the r.m.s. value of the pressure, just as we deal with r.m.s. values of current and voltage. Sound or acoustical power is proportional to the square of sound pressure, just as electrical power is proportional to the square of voltage (electrical pressure).

while 2,000,000 times corresponds to about 126 db. Thus you can see that increasing 2,000,000 times the sound pressure of a 2,000 cycle note gives the equivalent of 126 separate and distinguishable increases in sound, as far as the human ear is concerned.

Loudness of Common Sounds. You can get some idea of the relation between sound sensations and db levels from the following data; in each case the threshold of audibility is assumed to be 0 db. An ordinary whisper is at a level of about 15 db; the average noise in an office is about 40 db; ordinary conversation is about 55 db; the noise on a busy street is about 65 db; heavy street traffic is at about the 80 db level; a boiler shop where riveting machines are in action has a level of about 105 db; an airplane engine has about 110 db; thunder is about 115 db. Remember that these values are for complex sounds, not simple sine wave sounds.

Power Levels. Because the ear responds to sound in the peculiar way just described, radio men often prefer to speak of audio power in terms of decibels rather than electrical watts. They usually start with some arbitrary power level, such as 6 milliwatts, and say that it is zero level or zero db. Increasing the power to 10 times this zero level power corresponds to a

WATTS	DB	WATTS	DB	WATTS	DB	WATTS	DB	WATTS	DB
.00048	−11	.006	0	.076	11	.95	22	11.9	33
.00060	−10	.008	1	.095	12	1.2	23	15.2	34
.00076	−9	.010	2	.12	13	1.5	24	19.0	35
.00095	−8	.012	3	.15	14	1.9	25	23.7	36
.0012	−7	.015	4	.19	15	2.4	26	30.4	37
.0015	−6	.019	5	.24	16	3.0	27	38.0	38
.0020	−5	.024	6	.30	17	3.8	28	47.4	39
.0024	−4	.030	7	.38	18	4.7	29	60.0	40
.0030	−3	.038	8	.47	19	6.0	30	75.9	41
.0039	−2	.047	9	.60	20	7.6	31	94.9	42
.0048	−1	.060	10	.76	21	9.5	32	119	43

Fig. 14. Table giving relation between electrical power in watts and sound in decibels (db) when the zero db level is .006 watt. You will find many uses for this decibel table later in the Course.

10 db rise in power; likewise a decrease to one-tenth of the zero level power is a 10 db drop in power. Since power is the product of voltage and current in a resistance circuit, increasing 10 times either the voltage or current in an electrical circuit in which the resistance has not changed corresponds to a 20 db rise in power, because if one value is increased (either voltage or current), the other must also increase. You cannot compare power in terms of voltage and current in circuits having different resistances, and it is therefore always wise to compute powers and compare powers exclusively. The table in Fig. *14* gives db values for various values of power in watts when the reference level is .006 watt. You can see that 20 watts corresponds to about 35 db, 5 watts to 29.5 db, .002 watt to about 5 db below the zero level (commonly called 5 db down or minus 5 db, and written —5 db). If the table were continued down to even lower powers, you would find that .0002 watt is —15 db, .00002 watt is —25 db, etc.

There is no close connection between the electrical power input levels for a device and the sound output levels of the device unless the efficiency of the device is known.* When electrical power is converted into sound, however, the ear perceives definite sound sensations or loudness. Increasing the electrical power 5 db simply means that the sound sensation on the ear has also been raised 5 db, but the actual sound level in terms of bars of air pressure is not known.

Practical Aspects of Distortion. Now that we understand how frequency and amplitude distortion can be measured in terms of ear response, we can consider the practical aspects of distortion. The response of the ear to the complex sounds in speech and music is closely related to the decibel scale of response. Since the average human ear cannot detect changes less than about 3 db† in the intensity of complex sounds (corresponding to a power change of 3 db or a power ratio of about 2 to 1), frequency distortion is less troublesome to the radio engineer than would appear at first glance. Thus it is quite permissible to have radio apparatus amplify some frequencies almost twice as much as others or convert some frequencies into sound twice as well as others, for the human ear is not able to notice this amount of distortion. This characteristic of the human ear is very much appreciated by the radio engineer, since it is quite difficult for him to make radio apparatus amplify very low and very high frequencies equally as well as the in-between frequencies.

Amplitude distortion is more severe on the ear, for the introduction of strange frequencies into a program is readily detected. The average ear will not tolerate a third harmonic whose amplitude is greater than 5% of the amplitude of the fundamental, but will tolerate a second harmonic whose amplitude is as much as 10% of the fundamental.

If the very high frequencies are cut off by radio apparatus, sound loses some of its fidelity of reproduction; do not get the idea, however, that all high frequencies up to 20,000 cycles are necessary for understandability or appreciation of music. You can cut off sounds at about 3,000 cycles and still get understandable speech; you can cut off frequencies above 8,500 to 12,000 cycles and still get high quality speech and music. Why reproduce above 12,000 cycles when only young people and trained musicians are, as a rule, able to hear frequencies above that value at all, and when some very old people cannot even hear frequencies above 6,000 cycles? For all practical purposes it is not necessary to reproduce these high frequencies.

Most of the loudness of sound (sound power) is in the low frequency notes, and since the ear is not very sensitive to the lows and highs (low and high frequencies), the reproduction of sound at a level much below that of the original makes the music sound unreal. It is for this reason that the so-called low (or bass) boosters and high (treble) boosters are sometimes introduced into radio reproducers to amplify excessively these extreme frequencies and get effects which sound more natural to the ear. If you

* For example, 10 watts of electrical power fed into a cone type dynamic loudspeaker might give .5 watt of acoustical power output, while that same amount of electrical power fed into a horn type loudspeaker might give as much as 4 watts of acoustical (sound) power.

† As I said before, the average ear can distinguish a 1 db change in sound, but this is under carefully controlled conditions where the sound is a pure sine wave and the ear is alert to catch the slightest changes.

cut off the high notes, the speech and music sound "boomy," but fortunately most people like this.

SOUND PICK-UPS AND REPRODUCERS

Although you will study the operation and behavior of microphones and loudspeakers in detail later in this Course, at this time I want you to become familiar with the various types in common use. The principles of operation of five common types of microphones are illustrated in Fig. *15;* as you know, each of these is actuated by sound waves (motion or vibration of air), and *converts the sound into an equivalent electrical wave form.*

Carbon Microphone. Figure *15A* gives a simple sketch of the single-button carbon microphone; part *D,* a very thin aluminum disc or diaphragm (about .001 inch thick) is stretched over a fixed metal ring *R.* The pressure of sound waves on disc *D* moves the disc back and forth, alternately squeezing and loosening carbon particles *C* in the telescoping

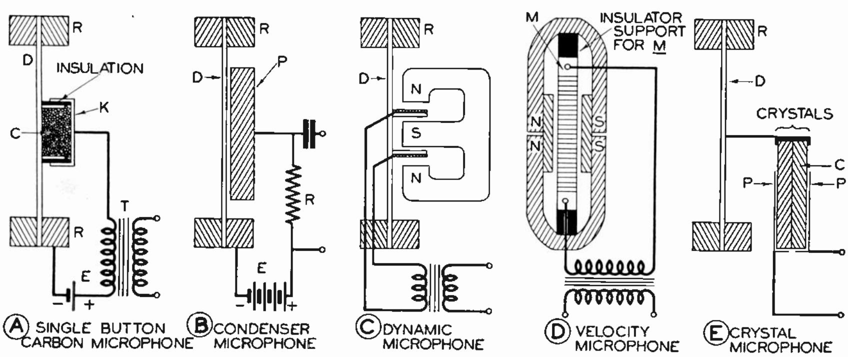


FIG. 15. Simplified diagrams illustrating the operating principles of five different types of microphones. Each converts changes in sound pressure into equivalent changes in electrical signals.

metal sack or button labeled *K.* The result is that the electrical resistance between disc *D* and container *K* varies continually with the motion of the diaphragm. When this single button microphone is placed in an electrical circuit containing a D.C. voltage *E,* the current passing through the circuit will vary in accordance with the wave form of the sound. Audio transformer *T* can be placed in this circuit to transfer the variations in current to another circuit.

Condenser Microphone. Figure *15B* shows a simplified cross-section view of a condenser microphone. The thin but stiff aluminum disc or diaphragm marked *D,* mounted on ring *R,* is placed about .001 inch away from the fixed heavy plate *P,* thus forming a simple two-plate air condenser. These two plates are connected into a circuit containing a high voltage D. C. supply *E* and resistor *R.* Varying sound pressures change the distance between *P* and *D,* changing the capacity of the condenser and thus changing its charge. The current through the circuit varies continually when the microphone picks up sound, and a varying voltage which has the same wave form as the original sound is produced across resistor *R.*

Dynamic Microphone. The dynamic microphone shown in Fig. *15C* has a thin diaphragm *D* on which is mounted a light-weight coil of wire; this coil moves between the poles of a permanent magnet when the action of sound moves the diaphragm; as a result there is induced in the coil a varying current whose wave form is a reproduction of the wave form of the sound.

Velocity Microphone. The velocity microphone illustrated in Fig. *15D* operates on much the same principle, except that here a thin crimped metal ribbon *M* moves in and out of a magnetic field produced by a permanent magnet under the action of sound waves, and a voltage is induced in this metal strip or ribbon. This induced voltage is stepped up by the transformer.

Crystal Microphone. The bending or straining of a Rochelle salt crystal produces on the opposite faces of the crystal an e.m.f. which is proportional to the strain; this principle is utilized in the crystal microphone illustrated in Fig. *15E,* where two square crystals are mounted back to back to increase the electrical action. This square crystal unit *C* is clamped at three of its corners and its free corner is linked to diaphragm *D*. Thus movements of the diaphragm caused by sound waves serve to bend the crystals; electrons which flow to the flat surfaces of the crystals under this bending are collected by metal collector plates *P*.

Headphones. Sound reproducers, such as headphones and loudspeakers, utilize audio power (electrical signals which represent sound waves) to set into motion a diaphragm or cone, alternately condensing and rarefying the air in front of the reproducer to reconstruct the original sound wave. In the common headphone unit, illustrated in Fig. *16A,* a thin flexible steel diaphragm is placed over the two poles of a horse-shoe magnet; a coil having many turns of insulated wire is placed around each leg of this magnet. The audio current flowing through the two coils alternately increases and decreases the attraction which the permanent magnet has on the diaphragm, causing the diaphragm to move in and out, and thus producing sound waves.

Magnetic Loudspeaker. Where a large displacement of air is required in order to secure a high sound output, large diaphragms or cones which can be moved appreciable distances by the reproducing device are required. The balanced armature electromagnetic reproducer shown in Fig. *16B* is widely used for this purpose; a soft steel armature is pivoted between two sets of N and S poles which are parts of a powerful permanent magnet. Also surrounding the armature is a solenoid or coil which carries the audio current. This coil makes the ends of the armature alternately of opposite polarity, as the audio current reverses its direction twice each cycle. The ends of the armature therefore move towards and away from the permanent magnet poles, this movement being mechanically relayed to the large paper cone. The action is such that the paper cone is pushed in and out, setting the surrounding air into vibration and producing sound which is a reproduction of the original wave form. The outer edge of the cone is designed in such a way that it can be attached to its ring-shaped supporting frame yet will still move freely in and out under the action of the armature.

Dynamic Loudspeaker. The dynamic loudspeaker shown in Fig. *16C* is, however, the most widely used sound reproducer, for it is capable of delivering high sound outputs. Here a coil of wire is wound on a thin bakelite or paper tube which is attached directly to a paper cone (as shown) or to a metal diaphragm (not shown). The audio signal passing through this coil causes the coil to slide alternately in and out of the magnetic field produced either by a permanent magnet or by an electromagnet. The separation between the north and south poles of the magnet is made as small as possible in order to get a strong magnetic field. A dynamic loudspeaker can handle from 3 to 50 watts of audio signal power (depending upon its size), while a balanced magnetic loudspeaker can handle between 1 and 3 watts and a headphone unit can handle only about 50 milliwatts.

ANALYZING A SCENE

Television involves the transmission of intelligence which affects our visual sense, this intelligence reaching our brain by means of the eyes.

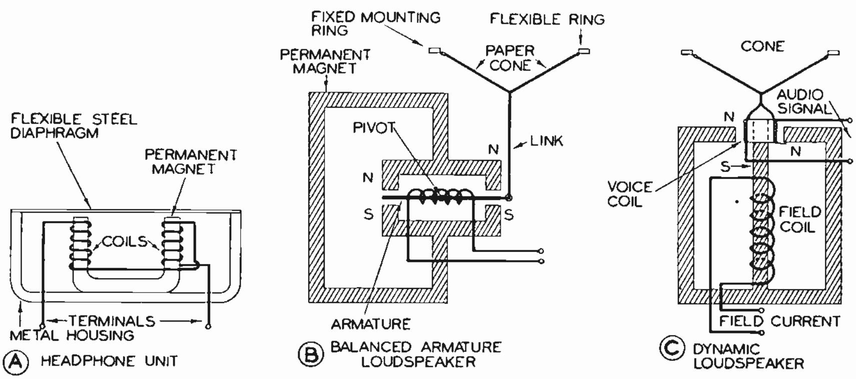


FIG. 16. Simplified diagrams illustrating the operating principles of three different types of sound reproducers, each of which converts electrical signal energy into mechanical energy, then converts mechanical energy into sound energy (sound waves).

First let us consider what the eye sees when it looks at an object. Ordinarily it looks at reflected light, made up of electromagnetic waves; occasionally it looks directly at light sources such as electric lamps, a fire or the sun. The eye sees color because the electromagnetic waves in the visual band have different frequencies, each frequency or group of frequencies giving us, through the action of our brain, a color sensation. The human eye serves as a complicated lens (much like the lens in a camera), for it projects these electromagnetic waves on the *retina,* a surface at the back part of the eye. This retina is composed of millions of nerve points, each of which is connected to the brain; these nerve points interpret the strength of each electromagnetic wave which hits them (as determined by the brightness of the object) and interpret the frequency of the wave (the color of the object).

One scientist calls the human eye nature's own ultra-ultra high frequency television system. The object viewed acts as the transmitter in the system, sending out electromagnetic waves which are picked up by the eye acting as a receiver, then relayed to the brain to give us the sensation of seeing.

A Suggested Television System. This action of our visual mechanism immediately suggests a method of constructing a television system. Why not arrange thousands or millions of tiny electric eyes on a screen to pick up the light waves, and connect these by thousands of wires or radio frequency transmitters to a receiver containing thousands of tiny glow lamps, each of which would reproduce the amount of light picked up by its corresponding electric eye, so the combination of all the lamps would reproduce the object viewed by the transmitter. Yes, a television system like this has actually been tried for land wire television, but only on a small scale; the scheme was found to work after a fashion, but obviously was far from practical. The cost of the system is prohibitive and the radio channel requirements,* if pictures were to be sent by radio, would be more than could be tolerated.

Persistence of Vision. The human eye retains an impression of an object for a short time after that object has disappeared from view; we call this characteristic of the eye its *persistence of vision.* Moving pictures are

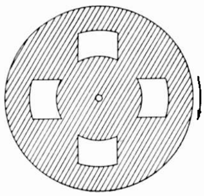


FIG. 17. Much like the revolving shutter of a movie projector is this disc; with your eyes in a position to see an object through the uppermost opening in the disc, you can demonstrate the "persistence of vision" characteristic of the eye by rotating the disc at various speeds.

based on this principle; about twenty-four pictures pass through the projector per second, each slightly different from the other. By revolving a disc similar to that shown in Fig. *17* (called a revolving shutter) in the path of the projected beam at such a speed that each picture is blocked out two or three times, persistence of vision "tricks" the eye into thinking it is seeing a moving scene made up of 48 or 72 separate pictures per second. The shutter thus eliminates the flicker which would be noticed if only twenty-four pictures were shown per second.

Television Problems. The great problem in practical television is to convert a scene into such a form that it can be sent over a single radio channel. With persistence of vision definitely recognized as a favorable characteristic of the eye, we can proceed to study the processes of separating an object into a series of impressions or small pictures, transmitting the electrical equivalents of these tiny pictures (the picture signal), receiving the picture signal, converting it back into light and rebuilding the picture. How can we take a scene and break it into an orderly series of light impressions? The answer is found in the reproductions of photographs which you see in newspapers, in magazines and in this Course.

Picture Elements. I will use the line drawing in Fig. *18A* as my illustration. We can reproduce this drawing in terms of equally spaced dots of different sizes as is done in Fig. *18B;* although this is nowhere near as good

* These frequency band width requirements will be considered shortly.

as the original, it is a recognizable reproduction. There are sixty dots on each line and sixty lines to the picture, giving a total of 3,600 dots or picture elements. By increasing the number of picture elements to 14,400, giving 120 dots per line and 120 lines, we get a much more faithful reproduction, as in Fig. *18C*. (Incidentally, photographic reproductions of this high quality are the standard for textbooks in this Course.) In breaking up an illustration, a photograph or an actual scene into rows of tiny elements for television purposes, we need not resort to large and small dots as we have in these illustrations, for the human eye and the electric eye are perfectly capable of viewing the same sized elements and interpreting differences in the intensity of light from each element to give the illusion of seeing a good reproduction.

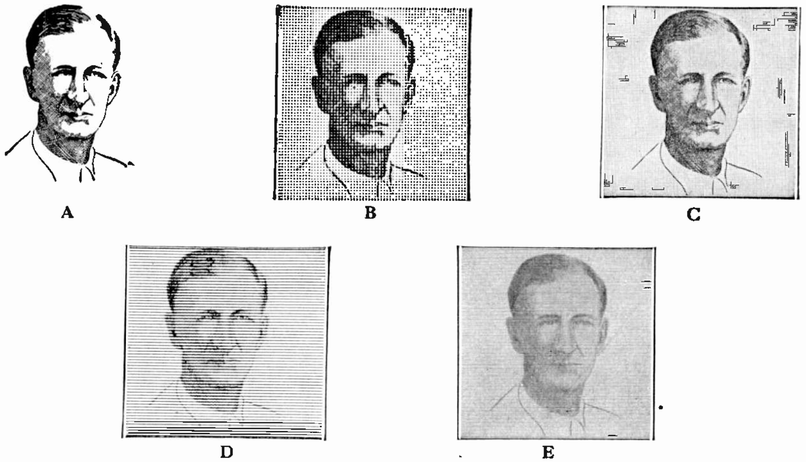


FIG. 18. When drawing *A* is reproduced by the process used in printing ordinary photographs, greater detail is obtained by using a large number of dots, as at *C*; when *A* is scanned horizontally, as it would be if transmitted over a television system, greater detail is obtained by using a large number of lines, as at *E*.

Television requires, therefore, a device which has a light-sensitive (photoelectric) surface and which will analyze the varying light coming from each element on a line of the scene, doing this for line after line of the scene, as shown in Figs. *18D* and *18E;* with a device like this we can convert a scene into a constantly varying electrical current. The more lines into which we break up the picture, the better will be the detail; Fig. *18E,* which has 120 lines, has more detail than Fig. *18D,* which has only sixty lines.

The next question which arises is that involving the number of lines required to reproduce satisfactorily the average scene or picture. The answer to this question involves additional analysis of the behavior of the eye, of the kind of picture sent (the number of objects in the scene), of whether the scene contains action, of the distance from which the reproduction is to be viewed, and of how large the reproduced scene must be. Of course, the more lines there are, the better is the reproduction, but increasing the number of lines places a greater burden upon the transmitting and receiving apparatus. Opinions vary; some experts recommend relatively low numbers of lines, while others state that the public will never be satisfied with anything which does not at least equal the detail present in modern moving pictures.

Note that as you move the illustrations in Fig. *18* farther and farther away from you, a point is reached for each illustration where the details seem to blend into a complete and nearly perfect reproduction of the original. This brings out an important fact about television; if a reproduced picture is made larger without increasing the number of lines, the picture will have to be viewed from a greater distance in order to get a satisfactory eye impression.

At the present time most experts are agreed that a 441 line picture, when reproduced 10 inches wide and 7½ inches high, and viewed from a distance of about 7 feet, gives satisfactory reproduction of average scenes.

SCANNING AND REPRODUCTION

Before considering the technical details of breaking up a scene into a number of lines, it will be valuable to get clearer ideas of how a scene is

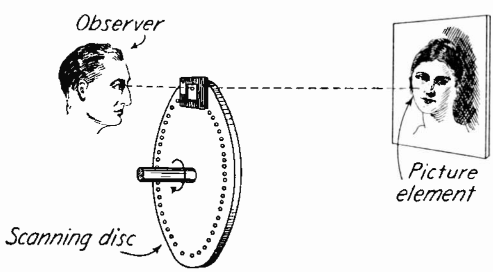


FIG. 19A. This diagram illustrates an elementary mechanical method of scanning a picture, using holes arranged spirally on a rotating disc; this is simply a theoretical example and *does not* represent a television system.

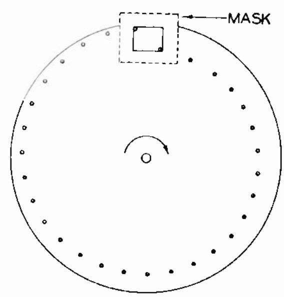


FIG. 19B. Arrangement of holes on a scanning disc which is to break up a picture or scene into 30 lines.

taken apart or *scanned,* and how a scene is reproduced. Only the basic schemes will be considered; naturally, different television experts have different ways of accomplishing the desired results.

You are really scanning this page when you read it, for you start at the upper left, read the first line, quickly swing your eyes back to the start of the second line and repeat, line after line, until you have read every line on the page.

Mechanical Scanning Methods. Even though mechanical methods of scanning are today considered inadequate, we will consider them first since they are easier to understand. Punch a hole in the center of a small business card with a pin and hold the card up to one of your eyes, so you can look through the hole. Turn to some object or scene; notice that you can see only a small part of this scene through the tiny hole. Now move the card horizontally from left to right; you see all the portions of the scene along the line which you are scanning. Move the card back and forth horizontally while shifting it vertically downward a little at the end of each line, and your eye will scan the entire scene, piece by piece.

The Scanning Disc. In place of this crude and illustrative scanning device, we can use the system shown in Fig. *19A,* in which a large number of holes are arranged in a spiral fashion on a rotating disc called the *scanning disc.* This disc really replaces the business card used in our previous example; one complete revolution of the disc gives one complete scanning of the entire picture, for each hole on the disc scans one line. If the disc is revolved fast enough, the entire picture can be seen at one time.

The exact arrangement of the holes on the scanning disc is more clearly shown in Fig. *19B*. The observer views the scene through the mask, a rectangular opening in a piece of black cardboard. As the disc is rotated, each hole moves across the opening in this mask, the outermost hole in the spiral moving across the top of the opening and each succeeding hole moving across one line down. Finally, when the innermost hole has moved across the bottom of the opening, at the end of one complete revolution, the outermost hole again scans the top line and the entire scanning process starts over again.

Mechanical Television Transmitters. If the observer in Fig. *19A* is replaced with a light-sensitive cell, this cell will deliver a varying electric current which is at all times proportional to the amount of light reaching the cell, and therefore proportional to the shade of lightness or darkness of the element of the picture being scanned at a particular instant; thus we have found a means of converting a picture or scene into a series of electrical impulses. These impulses or picture signals can be amplified and placed on a radio carrier for transmission through space; at the receiver, the carrier can be demodulated and the picture signal amplified sufficiently to operate a picture reproducer. If nothing has distorted the picture signal on its long jump from the actual scene to the reproduced scene, a high quality reproduction is obtained.

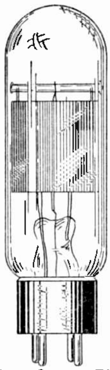


FIG. 20A. Glow lamp used in early mechanical television systems.

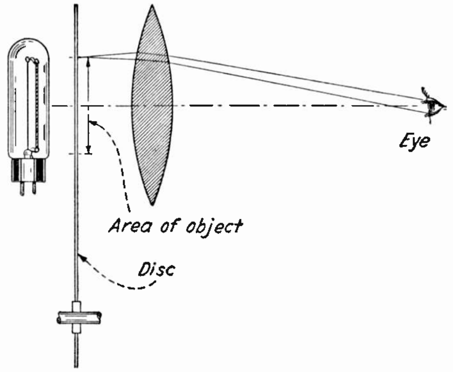
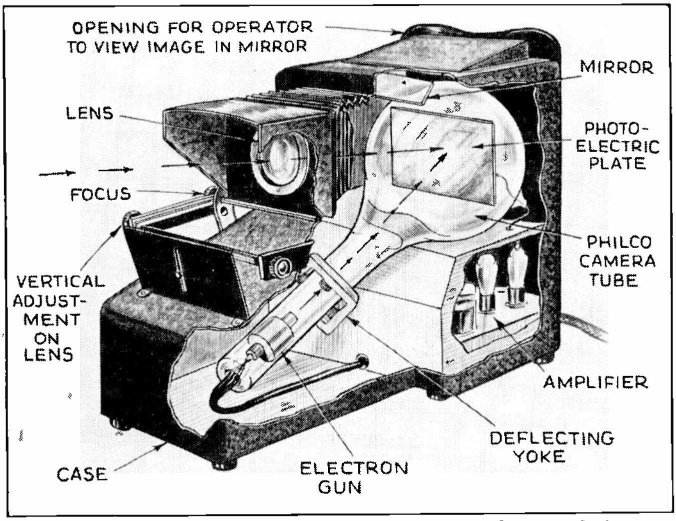


FIG. 20B. Arrangement of parts in one type of mechanical television reproducer, in which the scanning disc and glow lamp together reconstruct a picture or scene. The resulting image is enlarged several times by the lens.

Mechanical Television Receivers. In the early television receivers the amplified picture signal was fed to a neon glow lamp like that shown in Fig. *20A*; this lamp consisted of a rectangular flat metal piece which served as cathode and was the same size as the reproduced picture, and a wire anode mounted in a gas-filled glass envelope. A red glow of light formed on the plate when sufficient voltage was applied between the electrodes, the intensity of this glow varying with the applied voltage. The amplified picture signal was made to change the applied voltage, thus changing the intensity of the glow. A pin-hole scanning disc, in which each hole was the size of a picture element, was rotated before the glow lamp in such a way that the holes scanned the glowing plate. The transmitter and receiver were so synchronized that when the scanning disc at the transmitter started to scan the top line of the scene, the receiver scanning disc likewise started to scan the top line; line by line the scanning discs were kept in step or in synchronism, so that the intensity of the glow lamp at any instant corresponded to the intensity of the light reflected from that same element on the actual scene. The arrangement of the scanning disc and glow lamp are shown in Fig. *20B*; the lens shown is a magnifying glass used to enlarge the image to three or four times the size of the glow lamp plate.

Electronic Television Transmitters. Although present day methods of scanning and picture reconstruction differ greatly from the method just described, the principle of breaking up a picture into a number of elements which are scanned line after line is still used. Figure *21* illustrates a modern electronic television camera; the scene is focused on the photoelectric plate by a high grade camera lens combination. This light-sensitive photoelectric plate consists of millions of tiny light-sensitive spots, each insulated from the others and each scarcely larger than the point of a pin. Under a microscope this plate looks as if it were covered with grains of sand. When a scene is projected on the photoelectric plate by the lens, the action of light drives out electrons from each of the tiny light-sensitive units, these electrons passing through the space in the tube to the conducting surface on the



Courtesy Radio-Craft

FIG. 21. Cut-away sketch showing the arrangement of parts inside one type of electronic television camera.

inside of the glass envelope, which is at a high positive voltage and therefore attracts the electrons. The action of light thus leaves the photoelectric plate positively charged (because it has lost electrons).

Naturally the amount of electrons lost from any given section of this photoelectric plate depends upon the amount of light reaching that section; thus some spots on the plate are more positively charged than others and we actually have an electronic image of the scene. Now an electron gun shoots a fine stream of electrons at the photoelectric plate; electromagnetic deflecting coils (here designated as "deflecting yoke") shift this electron beam horizontally and vertically one line at a time to scan the entire photoelectric plate from top to bottom. When this electron stream strikes a positively charged surface, that surface recovers its electrons and in so doing relays the charge to the flat metal supporting electrode which is back of but insulated from the photoelectric plate.

Thus an electronic impulse is relayed to the electrode from each spot hit by the electron beam; the electrode therefore collects the picture signal. After a great deal of amplification, the picture signal is placed on a carrier wave and transmitted through space, just as in the mechanical television system. In addition, impulses are sent at the beginning of each line and at the beginning of each "frame" or new picture, to keep the image-reconstructing devices in step with the scanning mechanism at the transmitter.

Electronic Television Receivers. Figure *22* shows a simplified diagram of a typical electronic picture reconstructor. This employs an electron gun and two sets of electromagnetic deflecting coils. The current through these coils is controlled by the line and frame synchronizing impulses sent out by the transmitter. The special screen at the end of the tube glows when hit by the electron beam produced by the electron gun; the brilliance of the glow increases with the speed of the electrons in the beam and with the number of electrons in the beam. The picture signal voltage controls the

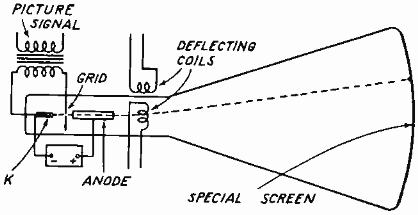


FIG. 22. Simplified diagram of an electronic picture reconstructor.

speed and number of the electrons in the beam by means of a special grid electrode, and the deflecting coils control the scanning of the beam across the screen up and down vertically. The combined action is such that while the beam is sweeping across the screen, its intensity is changing continually in accordance with the picture signal, and the effect of "painting" light on the screen is secured. The picture size is here controlled by the size of the screen; a 12-inch diameter tube gives a 7.5" x 10" picture.

PICTURE FREQUENCY

Greater picture detail can be obtained by increasing the number of lines per frame; increasing the number of frames per second gives less flicker of the reproduced picture. Both of these factors contribute to what is called high definition (or high fidelity) reproduction. Mechanical methods of television introduce problems in connection with high definition reproduction which are not readily solved; for this reason, some experts believe that electronic methods, where no parts are actually moving at high speed, are the correct solution to the television problem. As yet, however, the electronic method is quite complicated; increasing the number of lines and frames per second to get higher fidelity introduces electrical and radio problems which tax the ingenuity of engineers.

Picture Signal Cycles. The word "cycle" really means a definite change or difference; one picture element by itself is only a condition or an intensity level, but two picture elements, when at different intensities, constitute a definite change in intensity level. This is why we say that two picture elements constitute a cycle. The number of such cycles per second in the picture signal is the maximum frequency per second.

If each picture element is considered to be as high as it is wide, it is easy to compute the number of elements in one complete picture. Assuming a square picture with N lines, there will then be N picture elements per line, or N times N picture elements in the complete square picture, which is technically known as *one frame*. For example, in a 441 line square picture there will be 441 times 441 or 194,481 picture elements. For ordinary calculations, 195,000 elements will be sufficiently accurate.

Aspect Ratio. The pictures commonly involved in television are not square, however; they are wider than they are high. The width of a picture divided by its height is called the *aspect ratio;* let us designate it as a. In order to conform to motion picture standards, the aspect ratio a has been standardized at 4/3 or 1.33. This means that the number of elements in each line has been increased by the aspect ratio; the number of picture elements per frame or picture will therefore be N times N times a. For the example just considered, the total number of elements will therefore be 195,000 times 4/3 or 260,000.

Frame Frequency. The number of pictures sent per second is the *frame* or picture *frequency;* let us designate it as F. By multiplying the number of picture elements in a frame by the frame frequency, we get the total number of picture elements per second. The total number of picture elements per second is then $N \times N \times a \times F$. Since it takes two picture elements to make a cycle, we get the maximum number of cycles per second by dividing the preceding formula by 2. The standard frame frequency is 30; in our example, then, we get the maximum frequency involved by multiplying 260,000 by 30 and then dividing by 2; the result is 3,900,000 cycles per second.*

Factors Affecting Frequency. In actual television practice, the picture elements are being scanned only about 85% of the time; the remainder of the time is used for sending line and frame synchronizing impulses. Since a certain number of picture elements must be sent each second to get a certain quality of picture, the frequency is increased if these elements are crowded into 85% of one second or 85/100 second. The maximum picture frequency is thus increased about 15% (multiply the computed value by 1.15). In the example we have been considering, this will make the maximum picture frequency 1.15 times 3,900,000 or approximately 4,500,000 cycles.

Up to this point our analysis of the maximum frequency has been based upon the assumption that there is always a sharp contrast between adjacent elements of the picture or scene, one being dark and the next light. Of course this is not true in actual practice, for no scene is made up of per-

* The final formula is: Maximum theoretical picture frequency $f_p = \frac{1}{2} N \times N \times a \times F$.

fectly arranged checkerboard squares. Several adjacent picture elements in a line may reflect the same or nearly the same amount of light, and in most scenes, especially those having action, it is not necessary that slight variations between the shades of adjacent picture elements be transmitted. The average scene thus contains considerably less than the maximum possible number of cycles (changes from light to dark or vice versa). This is quite fortunate, for it reduces the maximum frequency required; tests and experience have shown that apparatus capable of sending about 60% of the maximum frequency is fairly satisfactory. Since the maximum number of cycles was assumed in our example, we multiply 4,500,000 by .6 and get about 2,700,000 cycles (2.7 megacycles) as the final maximum frequency for a 441 line picture scanned 30 times per second, with the standard aspect ratio of 4/3. Any increase in this frequency up to the extreme limit of 4.5 megacycles gives a definite improvement in picture fidelity.

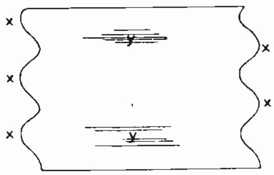


Fig. 23. The presence of moving humps *x* along the sides of the image and moving streaks *y* across the image, as shown here, was a distortion defect of early electronic television systems.

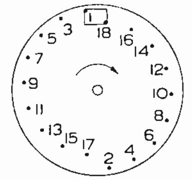


Fig. 24A. This double-spiral type of scanning disc illustrates the principle of interlaced scanning. The arrangement is such that the successive holes on one spiral skip a line of the image, and the holes on the other spiral scan the lines missed by the first spiral.

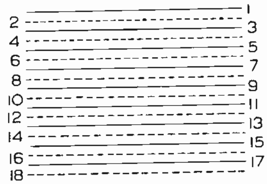


Fig. 24B. In interlaced scanning produced either by the double-spiral disc in Fig. *24A* or by an electronic television system, the lines of the picture are scanned (and reproduced) in the order 1-3-5-7-9-11-13-15-17-2-4-6-8-10-12-14-16-18.

The Minimum Frequency. The upper part of the average outdoor scene is bright (usually the sky) while the lower part is considerably darker. In scanning such a scene, the picture elements are varying in light intensity at a high level for the upper half of the picture and at a low level for the remainder of the picture, giving one cycle of change from light to dark for each scanning of the picture. Transmitting these changes properly calls for a minimum frequency corresponding to the vertical scanning frequency (the field frequency). Satisfactory reproduction of slow changes in background illumination requires, however, that frequencies down to at least 10 cycles be passed, so we should consider 10 cycles as the minimum frequency for a practical high-fidelity television system.

For a 441 line picture having an aspect ratio of 4/3 and a frame frequency of 30, the picture frequency may be any value between the minimum of 10 cycles and a maximum of at least 2.7 megacycles. Compare this with the frequency range of high fidelity sound, which extends from about 35 to 8,500 cycles per second. When you study the problems involved in designing radio apparatus to transmit high fidelity sound programs, you will begin to realize just how difficult are the problems involved in the design of television apparatus, which must handle a frequency range over 300 times as great. Nevertheless, these problems are being solved.

How Line and Frame Frequencies Are Selected. When scanning disc type television apparatus was at the height of its popularity, it was customary to employ 60 lines and 20 frames per second for the simple reason that 60 lines could be secured with a small disc and 20 revolutions per second could be easily obtained by driving the disc with a 1,200 r.p.m. constant speed motor. It was known, of course, that increasing the line and frame frequencies gave better images; 180 line mechanical scanning systems were soon developed and tried, and the frame frequency was increased to 24 per second to permit the use of motion picture film. Picture distortion, with light and dark portions of the image weaving back and forth and up and down in the picture, was characteristic of these early television images; it was discovered that this was caused by 60 cycle and 120 cycle power pack ripples getting into the picture signal circuits. The weaving of the image and of the light spots was eliminated by making the frame frequency either 20, 30, 40, 50 or 60 per second.

When electronic television methods were first introduced, the sides of the reproduced picture were found to be wavy, as shown in Fig. *23*, with the humps moving up or down when frame frequencies of 24 cycles per second (selected to permit the televising of motion picture film) and certain other values were used. In addition, bright streaks formed across the image, as shown at regions *y* in Fig. *23*. Setting the frame frequency at 30 or 60, as is the current practice where 60 cycle power is used, did not eliminate these conditions entirely but prevented their motion and thus made them less objectionable.

Increasing the number of frames per second reduces flicker, but it also steps up the maximum signal frequency. For example, a 441 line picture with an aspect ratio of 4/3 and 30 frames per second gives a maximum frequency of at least 2.7 megacycles; at 60 frames per second the maximum frequency becomes about 5.4 megacycles, which is way beyond the present ability of television apparatus. But scientists were not to be balked; they resorted to interlaced scanning, an old principle of television which was used on many of the scanning disc type systems. In these systems the holes were arranged in two sets of spirals, as shown in Fig. *24A*, one set of holes scanning or reconstructing every other line, as illustrated in Fig. *24B*. Although the number of lines in the picture is not increased, the frame is scanned vertically *twice* for each complete scanning of all the elements. This does not change the maximum signal frequency, but reduces flicker considerably.

This same principle of interlaced scanning has been applied to electronic television methods. It was discovered that if the frame frequency was doubled (increased from 30 to 60 times per second) without changing the line frequency and an odd number of scanning lines was used per picture, the picture would automatically interlace. This is why 441 lines is the present standard rather than 440 lines.

PRACTICAL CONSIDERATIONS

Radio apparatus designed for sound signals must handle the required range of frequencies in the sound, and must not introduce either harmonic or amplitude distortion; television signals also have these requirements, and one other, that there be negligible phase distortion. With sound signals phase distortion is of no consequence, for the human ear is concerned only with the frequency of a sound and with its strength, but in television the phase distortion may tend to shift an impulse from one picture element to the other, definitely causing distortion. The effects of phase distortion are illustrated in Fig. *25*. When the signal consists of a fundamental frequency *A* and third harmonic *B*, the resultant wave *C* will, when fed into a suitable reproducing device, cause light and dark areas to appear on the screen in exact reproduction of the light and dark areas of the original scene. If, however, radio apparatus were to shift the third harmonic by 90 degrees, as at *D* and *E*, the resultant wave at *F* will no longer represent the original scene. This can easily be proved by comparing corresponding points, such as x, on the waves of Fig. *25 C* and *F*; the image element corresponding to point x on the latter wave will clearly be too light.

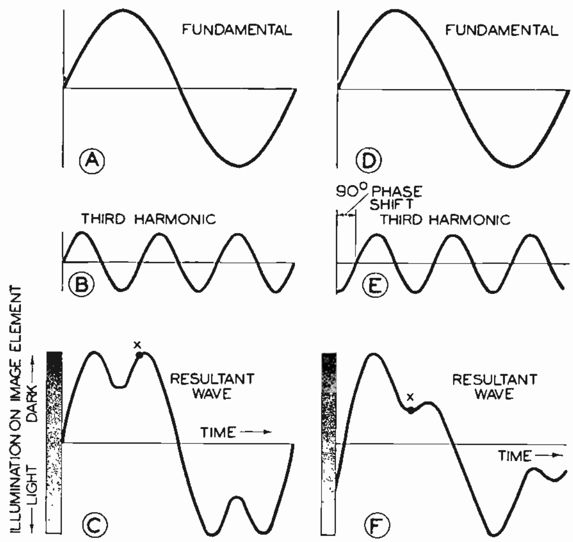


Fig. 25. The effects of phase distortion in a television system are here illustrated.

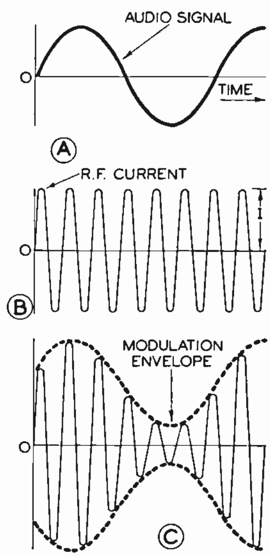


Fig. 26. The process of modulation is illustrated by these diagrams.

Production of Side Frequencies. The process of modulating the carrier signal of a transmitter with either a sound or picture signal introduces new radio frequencies which are called side frequencies; these are important enough to warrant study at this time.

The wave form of an audio current is illustrated in Fig. *26A*, and the wave form of an R.F. current in Fig. *26B*. When we say that we are modulating the R.F. current with the audio current, we mean that we are making the amplitude *I* of the R.F. carrier increase and decrease with the strength and frequency of the audio signal, as shown in Fig. *26C*. A complicated mathematical analysis proves that this act of modulation does not change the power of the original R.F. carrier, but rather adds new frequencies whose power is supplied by the audio signal. Two new R.F. frequencies are introduced by modulation when the audio signal is of one fixed frequency; one is above the carrier frequency by a value equal to the audio frequency, and the other is lower than the carrier by the A.F. value. These two new R.F. signals are called the *side frequencies*.

Here is an example of how side frequencies are formed. When a 1,000 kc. carrier is modulated with a 1 kc. signal, the three resulting frequencies are 1,000 kc., 1,001 kc. and 999 kc. The amount of power in each side frequency depends upon how much the carrier amplitude (*I* in Fig. *26B*) is being changed by the modulation; the power in each side frequency can never be more than 50% of the carrier power without causing distortion.* If, as holds true in actual practice, the modulation or intelligence signal contains many different frequencies, there will be a great number of side frequencies in pairs, one above and one below the carrier value.

Problems Caused by Side Frequencies. All this means that every part of the radio system which is carrying the modulated radio frequency cur-

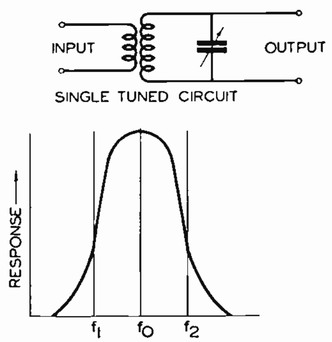


Fig. 27A. When a single tuned circuit, containing a coil and condenser, is adjusted to resonance at a carrier frequency f_0, it amplifies that carrier frequency considerably more than the side-band frequencies which are between f_1 and f_2.

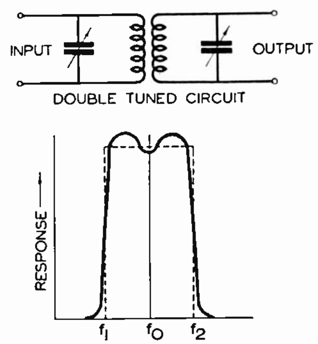


Fig. 27B. Double tuned circuits come close to amplifying the carrier and side frequencies uniformly. The heavy line curve can be secured in practice; the dotted lines represent the ideal response curve.

rent must be able to handle the side frequencies as well. The big problem arises in the R.F. amplifiers of transmitter and receiver.

Here is an illustration of one of the problems involved. A simple coil-condenser resonant circuit, shown in Fig. *27A*, will give the best response at its resonant value, and if tuned to a certain carrier frequency, will favor that carrier. The amplitudes of frequencies above and below that resonant value will be reduced considerably, as shown by the curve in Fig. *27A*, where f_0 is the carrier frequency. If a modulated carrier is passed through such a circuit, the side bands (extending between f_1 and f_2) will be cut down; this is highly undesirable, for the side frequencies must be amplified equally as well as the carrier if frequency distortion is to be kept at a minimum. If it were not for the side frequencies, the sound or picture signal would not exist after demodulation (after detection) of the carrier.

Side Bands. The frequencies between the lowest and the highest side

* This limiting side frequency power occurs at the condition commonly referred to as 100% carrier modulation.

frequencies are called the *side band frequencies.* The total frequency width or frequency range which must be transmitted is twice the maximum frequency of the picture or audio signal. In audio or sound broadcasting the side bands cover 2 times 5,000, or 10,000 cycles, for the average transmitter; for high fidelity sound broadcasting the side bands cover 2 times 8,500, or 17,000 cycles (17 kc.); for television, assuming a maximum picture frequency of 4 mc., the side bands would cover 8 mc. Since transmission of an 8 mc. wide frequency range increases greatly the complexity and cost of a television system, it is now customary to suppress one side band as much as possible at the television transmitter. This makes it possible to transmit in a band only 6 mc. wide both the sound and sight carriers, along with both side bands of the sound carrier and one side band of the picture carrier Double-tuned circuits like that in Fig. *27B* are widely used in R.F. amplifiers which must handle wide ranges of side frequencies.

Selecting the Carrier Frequency. A double tuned circuit like that in Fig. *27B* cannot always be made to have a flat top response which will pass any desired frequency band. Only when the carrier frequency is more than 2 or 3 times the value of the side band frequency range is this possible. This is one reason why carrier frequencies of from 40 to 90 megacycles are being used to transmit television signals having a pass band width of 6 megacycles. Another reason is that clear channels having the required 6 mc. width are available only in the ultra-high-frequency bands.

TEST QUESTIONS

Be sure to number your Answer Sheet 14FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Name the three forms of intelligence which can be sent over either wire or radio communication systems.
2. Why isn't sound transmitted by a perfect vacuum?
3. What is the speed of sound waves through air under normal conditions?
4. What three things can happen to sound waves which strike a material?
5. How can the reverberation period of a room be reduced?
6. What are the two important characteristics of a sound having the form of a simple sine wave?
7. What two objectionable types of distortion may occur when a sound signal passes through a radio vacuum tube stage?
8. Can the average human ear detect changes of less than 3 db in the intensity of a complex sound?
9. What characteristic of the human eye allows it to retain an impression of an object for a short time after that object has disappeared?
10. What is meant by the aspect ratio of a television picture?

LOW FREQUENCY AMPLIFIERS FOR SOUND AND TELEVISION SIGNALS

15FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

INDECISION

Beginning is for some people the hardest part of any job which they tackle. So formidable does each task appear to them before starting, that they waste the day in dilly-dallying, in day-dreaming, and in wishing they could in some way avoid having to do the job. The next day, and the next after that are the same story. Indecision brings its own delays, making it harder and harder to buckle down to work, and soon opportunity-filled days are being wasted in lament over the days gone past when the job could have been and should have been done.

Are you in earnest? Then seize this very minute; begin what you can do or dream you can. Boldness in starting a new lesson is a great moral aid to mastery of that lesson; only begin, and your mind grows alert, eager to keep on working. Begin, and surprisingly soon you will have finished.

J. E. Smith.

1941 Edition

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Low Frequency Amplifiers for Sound and Television Signals

TYPES OF AMPLIFIERS

RADIO signals of all kinds generally have a very low voltage or power level at the point where they are initially picked up; before these signals can be made to do useful work, their voltage or power levels must be substantially raised. This is the job of the amplifier.

All amplifiers may be divided into two broad groups, *high frequency amplifiers* and *low frequency amplifiers.* High frequency amplifiers handle the *R.F. carrier signals* (which may or may not be modulated), while low frequency amplifiers carry only the *audio* or *video intelligence signals.* The low frequency amplifier in a sound radio receiver is commonly called an *audio amplifier*, while that used in a television receiver is known as a *video amplifier. Only low frequency amplifiers* will be considered in this lesson; these include the stages following the second detector or demodulator in sound or picture signal receivers, the modulator stage and the low frequency amplifier stages which precede it in a sound or picture signal transmitter, and all stages of public address amplifiers, electronic musical instruments, electric phonograph amplifiers and photoelectric control amplifiers.

Types of Low Frequency Amplifiers. The audio frequency signals produced by microphones and phonograph pick-ups, as well as the video (picture) frequency signals produced by television cameras, have so low a signal strength that low frequency amplifiers are required at the transmitter to get enough power to modulate the carrier, and at the receiver in order to secure sufficient power to drive the reproducing device (the loudspeaker or image reconstructor tube). The two distinct types of low frequency amplifiers are *voltage amplifiers* and *power amplifiers.*

Frequency Ranges of Low Frequency Amplifiers. In addition to their primary function of amplifying either voltage or power, low frequency amplifiers must be able to handle all signal frequencies in the desired range; thus audio amplifiers used for ordinary telephone work must handle frequencies from about 200 to 3,000 cycles. The low frequency amplifiers found in the average sound signal radio receiver or transmitter must handle from about 100 to 5,000 cycles, while high fidelity sound equipment must have a frequency range of from about 35 to 8,500 cycles or even, in the opinion of some experts, as high as 15,000 cycles. Low frequency amplifiers for picture signals must handle from about 30 to 3,000,000 cycles in a high definition television system. Low frequency amplifiers for photoelectric control work and for the sweep circuits* used in television systems need

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*That circuit which furnishes the power to make the electron beam in a cathode ray television tube sweep from side to side across the screen is known as the *sweep circuit.*

handle only a narrow band of frequencies or perhaps only a single frequency. With such widely varying requirements, it should be clear that we cannot neglect the question of frequency range in connection with this study of low frequency amplifiers.

REQUIREMENTS OF A LOW FREQUENCY AMPLIFIER

Assuming that we are starting with a *low frequency* signal having a low power and low voltage, we may have to meet one or all of the following requirements: *1,* the *voltage* shall be increased; *2,* the *power* shall be increased; *3,* there shall be *no frequency distortion; 4,* there shall be *no amplitude distortion; 5,* in the case of television signals, there shall be *no phase distortion.* These requirements of a low frequency amplifier are important enough to warrant further explanation; let us consider them one by one.

1. Voltage Amplification. Amplifiers which increase the *voltage* of a low frequency signal are required whenever the voltage of the original low frequency signal is too low. For example, when the output signal voltage of the second detector in a sound signal radio receiver is too low to operate the output stage of the receiver, a voltage amplifier is needed to convert the low signal voltage to the required high signal voltage value; when the output

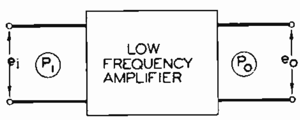

FIG. 1. Block diagram of a low frequency amplifier, which could be the audio amplifier in a broadcast or all-wave radio receiver, the video or picture amplifier in a television receiver, or the amplifier used in certain types of electronic control apparatus.

signal voltage of the second detector in a television receiver is too low to operate the image reconstructor tube, a low frequency voltage amplifier is required; likewise in public address amplifiers it is necessary to increase the signal voltage output of the microphone (which may be about .002 volts A.C.) to a value of about 20 volts A.C. (a voltage amplification of about 10,000) to meet the input voltage requirements of the first power amplifier stage. The required voltage amplifier may consist either of one voltage amplifier stage or of several such stages connected one ahead of the other in what is commonly known as a cascade arrangement.

2. Power Amplification. A high signal voltage alone is ordinarily not enough to operate the load device (loudspeaker) in a radio receiver; there must also be a high signal current, and therefore a high signal power level. The low frequency amplifier stage which feeds into a loudspeaker must therefore convert signal voltages into high signal powers; the stage is then said to be operating as a power amplifier. If one tube alone cannot give the desired amount of signal power, two or more tubes may be connected together in parallel or placed in special power circuits to form the power amplifier stage; sometimes one or more extra power amplifier stages of a type which convert low power levels to high power levels are added to the power amplifier. In public address systems especially, many power amplifier stages may be used to secure the signal power required for the many giant loudspeakers used in outdoor installations.

The total voltage amplification or voltage gain of a voltage amplifier is the output voltage e_o divided by the input voltage e_i (see Fig. *1*). The total power gain of any amplifier is the output power in watts (P_o in Fig. *1*) divided by the input power in watts (P_i); this gain in power is commonly expressed in decibel units.

3. Frequency Distortion. That type of distortion which occurs when a radio circuit or device amplifies or transmits *unequally* the different frequencies in its operating range is known as *frequency distortion* (and sometimes as *harmonic distortion*). For example, if a certain audio amplifier is to handle equally well all frequencies in the range from 100 to 5,000 cycles, the voltage gain (or power gain) of the amplifier must be the same for each of the frequencies in this range. If the gain is 10,000 for a 1,000 cycle signal, it should be 10,000 for a 100 cycle or a 5,000 cycle signal in an amplifier having fair fidelity; the more nearly constant is the gain of the amplifier at the various frequencies, the better is its fidelity (faithfulness of reproduction).

The manner in which a radio circuit or device amplifies, relays or transmits the different signal frequencies in its operating range is called the *frequency response* characteristic. It is common practice to use a *frequency response curve* like that in Fig. *2* in order to show how each frequency is amplified by a particular amplifier; for convenience the gain is usually ex-

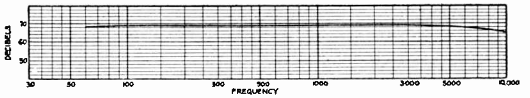

FIG. 2. Frequency response curve of a typical high fidelity audio amplifier, using in its output stage two type 2A3 tubes operating in push-pull.

pressed in decibels. The curve shows that the gain is practically constant for all frequencies between 100 and 3,000 cycles, but drops slightly for frequencies below and above this range. Generally speaking, frequency distortion is caused by the circuit parts (coils, condensers and transformers) associated with the vacuum tube in an amplifier stage.

4. Amplitude Distortion. When a radio circuit or device does not produce current or voltage changes which are *exactly proportional*, at each instant of time, to the changes occurring in the voltage or current values of the incoming signal, we have what is known as *amplitude distortion.*

Amplitude distortion definitely results in *the production of harmonics which are not present in the original signal;* these undesired harmonics are the result of distortion in the wave form of the signal. In a vacuum tube circuit, amplitude distortion is caused essentially by non-linear operation of the tube; in certain radio parts, hysteresis and eddy current effects can also cause amplitude distortion.

A low frequency amplifier of high quality must amplify signals without changing their wave forms; this means that there must be no amplitude distortion. For example, if the sine wave signal shown at *A* in Fig. *3* is fed into a low frequency amplifier, the output wave form must also have a sine wave form, and must not be distorted like the signal at *B* in Fig. *3*. (Amplitude distortion like that shown at *B* occurs when the grid voltage swings over a curved portion of the dynamic E_g-I_p curve of a tube; grid swings in one direction then give greater plate current changes than swings in the opposite direction.) The amplitude of a wave can, of course, be increased without having distortion, as at *C*, for this is ordinary and desirable amplification.

5. Phase Distortion. When a radio circuit or part changes the phase relationship between different frequencies in the incoming signal, we have *phase distortion.* The distance (phase) between peaks of the different signal components changes, with the result that there is a change (distortion) in the wave form of the output signal. While phase distortion is not objectionable in sound signals, it is very important that there be no phase distortion in the picture signal amplifiers of a television receiver or transmitter. For example, if a particular television signal consists of a fundamental and a fifth harmonic, and the fifth harmonic leads the fundamental by 10 degrees in the original signal, there must be this same phase difference in the output signal if a true reproduced image is to be secured.

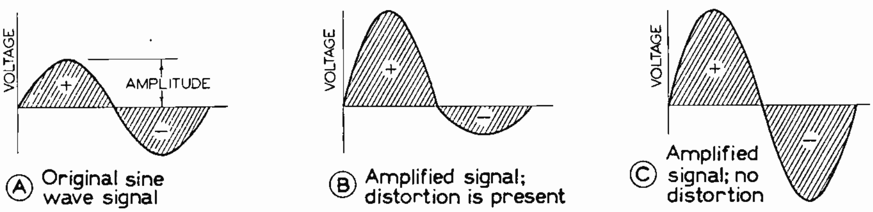

FIG. 3. The effect of amplitude distortion on a sine wave signal (*A*) is shown here at *B*, while a properly amplified sine wave signal appears at *C*.

The three forms of distortion which may occur in a low frequency amplifier are thus *frequency distortion, amplitude distortion* and *phase distortion.*

DYNAMIC E_g-I_p CURVES

A vacuum tube circuit can act as an amplifier simply because a change in its grid voltage causes a change in its plate current, resulting in a greater change in the voltage across the load. The nature of this control over the plate current is best shown by means of an E_g-I_p characteristic curve for the tube. Since the value of the plate current is affected by the plate load (considered to be essentially resistive in all practical amplifier circuits), it is necessary to use a special characteristic curve which takes into account the presence of the plate load. This special curve is called a *dynamic E_g-I_p curve,* whereas the curve for no-load conditions is called a static E_g-I_p curve.*

*The material which you will find in smaller type throughout this Lesson has been included in order to give you valuable extra data (generally of a more technical nature) on certain subjects. You should read through this small-type material at least once so you will know what it covers, but it is not essential that you master it now. Consider it rather as reference data to be referred to in the future when you encounter the particular problems which are covered.

Experimental Method of Securing a Dynamic E_g-I_p Curve. A dynamic E_g-I_p characteristic curve for a tube can readily be obtained with a circuit similar to that in Fig. *4*, in which the plate load R_L is a resistance equivalent to the effective load resistance of the amplifier circuit in which the tube is to be used. Potentiometer P_1 controls the value of E_g, the operating C bias, while movable tap P_2 controls the operating plate voltage E_p. The plate voltage is fixed at a desired value, and readings of plate current I_p are taken for various values of E_g; when these readings are plotted, a dynamic E_g-I_p curve (like curve *D* in Fig. *6*) is obtained.

Graphical Method of Securing a Dynamic E_g-I_p Curve. A radio engineer generally uses a graphical method for securing a dynamic E_g-I_p (grid voltage-plate current) curve in preference to the rather tedious experimental method just described. The load resistance being used must be known, and a set of static E_g-I_p or E_p-I_p (plate voltage-plate current) curves must be available; a straight line, known as a *load line*, is drawn across the static curves to represent conditions with the load in the circuit, and data for the dynamic E_g-I_p curve is taken directly from this load line. An example will best illustrate this procedure for securing a load line and dynamic curve.

The family of E_p-I_p curves for a 2A5 power pentode tube (identical with the type 42 tube) is given in Fig. *5*. Manufacturers of this tube recommend an operating plate voltage of 250 volts and an operating C bias of —16.5 volts.

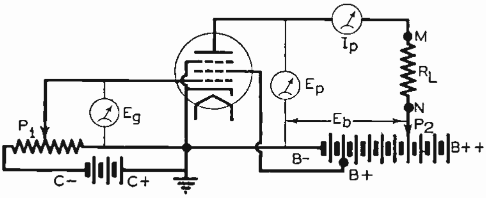

FIG. 4. Simple experimental amplifier circuit with resistance load, used for determining dynamic E_g-I_p characteristic curve of a tube by actual measurements. This circuit may be used with triodes and tetrodes as well as with the pentode shown.

Point *O* on the curve is therefore the operating point; the operating plate current, as you can see, is 34 ma. A 7,000 ohm plate load being recommended for this tube, there will be a voltage drop of 7,000 × .034, or 238 volts across the load; this means that the supply voltage E_b must be 250 + 238, or 488 volts in order to offset this voltage drop in the load.

The Load Line. In order to draw the load line, a designing engineer must know what the plate voltage will be at two different values of plate current when the load is in the circuit. He already knows this voltage for the operating point (250 volts at 34 ma.); he assumes some other reasonable value of plate current, such as 58 ma., and figures out what the plate voltage will be. Thus, when I_p is 58 ma., the load voltage drop will be .058 × 7,000 or 406 volts, and E_p will be 488 volts minus 406 volts, or 82 volts; this value corresponds to operating point *1* in Fig. *5*, and is the other point required for the load line. He now draws a line between points *1* and *2*, as is done in Fig. *5*; this will be the *load line* for a 7,000 ohm resistance load. The load line will always be straight for a resistance load, and hence only two points are needed to locate its position.

Once the load line is secured, the values of E_g and I_p for various points on the line are determined and plotted on a graph as in Fig. *6* to give curve *D*, the desired dynamic E_g-I_p characteristic curve for a 7,000 ohm load. Thus E_g is —5 volts for point *1*, —16.5 volts for point *O* and —30 volts for point *2*.

Since the plate voltage is constant for all values on a static curve, vertical line *x-o-y* in Fig. *5* represents the no-load condition; the points for a static E_g-I_p curve, such as for static curve *S* in Fig. *6*, can therefore be taken from this vertical line.

Comparison of Static and Dynamic E_g-I_p Curves. Static and dynamic E_g-I_p curves for the same tube are shown in Fig. *6* for comparison. Notice that dynamic curve *D* in Fig. *6* is straighter (more linear) than static curve *S*; in fact, increasing the ohmic value of the load resistance makes the dynamic E_g-I_p curve for the tube circuit *straighter* (more linear) in the case of a triode tube. With tetrode and pentode tubes this rule does not hold, however, and several load values must be tried in order to determine the one which gives the most nearly linear curve. With power amplifiers, also, it is necessary to try several loads. That load is chosen which gives a high power change and a reasonably linear dynamic curve.

How to Figure How Much A.C. Power Is Absorbed by the Load. The load line is very useful when it is necessary to find out how much A.C. power is being absorbed by the load. An example will best illustrate the procedure.

Referring to Fig. *5*, suppose that the operating point for our example is point *O*, where the grid bias is —16.5 volts, and suppose that the grid voltage is being swung from —33 volts to $E_{c1} = 0$ by an incoming signal voltage (from point *3* to point *4* on the load line). The plate voltage will then be varying between 430 volts and 40 volts, giving a total swing of 390 volts, while the plate current will be varying from 8 ma. to 63 ma., giving a total swing of 55 ma. To secure the swing power, multiply together the swing voltage and swing current; .055 × 390 gives approximately 21.5 watts for the swing power. We must divide this value by 8* to convert it to effective or r.m.s. power, and thus we secure a value of 2.7 watts as the total A.C. power absorbed by the load in this example. Tube manufacturers rate this 2A5 tube as capable of delivering 3 watts of effective power, a value which checks closely with our calculation.

Why an Amplifier Stage Causes a 180-Degree Phase Shift. The load line in Fig. *5* tells us one more fact which is of especial importance in connection with the low frequency amplifiers used in television systems. When the amplifier in Fig. *4* was adjusted to operating point *O* on the load line of Fig. *5*, we found that a plate supply voltage of 488 volts was required; point *N* on the load resistor in Fig. *4* therefore has a potential of +488 volts *at all times.* Point *M*, being connected directly to the plate, will have a potential of +250 volts *with respect to the cathode* under normal operating conditions; since this potential is lower in value than +488 volts, point *M* is negative with respect to point *N*. Now suppose that the grid is made to swing more positive (say up to —5 volts, which is point *1* on the load line); the plate current will increase to a new value of 58 ma. and the plate voltage will drop to 80 volts. Point *M* will now be +80 volts, which is considerably lower than its former value of +250 volts, and hence is more negative than before. The amplifier output voltage, as measured across *M-N*, thus becomes *more negative* as the grid becomes *more positive.* Engineers describe this behavior by saying that there is a *phase shift of 180 degrees* or *one half-cycle* between the input and output A.C. voltage of each amplifier stage.

CLASS A, B, AB AND C AMPLIFIERS

Vacuum tube amplifiers may be operated in a number of ways, depending upon the value of the operating C bias and the amplitude of the grid swing. The four methods in common use are referred to as Class A, B, AB and C amplifiers; let us consider the important facts about each in turn.

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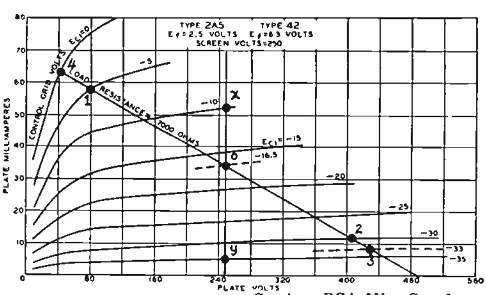
*To change swing power to effective power, you must first divide by 2 to change swing voltage to peak voltage, then divide by 1.414 to change peak voltage to effective voltage, and likewise divide by 2 and 1.414 to change swing current to effective current. Thus you must divide swing power by 2 × 1.414 × 2 × 1.414, which is 8.

Class A Amplifiers. When an amplifier tube operates over a linear portion of its dynamic E_g-I_p characteristic curve, so that the plate current is at all times proportional to the grid voltage, we have what is known as a *class A amplifier*. The action is shown in Fig. *7A;* if a sine wave grid voltage e_g is fed to the amplifier tube, the plate current i_p will also be a sine wave. Notice that the operating region of the dynamic curve (between points *1* and *2*) is a straight line. Some engineers prefer a more general definition which says that in class A operation, where the tube operates as a class A amplifier, the grid may swing positive or negative any amount along the linear dynamic curve *as long as plate current never stops flowing.*

Class B Amplifiers. When the operating C bias is set to plate current cut-off value, as at point *1* in Fig. *7B,* plate current flows only for one half of each cycle and we have a *class B amplifier.* The grid may be swung positive in this case but usually never swings beyond point *3,* at the upper limit of the linear portion of the curve. With class B operation, little or no plate current flows when there is no incoming signal.



Courtesy RCA Mfg. Co., Inc.

Fig. 5. Static E_p-I_p characteristic curves for a 2A5 tube, with load line *4-1-0-2-3* drawn in for a 7,000 ohm load. Line *x-o-y* is drawn in for the no-load condition.

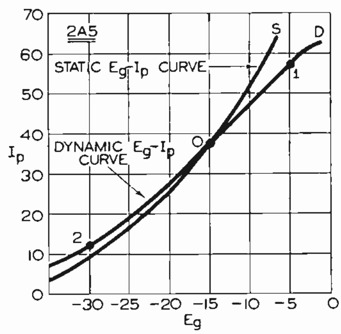


Fig. 6. Static and dynamic E_g-I_p curves for a 2A5 tube having operating point *0* in Fig. *5*.

Class AB Amplifiers. When a value of operating C bias is selected which is insufficient for plate current cut-off and yet too negative to permit class A operation we have a class AB amplifier, also known as class A′ (A prime). With class AB operation, plate current will flow for more than one half a cycle, but not for a whole cycle.

Class C Amplifiers. Here the operating C bias is much more negative than the plate current cut-off value, and is generally twice the cut-off value. Plate current therefore flows for less than one half cycle. The grid is often allowed to swing to the plate current saturation point (to point *4* in Fig. *7C*) on the dynamic E_g-I_p curve, or even beyond to point *5*. This gives a plate current wave form with steep sides and a flat or hollow top.

Additional Data on Low Frequency Amplifiers in General. One cycle of A.C. grid voltage may be considered to exist for 360 electrical degrees, as you already know. With the four operating methods, the plate current flows as follows: Class A—360 degrees; class B—180 degrees; class AB—

180 to 360 degrees; class C—less than 180 degrees. The angle during which plate current flows in each case is called the *operating angle.*

Class A operation is always used for low frequency amplifiers which have only one tube per stage. When two, four or more tubes in a single stage are connected together in balanced push-pull or push-push fashion (special circuits which are to be considered soon) either class AB or class B operation may also be used; these balanced circuits prevent distortion of the wave form of the signals. Class C operation is not used for picture or

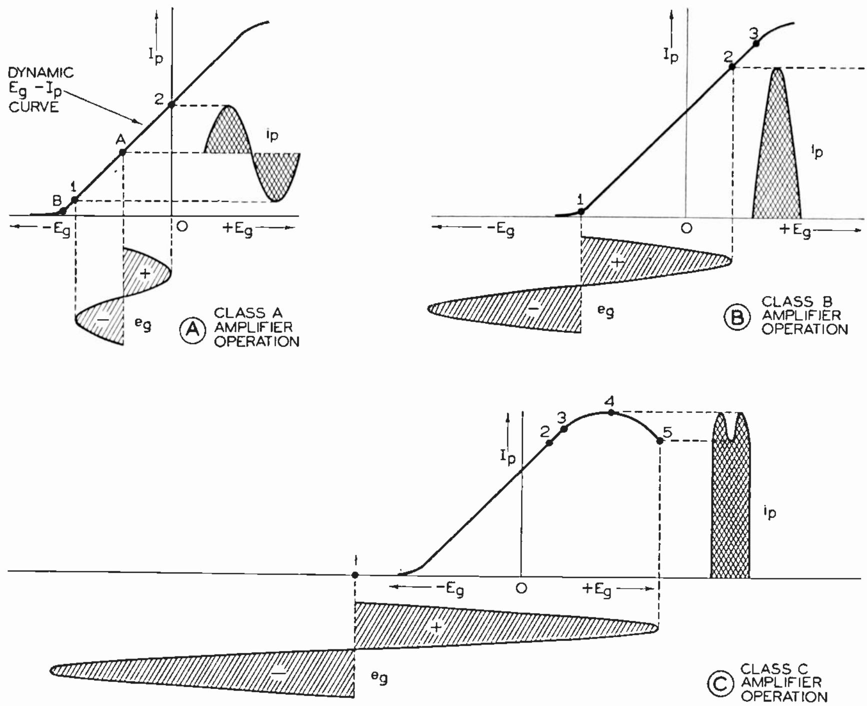


FIG. 7. The three basic types of amplifier operation are illustrated by these diagrams. For class AB operation, the operating point would be somewhere between points *B* and *A* on the curve for class A operation; the plate current is then cut off for a part of each negative half-cycle.

sound signal amplifiers. Radio frequency amplifiers may use any class of operation either in single or multiple tube stages, but in general, class B and class C operation are used only for the R.F. power amplifiers of transmitters.

The efficiency of an amplifier as a power device can be determined by dividing the power absorbed in the load* by the D.C. power being supplied to the amplifier (filament power is not considered). Class C amplifiers are most efficient, with class B, class AB and class A following in the order

*Load power is obtained by multiplying the effective A.C. voltage across the load by the effective A.C. current flowing through it.

given (the class A amplifier has the lowest efficiency). In any case, if the grid swings positive the signal input source must be able to supply the required power to the grid with negligible change in the input impedance.

VOLTAGE AMPLIFIERS WITH PURE RESISTANCE LOADS

Now that we have covered the important fundamental facts dealing with the operation of various types of low frequency amplifiers, we are ready to study practical voltage amplifier circuits as used in actual sound and television radio receivers and transmitters.

Any study of practical low frequency amplifier circuits logically begins with a consideration of those circuits which use a pure resistance as a plate load. Such amplifier stages are generally used on voltage amplifiers, the A.C. voltage developed across the load resistor being fed either directly, through a resistor or through a condenser to the grid-cathode terminals of the next amplifier tube or to the deflecting plates of an image reconstructor tube.

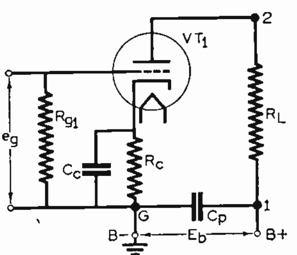


FIG. 8A. Simple voltage amplifier circuit with resistance load, intended for class A operation.

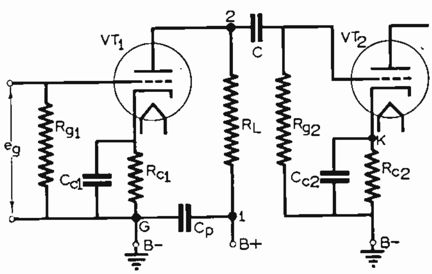


FIG. 8B. Resistance-capacitance type of voltage amplifier circuit, using a resistance load and capacitance coupling.

Preliminary Considerations. Let us first consider a simple class A voltage amplifier circuit, that shown in Fig. *8A*. Automatic C bias is furnished by resistor R_c. Condenser C_c is a by-pass condenser, serving to prevent fluctuations in the current through R_c. Condenser C_p is also a by-pass condenser, and provides a low impedance path to ground for the A.C. component of plate current. The presence of resistance load R_L requires that the plate supply voltage E_b be increased by the voltage drop in R_L, so the plate voltage will be at the required operating value when there is no signal voltage (e_g) on the grid. The tube is operated as a class A amplifier and hence the application of an A.C. signal e_g to the grid-cathode terminals will cause an A.C. voltage of corresponding wave form to appear across R_L. When the tube operates over the linear portion of the dynamic E_g-I_p characteristic curve, no amplitude distortion will occur; frequency distortion (also called harmonic distortion) will appear at very high audio or picture frequencies, because the plate-to-cathode inter-electrode capacity of the tube (discussed later) effectively shunts R_L, by-passing the higher frequencies around R_L.

Resistance-Capacitance Coupled Amplifier. The circuit shown in Fig. *8B* is called a resistance-capacitance coupled amplifier or simply a *resistance-coupled amplifier* because of the method of coupling used between the stages. As you can see, both stages are the same as those in Fig. *8A*, and are coupled together by condenser C. Before the A.C. voltage developed across R_L can be fed to the grid-cathode of tube VT_2, precautions must be taken to prevent the D.C. plate supply voltage of VT_1 from being fed to the grid of VT_2. Point *1* on the load resistor in Fig. *8B* is essentially at ground potential for signal currents because the reactance of C_p, which connects point *1* to point G, is very low for signal currents and point G is grounded directly.* Since cathode K of tube VT_2 is also essentially at ground potential (the reactance of C_{c2} being very low), there is no need to run a wire between these two points. Point *2*, however, must be coupled to the grid of the next tube through coupling condenser C in order to block D.C. while allowing the A.C. signals to pass.

Resistors R_{g1} and R_{g2} permit the input signal voltage to be applied to the grids of the tubes and at the same time allow the automatic C bias voltages to be impressed upon the grids of the tubes. At low audio and video frequencies, coupling condenser C has a relatively high A.C. reactance and reduces the amount of signal which is transferred from R_L to the grid-cathode terminals of tube VT_2; at higher frequencies C becomes a low reactance path and R_{g2} shunts R_L, reducing the effective load resistance of tube VT_1. At very high sound and picture frequencies the plate-cathode tube capacity of tube VT_1 and the grid-to-cathode capacity of tube VT_2 shunt R_L, lowering the A.C. voltage which the load passes on to the grid of tube VT_2. For these reasons a resistance-capacitance amplifier has lower amplification at very low and very high frequencies than at medium frequencies in the sound or picture signal range; this is frequency distortion, which can be reduced by proper selection of circuit parts.

Sometimes resistor R_{g2} in Fig. *8B* is replaced with a choke coil, which together with coupling condenser C acts as a series resonant circuit which has the A.C. voltage across R_L as a source. The A.C. voltage output of the tube VT_1 can thus be resonance amplified before being fed to tube VT_2. The electrical values of the choke and coupling condenser can be chosen to resonate broadly at either low or high signal frequencies, giving desirable extra amplification which compensates for frequency distortion in other circuits. It is important in this circuit that the reactance of the choke coil be much higher than the resistance of R_L, for otherwise the impedance of load R_L will be lowered, and the total amplification will be less.

Direct Resistance-Coupled Amplifier Circuit. For amplification of very low frequencies or very slow grid voltage changes such as are found in photoelectric control circuits, the presence of condenser C in Fig. *8B* is quite objectionable. The direct resistance-coupled amplifier circuit shown

*If you actually measured the A.C. signal voltage between ground (point G) and point *1* on a voltage amplifier, it would be zero, proving that point *1* is at ground potential for signal currents. If you made this test with a D.C. voltmeter, however, you would find that point *1* is positive with respect to ground for direct current.

in Fig. *9* (also called the Loften-White amplifier after its originators) is used for applications like these, for it gives excellent low frequency response.

Design of a Direct Resistance-Coupled Amplifier Circuit. The essential requirement of a successful direct resistance-coupled amplifier is that each tube shall have correct electrode voltages with respect to its cathode. An example will illustrate how this is accomplished in the practical amplifier circuit of Fig. *9*. The first tube is a type 57 pentode* having a 75,000 ohm resistor load and requiring the following electrode voltages; $E_p = 250$ volts; $E_g = -3$ volts; $E_{s.g.} = 100$ volts; this tube is coupled to a type 56 tube which requires: $E_p = 250$ volts; $E_g = -15$ volts. The type 57 tube draws .002 ampere of plate current under these operating conditions, hence the drop in load resistor R_L is $.002 \times 75{,}000$, or 150 volts; the plate supply voltage for this tube must therefore be 250 + 150, or 400 volts. Since a negative bias of 3 volts is required for the grid, the total supply voltage for this tube is 403 volts. The values of resistors R_1, R_2, R_3 and R_4 in the voltage divider circuit are so chosen that these voltages are provided for the type 57 tube, each voltage being correct with respect to the cathode.

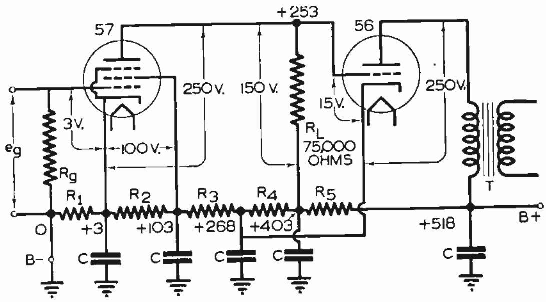


FIG. 9. Direct resistance-coupled or Loften-White amplifier circuit. Numerals indicate D.C. voltage (with respect to ground) at various points in the circuit.

Now we must figure out the electrode voltage values for the next tube, a type 56 triode. Notice that the plate of the first tube and the grid of the second are connected directly together and are at a D.C. potential of 253 volts with respect to ground; the cathode of the second tube must therefore have a potential of 268 volts with respect to ground if its grid is to be 15 volts more negative than its cathode. The plate of the 56 must be 250 volts more positive than its cathode and must therefore be at a potential of 268 + 250, or 518 volts with respect to ground. Each electrode supply lead is by-passed to ground with a condenser (*C*) in order to prevent the A.C. currents from flowing through the voltage-dividing resistors. Since a transformer, which has a very low D.C. resistance, is used as a plate load for the *56*, no allowance need be made here for a D.C. voltage drop in the load.

Disadvantages of the direct resistance-coupled amplifier include the high supply voltage required, the fact that changes in tube characteristics with age will upset the distribution of voltages to the tubes in the circuit, and the difficulties encountered in servicing such amplifiers. Although the circuit fell into disfavor in radio receivers for this reason, it is still used when A.C. voltages below about 10 cycles are to be amplified.

The circuits shown in Figs. *8B* and *9* work alike as amplifiers. In each case the applied A.C. signal e_g causes the net grid voltage to vary about the

*Pentode and tetrode tubes amplify exactly like triodes when the correct fixed D.C. voltages are applied to the extra grids.

operating value. This causes the plate current to vary about its operating value, producing a pulsating voltage across load resistor R_L. The A.C. component of this voltage then acts on the grid of the second tube either directly or through a coupling condenser.

VOLTAGE AMPLIFIERS WITH IMPEDANCE COUPLING

Inductive Loads. An inductance is sometimes used as an amplifier load; Fig. *10A* gives an example of the circuit used. This circuit is also called an impedance-coupled amplifier. The A.C. voltage which is developed across coil L by the varying plate current of tube VT_1 is fed to the grid of tube VT_2 through coupling condenser C, making the method of coupling exactly the same as in the resistance-capacitance coupled amplifier circuit. Resistor R_g, which allows the automatic C bias voltage to act upon the grid of tube VT_2, may be replaced with a choke coil, as was pointed out in connection with Fig. *8B*; if the resistance of R_g (or the impedance of the grid choke) is very high with respect to both coupling condenser C and plate load L, we can assume that L is the real load in this circuit.

Characteristics of Inductive Loads. The reactance of coil L depends not only upon the coil inductance in henrys, but also upon the frequency of the A.C. current flowing through the coil. The numerical value of this reactance (designated as X_L) is equal to $6.28 \times f \times L$, where L is the inductance of the coil in henrys and f is the frequency in cycles per second. The equivalent tube circuit for this case is shown in Fig. *10B*; although we have both inductance and resistance, the circuit can be analyzed by a special application of Ohm's Law. The exact mathematics involved does not concern us here, but the following facts resulting from this analysis of an inductive load are important:

1. FREQUENCY RESPONSE. The amplification secured with an inductive load increases with frequency; at very low frequencies (below 10 cycles) there is practically no amplification. When the frequency is increased to a value which makes X_L (the load impedance) more than 9 times greater than r_p (the A.C. plate resistance), the amplification becomes essentially equal to the μ (amplification factor) of the tube. It is common practice to select a value for L which will make X_L at least 5 times the value of r_p at the lowest frequency to be amplified. Sometimes an extra resistance R is placed in series with the load inductance L, as in Fig. *10C*, to control the minimum plate load at low frequencies.

2. PHASE SHIFT. You will remember that when the plate load of an amplifier stage is a pure resistance, the A.C. output voltage will lead the A.C. grid input voltage by 180 degrees. If an inductance load L is placed in series with a resistive load R, as is the case in Fig. *10C*, the angle of lead will be somewhere between 90 and 180 degrees; if the resistive load is omitted, leaving only a pure inductive load L, as in Figs. *10A* and *10B*, the angle of lead will become exactly 90 degrees. The insertion of inductance in the plate load circuit thus can shift the phase relationship of input and output A.C. voltages as much as 90 degrees.

3. VOLTAGE REQUIREMENTS. An important advantage of an inductive load is its low D. C. resistance, which allows practically the entire plate supply voltage to be applied to the plate of the tube and consequently lowers the required plate supply voltage. The magnetic energy which is stored in the load coil when plate current increases and which is released when plate current decreases serves to produce across the coil an A.C. voltage which adds to and subtracts from the supply voltage; the peak value of this plate voltage swing can never exceed the D.C. plate supply voltage. Quite often the load inductance in Fig. *10A* is shunted by a resistor in order to broaden or flatten the frequency response of the amplifier without increasing the required value of plate supply voltage; such a circuit is shown in Fig. *10D*.

4. RESONANCE EFFECTS. No coil can be built without distributed capacity, so at very high frequencies coil *L* in Fig. *10A* is in effect shunted by a condenser which reduces the load reactance somewhat. If the resonant frequency of *L* and its distributed capacity is in the range of audio or picture frequencies being amplified, the load impedance will become quite large at this frequency, boosting the amplification. For this reason a resonant load is often introduced purposely as in Fig. *10E*, to raise the amplification of the stage at a particular frequency.

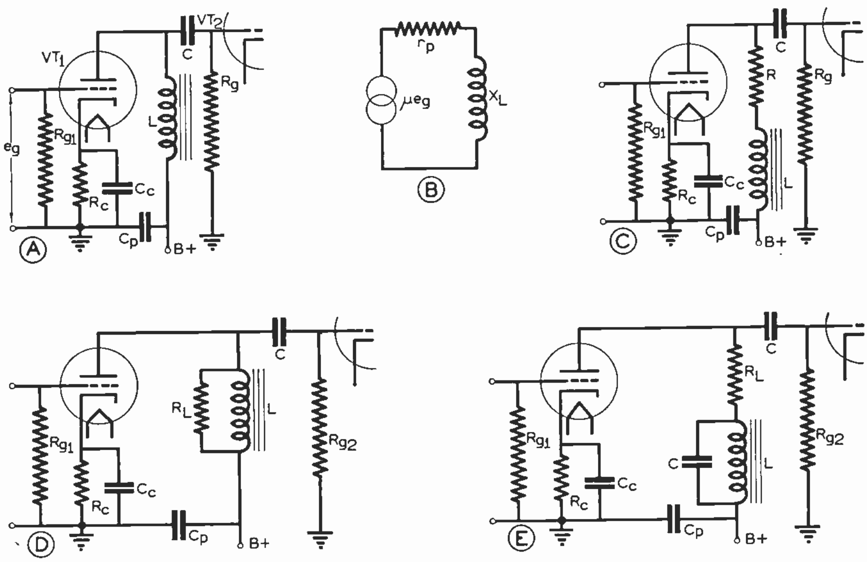


FIG. 10. These circuits illustrate various types of reactance loads for frequency amplifier circuits used for sound or television signals.

5. POWER LOSSES. No coil, especially of the iron core type, exists which does not have a certain amount of power loss. Hysteresis and eddy current losses have the effect of placing a high resistance in parallel with the coil, just as was purposely done in Fig. *10D;* this lowers the amplification somewhat but gives a flatter frequency response, which is sometimes quite desirable.

VOLTAGE AMPLIFIERS WITH TRANSFORMER COUPLING

A transformer is widely used for coupling one amplifier stage to another. The circuit of a voltage amplifier which utilizes transformer coupling is given in Fig. *11*. Secondary coil *S* has many more turns than primary coil *P*, and hence secondary voltage v_S is many times greater than voltage v_P which is developed by the plate current flowing through the high-reactance primary winding. Magnetic coupling through a common iron core links the two circuits together in this case. Since the primary winding has a very low D.C. resistance, practically the entire plate supply voltage is available for the tube. No grid resistor is needed across the secondary winding, for the winding itself provides a direct path from grid to ground.

Transformer coupling can boost the gain of an amplifier stage considerably, especially if the reactance of the transformer primary is high with respect to the A.C. plate resistance of the tube and the ratio N of secondary turns to primary turns is made high. A high reactance for primary winding P insures that the voltage v_P which appears across it will be practically equal to the mu of the tube multiplied by the A.C. grid input voltage e_g. The secondary voltage v_S will then be N (the turns ratio) times the primary voltage. Thus the theoretical maximum amplification which can be secured per stage with transformer coupling is the *amplification factor of the tube multiplied by the turns ratio of the coupling transformer*. With other types of coupling the theoretical maximum amplification is the mu of the tube; this is why transformer coupling is used so widely for low frequency voltage amplifiers.

The theoretical maximum amplification of a transformer-coupled stage is reduced somewhat by certain shortcomings of the iron core transformer: *1*, hysteresis and eddy current losses in the iron core; *2*, a certain amount of leakage inductance due to the inability of the core to provide absolutely perfect magnetic coupling between primary and secondary; *3*, losses in the coils; *4*, the distributed capacity of each coil and the capacities between the primary and secondary windings. The relative effects of each of these shortcomings varies with the frequency of the input signal. At the high frequencies in the range being handled by the amplifier, the leakage inductance and the stray capacities together form a resonant circuit which may make amplification even higher than at the medium frequencies. A frequency response curve for a particular transformer will tell you all these things at a glance. Since the nature of the frequency response of a transformer depends entirely upon its construction, it should be clear to you that exact duplicate units should always be used when replacing coupling transformers in high fidelity radio equipment.

EFFECTS OF TUBE CAPACITIES

Every amplifier circuit contains capacities inherent in the amplifier tube itself. A triode tube thus has the three inter-electrode capacities shown in Fig. *12*—the capacity C_{gk} between grid and cathode, the capacity C_{pk} between plate and cathode, and the capacity C_{gp} between grid and plate. Clearly C_{gk} will shunt the load of the preceding stage and C_{pk} will shunt the load of the tube itself, reducing the gain somewhat, especially at the higher frequencies.

Tube capacity C_{gp} gives the most trouble, for it provides a path along which signals can travel back from the plate circuit to the grid. Thus in Fig. *11* the primary voltage v_P can feed back through the grid-to-plate capacity to the grid of tube VT_1. Since C_{gp} produces a change in phase, the exact nature of the feed-back voltage depends on whether the load is resistive, capacitive or inductive. The feed-back voltage may therefore either add to the input voltage, giving a so-called *regenerative* effect, or may subtract from the input voltage to give a *degenerative* effect. When the load is *inductive,* regeneration takes place and the amplifier has more gain than normal; degeneration, with less gain than normal, occurs for the other types of loads. Furthermore, this feed-back action has the effect of shunting the input circuit with a capacity many times greater than C_{gp}, lowering the high frequency response of the amplifier. Regeneration and degeneration are both undesirable unless accurately controlled.

An audio amplifier using a tetrode or pentode tube does not have capacity feed-back trouble, for the screen grid is grounded as regards A.C. and this

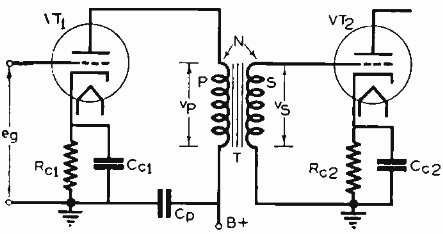


Fig. 11. The use of a transformer in coupling together two low frequency amplifier stages is illustrated in this circuit diagram.

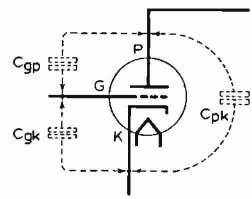


Fig. 12. The dotted lines here indicate the three inter-electrode capacities which are present in a triode tube.

reduces the grid-to-plate capacity hundreds of times. At high picture frequencies, however, even these screen grid tubes suffer from the shunting effects of the inter-electrode tube capacities.

COMPARISON OF FREQUENCY RESPONSE CHARACTERISTICS OF LOW FREQUENCY AMPLIFIER STAGES

The range of frequencies which will be uniformly amplified by an amplifier circuit depends essentially upon the type of coupling used. Having studied the operating principles involved in each type of coupling, we are ready to compare the frequency response characteristics of resistance-coupled, impedance-coupled and transformer-coupled amplifier stages. A glance at the curves in Fig. *13* gives you a general idea of how these three types of amplifier circuits respond to different frequencies; let us now analyze each curve in turn.

Resistance-Capacitance-Coupled Amplifiers. Curve *A* in Fig. *13* gives the frequency response for a typical resistance-capacitance-coupled amplifier stage like that in Fig. *8B*. Notice that the amplification is quite uniform over a wide range of frequencies. The amplification decreases at low frequencies because of the increased reactance of coupling condenser *C* at lower frequencies; at high frequencies the plate-to-cathode capacity of tube VT_1, the grid-to-cathode capacity of tube VT_2 and the increased grid-to-plate capacity of VT_2 have appreciable effects, shunting the load resistance R_L and thus reducing the voltage amplification. A direct resistance coupled amplifier would have a similar response curve except that the response at low frequencies would remain flat right down to 0 cycles (direct current).

The range over which a uniform frequency response is obtained in a resistance-capacitance-coupled amplifier can be widened *by reducing the ohmic value of the plate load resistor;* this makes the effects of any load-shunting capacities negligible but of course reduces the gain of the stage considerably. Increasing the capacity of coupling condenser C improves (raises) the low frequency response.

Impedance-Coupled Amplifiers. Curve B in Fig. *13* applies to an impedance-coupled amplifier circuit like that in Fig. *10D*, where R_L may represent either the losses in coil L or a separate resistor shunting the coil. Amplification is higher than for a resistance-capacitance-coupled circuit, but is uniform for a narrow band of frequencies. At low frequencies the reactance of coil L decreases, making the load reactance low and decreasing the amplification. As the frequency increases, the reactance of coil L increases to a very large value, so that R_L becomes the effective load; amplification then rises to a level which is determined by the value of R_L, remaining constant until the frequency has increased to the point where the distributed capacity of the coil and the tube capacities shunt the load and reduce amplification.

The low-frequency response of an impedance-coupled amplifier can be improved by using a choke which has a very high inductance; to insure good high frequency response, the choke must also have a low distributed capacity, and tube capacities must also be low. The coil must in addition have low losses in order to provide maximum amplification.

Transformer-Coupled Amplifiers. Curve C in Fig. *13* is for a transformer-coupled circuit like that given in Fig. *11*. For comparison purposes a 1-to-1 transformer was assumed when making the curve; in actual practice a high turns ratio would be used, greatly increasing the amplification. At low frequencies, curves B and C are much alike. Transformer losses are in effect a resistance load; at medium frequencies, therefore, when this resistance is less than the load reactance, the losses control the amplification over the flat portion of curve C. At high frequencies a combination of leakage reactance, distributed coil capacity, tube capacity and stray lead capacity effects result in an amplification rise at a certain resonant frequency. Above resonance, amplification drops rapidly because of the shunting effects of tube capacities.

Good response at low frequencies with a transformer-coupled amplifier can be obtained by making the inductance of the transformer primary high. Keeping the leakage reactance and the distributed capacity low insures good high frequency response, while high gain is secured by keeping the losses low and using a high turns ratio.

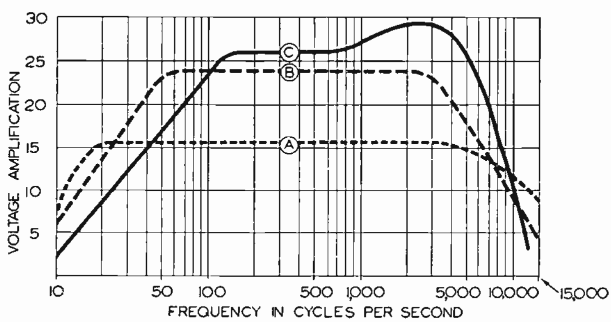
Practical Conclusions. The behavior of representative types of low frequency voltage amplifiers has been taken up principally to show that, because of the differences in the characteristics of these circuits, you cannot replace the coils or transformers used in amplifiers with parts which look alike and expect to get the same results which were originally secured by the designing engineers. Even though two transformers have the same turns ratio, they will not give the same results if their losses are different. Resistors are about the only parts you can safely replace by considering only their resistance values, provided that they are used in low current circuits where wattage ratings are unimportant. In all other cases exact duplicate parts, obtainable from the manufacturer of the amplifier or from certain radio supply houses, should be used *when fidelity is important.*

Limitations As to Maximum Gain. Remember that the μ of the tube is the theoretical limit for the gain in any resistance-capacitance-coupled or impedance-coupled amplifier stage, and that this theoretical limit is increased by the turns ratio N in the case of transformer-coupled amplifiers.

SINGLE-TUBE LOW FREQUENCY POWER AMPLIFIERS

Up to this time we have concentrated our attention on low frequency *voltage* amplifiers; low frequency *power* amplifiers are basically no dif-

FIG. 13. This chart gives a comparison of the frequency response characteristics of: *A*, resistance-capacitance coupled amplifier stage; *B*, impedance-coupled amplifier stage; *C*, transformer-coupled amplifier stage. A special scale is used for frequency in order to show the low frequency response clearly and at the same time show the response for a wide range of frequency values.



ferent, except that the load in the plate circuit is made a value which will give large plate current changes as well as large load voltage changes; thus changes in grid excitation produce the desired large *power* changes. Power amplifiers seldom have resistors as loads, hence we must give special attention to the type of load encountered in practical power amplifier circuits.

Loads Which Act As Resistances. Up to this point, when we considered resistive loads, we were dealing actually with resistors. A loudspeaker is a load device which contains a coil having impedance (reactance and A.C. resistance*); it will act like a resistance when coupled to the plate circuit of a low frequency power amplifier, because whatever reactance the loudspeaker may have is negligible with respect to its A.C. resistance. The question is, what will the effective *A.C. resistance* of this load be? We simply divide the A.C. voltage of the load by the A.C. current flowing through the load (Ohm's Law) to get impedance; since the A.C. load voltage and current are in *phase* in practically all amplifier loads, the impedance is also the A.C. resistance.

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*Any A.C. loss in a circuit contributes to the A.C. resistance; if the device has D.C. resistance, this will also be included in the A.C. resistance value.

Here is an example: If a certain loudspeaker requires an A.C. signal voltage of 4 volts and an A.C. current of 2 amperes (8 watts of power), its impedance or A. C. resistance (assuming that its reactance is negligible) is 4 ÷ 2, or 2 ohms (this low value is typical of dynamic loudspeakers). In all cases the A.C. resistance of the load will be considerably higher than the D.C. resistance. (Actually the A.C. resistance is equal to the D.C. resistance plus a resistance value which is dependent upon the amount of power drawn by the load, upon the losses in the load coil, and upon hysteresis and eddy current losses in the iron core of the load device.)

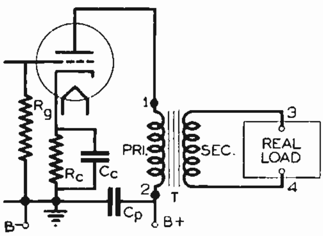
Optimum Load Resistance Values. I have already pointed out that a low frequency voltage amplifier stage gives optimum (best) results with a particular value of load resistance; power amplifier stages likewise require particular values of load resistance. For a triode, *maximum undistorted power output* is obtained when the load resistance is about *twice* the A.C. plate resistance (maximum power is obtained when the two values are equal, but severe amplitude distortion occurs, making it necessary to use a higher load resistance value as a compromise). With pentode tubes a load resistance which is between one-fourth and one-tenth the A.C. plate resistance will give maximum undistorted power output.

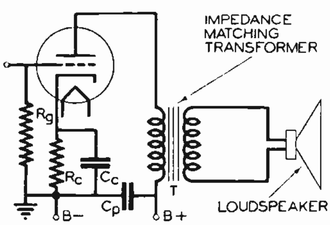
What can we do when our load (whether it be a pure resistance or a device which has A. C. resistance) must be connected to a tube which has too low or too high an A.C. plate resistance for best results with that particular load? There is one very simple and widely used solution to this problem—place a matching transformer between the plate circuit of the tube and the load. A *transformer* will match two *entirely different resistances;* here is how it is done.

Matching Characteristics of a Transformer. The circuit of a transformer connected between a load and the plate circuit of an amplifier stage is shown in Fig. *14A*. The load here has a definite resistance (entirely different from the desired value for the tube) and requires a definite amount of power. Assume that we have a *step-down* transformer, in which the primary has more turns than the secondary; the primary voltage, as measured between points *1* and *2,* will therefore be *greater* than the secondary voltage measured between points *3* and *4,* and the primary current will be *less* than the secondary current. Since resistance equals voltage divided by current, the A.C. resistance as measured across the primary winding will be considerably higher than the load resistance; actually the primary A.C. resistance will be equal to the load or secondary resistance *multiplied twice by the turns ratio of the transformer* (mathematicians say the secondary resistance is multiplied by the square of the turns ratio). A transformer connected between a source and load alters the load impedance by changing the voltage and current drawn from the source; a properly designed transformer can thus make the load impedance match the source impedance without changing the amount of power transferred from source to load.

An Example of Matching. An example will clarify these transformer characteristics. Suppose the load in the circuit of Fig. 14A requires 4 volts and 2 amperes, or a power of 8 watts, and the transformer has a turns ratio of 50, with the primary having 50 times as many turns as the secondary. The primary A. C. voltage will then be 4 × 50, or 200 volts, and the primary A.C. current will be 2 ÷ 50, or .04 ampere. The primary power is thus 200 × .04, or 8 watts, showing that primary and secondary power are the same. The primary A.C. resistance will be 200 ÷ .04, or 5,000 ohms, as compared to 4 ÷ 2, or 2 ohms for the secondary; since 2 × 50 × 50 is 5,000, we have verified our statement that the effect of a transformer is to multiply the load resistance *twice* by the turns ratio without changing the load power.

Reflected Resistance. The primary A.C. resistance (the effective load resistance in the plate circuit of the tube) can be made any desired value by choosing the proper turns ratio for the matching transformer. We often say that the load resistance is *reflected* into the plate circuit through the matching transformer; adjusting the value of this reflected load to secure the best amplifier operation is called *matching* the load with the amplifier





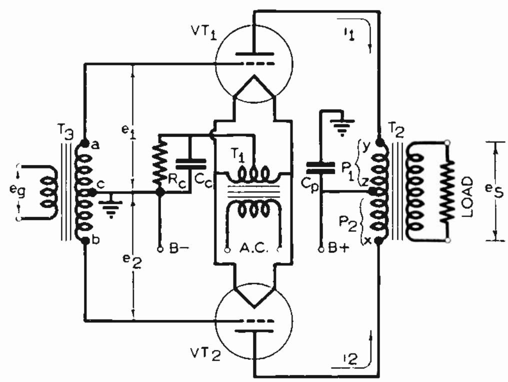


FIG. 14A (above). This circuit shows how a transformer can be used to match the impedance of a load to the value required by the tube for maximum power output.

FIG. 14B (below). A practical example of a circuit where the impedance or A.C. resistance of the loudspeaker is matched to the A.C. plate resistance of the power output tube.

FIG. 15. Schematic circuit diagram of a typical low frequency push-pull amplifier. The input signal is e_g, while the amplifier output signal is e_s. By-pass condenser C_p keeps A.C. out of the plate supply lead.

tube, and for this reason the transformer used is often called a matching transformer. Remember—reflected resistance is that effective resistance which appears across the primary terminals of a matching transformer when a load is connected across the transformer secondary.

A practical single-tube power amplifier circuit in which a transformer is used to match the load with the amplifier tube is shown in Fig. *14B*. The loudspeaker here has a very low A.C. resistance (perhaps about 10 ohms), while the triode tube may require a resistance of at least 10,000 ohms for its plate load; the *transformer* matches these *entirely different resistances* (or impedances) by reflecting into the plate circuit of the tube an effective load resistance of the proper value.

The higher the mutual conductance, the higher the D.C. plate supply voltage and the higher the D.C. plate current, the greater will be the power which you can expect to obtain from a tube being used as an amplifier; tubes which are designed especially for high power outputs are often called *power tubes*. The higher the mu of a tube for a given power output, the lower will be the A.C. grid voltage required to give this output.

Most power tubes can, when operated as class A amplifiers, be used singly for low frequency power amplification. If the output of a single tube is not sufficient, two or more power tubes may be connected together in parallel to give the effect of a tube having higher power output rating; furthermore, a single tube having a higher power rating can be used to get greater output or special balanced multi-tube circuits (push-pull and push-push circuits, which are now to be considered) can be used.

PUSH-PULL POWER AMPLIFIERS

It is amplitude distortion, resulting in the introduction of undesired harmonic frequencies, which limits the maximum amount of useful power which can be obtained from a single power tube; by using a special arrangement of two tubes which is known as a *push-pull circuit*, it is possible to eliminate *all even harmonics* resulting from amplitude distortion. This leaves only the odd harmonics (particularly the third harmonic) resulting from amplitude distortion as a limit on maximum power output. With a push-pull arrangement it is possible to use with each tube a load resistance which is more nearly equal to the A.C. plate resistance of the tube, and consequently the amount of undistorted power more nearly corresponds to the maximum obtainable amount of power. Two tubes connected in push-pull will therefore give consideraly more than twice the undistorted power which a single tube could deliver.

The action of a two-tube push-pull stage is best understood by referring to a practical circuit diagram as given in Fig. *15*. The filaments of tubes VT_1 and VT_2, which have identical static and dynamic characteristics, are fed in parallel from voltage step-down transformer T_1. The center tap of the transformer secondary is grounded through resistor R_c; the plate currents for the two tubes, flowing through R_c, provide a voltage drop which serves as operating C bias for both tubes. A common plate voltage source is used, tube VT_1 getting its supply through one-half of the primary of transformer T_2 and tube VT_2 getting its plate supply through the other half. When no grid input signal is present, "current" flow in the plate circuit of each tube is in the direction indicated by the arrows alongside i_1 and i_2;* since each tube gets the same C bias, the D.C. plate currents will be *equal in value* and will flow *in opposite directions* through the halves of the transformer primary. The effects of the fluxes produced by the D.C. plate cur-

*The term current, as used in the discussion of push-pull and push-push amplifiers, refers to the flow of electrons; in vacuum tube circuits it is convenient and desirable to do this because the tubes always act as sign-posts, telling which way electrons flow.

rents thus cancel, and no resultant flux exists in the transformer core when there is no signal.

We shall now assume that a low frequency sine wave signal e_g is being supplied to the primary of grid input transformer T_3; the secondary of T_3 will therefore have a larger A.C. voltage because of the voltage step-up ratio. Half of the secondary A.C. voltage is applied to the grid of VT_1, the other half to the grid of VT_2. Since point *c* is the center tap of the secondary winding of T_3, one-half of this voltage, say the voltage across section *ca*, will be 180 degrees out of phase with the other half (across section *cb*) and the grid input voltages, e_1 and e_2, will have the 180 degree relation shown in Fig. *16A*. In other words, when e_1 is a maximum positive value, e_2 will be a maximum negative value.

Action of a Push-Pull Circuit. Since tubes VT_1 and VT_2 and their effective loads are identical, we can use the same dynamic E_g-I_p curve for both; Fig. *16* therefore portrays *operating conditions* in a push-pull amplifier circuit. Notice that the operating point, as determined by the voltage drop across R_c, is at a sharp bend on the dynamic E_g-I_p curve (at *1, 3, 5* in Fig. *16B*), so that positive grid voltage swings give much greater plate current changes than do negative grid voltage swings. This is the condition for class AB operation; with class A operation the operating point would be on a more linear part of the dynamic characteristic curve. This class AB operation was selected to show in a more pronounced manner the effects of curvature in the dynamic characteristic.

On that half of a cycle when point *a* in Fig. *15* is positive with respect to *c*, the grid voltage e_1 of VT_1 will swing in a positive direction, causing the plate current to rise to a maximum value and drop back to the operating plate current value. This grid voltage swing (from *1* to *2* to *3* in Figs. *16A* and *16B*) causes the plate current i_1 of tube VT_1 to swing from its operating value (point *1* on the curve in Fig. *16C*) to *2* and then down to *3* during the first half of the cycle. During this same half cycle point *b* in Fig. *15* will be negative and the grid voltage e_2 of VT_2 will swing in a negative direction, from *1* to *4* to *3* on the dynamic curve, and cause plate current i_2 of tube VT_2 to swing from its operating value (*1* in Fig. *16C*) down to *4* and up again to *3*.

Thus you can see that for the first half of the cycle, a positive grid voltage swing e_1 on tube VT_1 produces a much greater change in plate current i_1 than does an equal negative grid voltage swing e_2 on tube VT_2. The same analysis can be applied to the currents for the second half of the cycle; in this case the grid of VT_2 swings positive, causing the plate current i_2 to change from *3* to *2* to *5* (Fig. *16C*), while a negative grid swing on tube VT_1 causes plate current i_1 to change from *3* to *4* to *5*.

Plate current i_1, flowing from *y* to *z* through primary winding P_1 in Fig. *15*, produces in the transformer core a varying flux Φ_1 whose wave form (shown in Fig. *16D*) is exactly like that of plate current i_1 in Fig. *16C*, which produced this flux. At the same time, plate current i_2, flowing from *x* to *z* through primary winding P_2 in Fig. *15*, produces a varying flux Φ_2 (Fig. *16E*). The two varying plate currents, i_1 and i_2, are 180 degrees out of phase (since one increases while the other decreases), but they flow in opposite directions through the primary winding of the transformer and hence the varying fluxes which they produce are in phase (both fluxes increase at the same time).

We thus have two varying flux waves, Φ_1 and Φ_2, acting in phase in the transformer core at all times; to determine the wave form of the resultant flux, we must combine these two flux waves. We could do this by combining wave Φ_1 in Fig. *16D* directly with wave Φ_2 in Fig. *16E*, getting resultant flux wave Φ in Fig. *16H*, but we will learn more about what happens to the undesired harmonics if we add the components of these fluxes together.

Flux wave Φ_1 consists essentially of a D.C. component, the fundamental A.C. component and a number of harmonics, as shown in Fig. *16F*. Flux wave Φ_2 has these same components, as shown in Fig. *16G*. (These statements can be proved with advanced mathematics or by adding together the components of a wave graphically.) It will be sufficient to consider only the second and third harmonics at this time, since they are the most important. We can combine the effects of Φ_1 and Φ_2 by combining one component of each flux wave at a time.

First of all, consider the D.C. components of the varying fluxes; the D.C. component of Φ_1 in Fig. *16F* is in the opposite direction from the D.C. component of Φ_2 in Fig. *16G*, hence the two D.C. components of the varying flux cancel. Now consider the fundamental components of Φ_1 and Φ_2; you can see from Figs. *16F* and *16G* that they act in the *same* direction and hence their effects add together. The second harmonic components act in *opposite* directions at any instant of time, however, and their effects cancel. The effects of the third harmonic components add, just as in the case of the fundamentals. If we continued the analysis for all harmonics, we would find that the effects of all even harmonic components of flux cancel out, leaving only the fundamental and the odd harmonic components (fortunately all harmonics above the second are quite weak). The resultant varying flux (shown in Fig. *16H*) will therefore be a practically pure sine wave, which will induce in the transformer secondary the sine wave output voltage wave designated by e_s in Fig. *16I*.

The action of a push-pull amplifier circuit is often explained briefly in the following manner: Currents i_1 and i_2 in Fig. *16C* flow in opposite directions through the primary of the output transformer at any instant of time, producing the flux waves Φ_1 in Fig. *16D* and Φ_2 in Fig. *16E*. To combine these flux waves and find the resultant flux we simply add together corresponding values on each wave. For example, we add distance *cd* in Fig. *16E* to distance *ab* in Fig. *16D*; distance *ef* in Fig. *16H* is the result. Carrying this process through for the entire cycle gives resultant flux wave Φ in Fig. *16H*. Distortion has been reduced because, considering the first half cycle, the larger-than-normal current i_1 (caused by the upward bend in section *1-2* of the dynamic curve) is offset by the lower-than-normal current i_2 (caused by the flattening of section *1-4* of the dynamic curve).

Any harmonics which are present in the original grid input signal will obviously be affected in the same way as the fundamental wave just discussed, adding to give the desired amplified output; this is just what we want—all harmonics in the original signal must be reproduced and the introduction of new harmonics must be kept at a minimum.

In a push-pull class A circuit it is not necessary to place by-pass condenser C_c across C bias resistor R_c (Fig. *15*) in order to offset variations in plate current, for any increase in plate current i_1 will automatically be balanced by an equal decrease in i_2, keeping the resulting current through R_c constant. With class AB operation, however, this by-pass condenser is necessary.

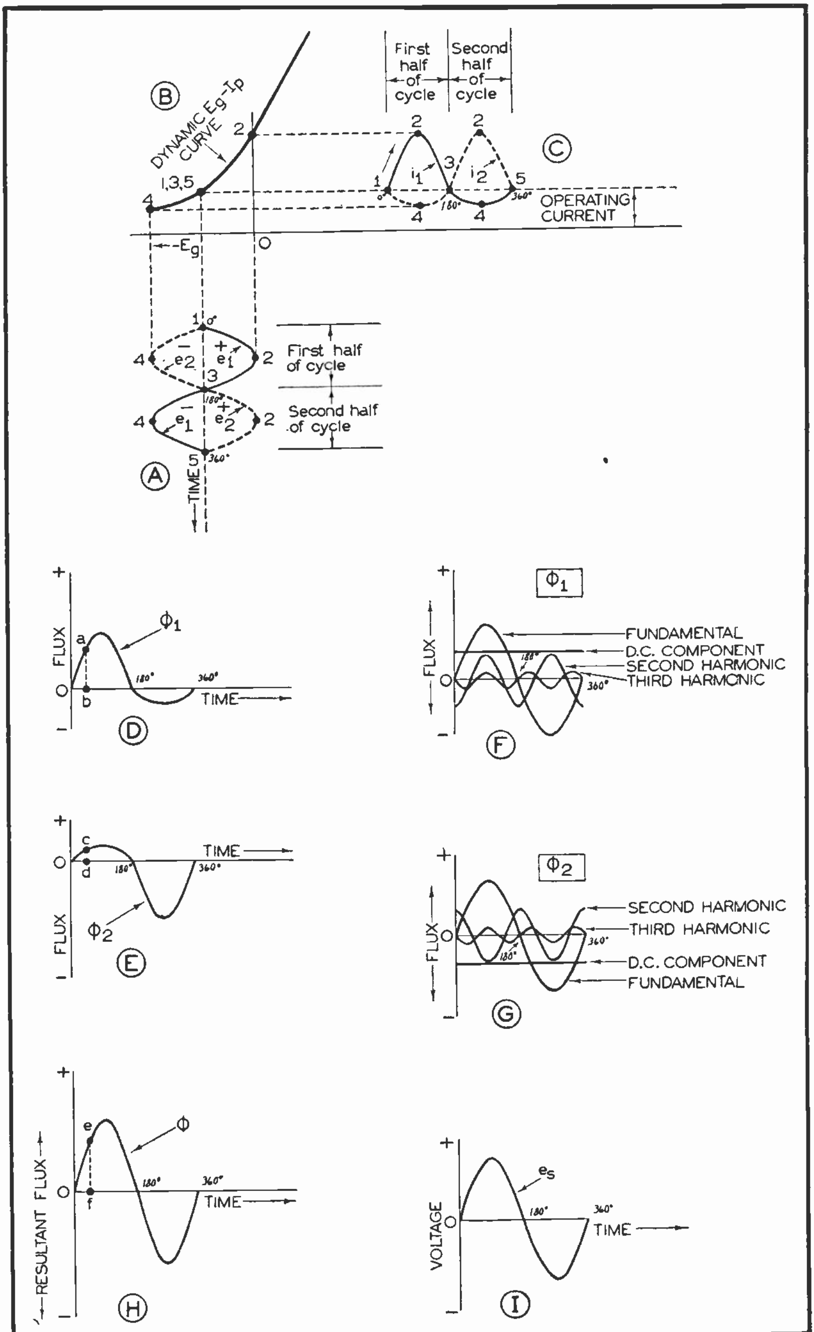


FIG. 16. The operating principles of a push-pull amplifier are illustrated here. No attempt was made to draw these curves to scale.

PUSH-PUSH POWER AMPLIFIERS

Although the push-pull class A amplifier just discussed gives a higher output than can be obtained with two tubes in a conventional parallel circuit, its efficiency is rather low, so that higher power outputs can be obtained only by using very high plate supply voltages and tubes which are large and costly in proportion to the amount of useful power output which can be obtained. By changing to class B operation, however, this same push-pull circuit can be converted into a *push-push amplifier* which will deliver large power outputs at a much higher efficiency; small tubes can therefore be used without excessive overheating of the tube electrodes.

Push-Push Requirements. The two essential requirements for a push-push amplifier are: *1,* The dynamic E_g-I_p curve must be essentially straight from its plate current cut-off point to the positive grid voltage value at which secondary emission from grid and plate just becomes objectionable; *2,* the grid bias must be set for class B operation (at the plate current cut-off point). You can either use a tube whose plate current cuts off at zero grid bias (eliminating the need for a C bias) or you can replace the automatic C bias (used in push-pull) with a fixed C bias source, adjusting the C bias for plate current cut-off. The circuit is no different from that given in Fig. *15* for a push-pull amplifier except for the C bias connection; only the method of operation differs.

When the circuit in Fig. *15* is adjusted, and the proper tubes and load are used to meet the above two requirements, the application of a sine wave input signal to the primary of input transformer T_3 will make plate current waves i_1 and i_2 each a perfect half sine wave.* One tube pushes current through the primary of T_2 for one-half of a cycle, and the other tube pushes for the other half of a cycle, hence the name *push-push.* Addition of the effects of the two plate currents in the primary of the output transformer gives a perfect sine wave, and the output voltage e_S will likewise be a sine wave.

A push-push circuit using special high μ tubes (designed especially for class B operation) is given in Fig. *17.* Connecting together grids *1* and *2* and connecting grid *3* to the plate gives the desired high μ, zero-bias plate current cut-off characteristics. Assuming a sine wave input signal e_g, the

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*Provided the input transformer has a low or negligible impedance, so it will not distort the wave form. The voltage applied to the grid of the tube will be equal to the voltage of the source (the secondary of the input transformer) only when the grid draws no current. When the grid does draw current, the tube will get the difference between the input source voltage and the voltage drop produced by grid current flowing through the input transformer secondary. In the case of tubes which require no C bias, grid current does flow at all times; unfortunately the grid current-grid voltage curve is distorted (not linear), and consequently there is distortion unless the impedance of the input transformer is made sufficiently low that the voltage drop in it is negligible with respect to the applied voltage. In the case of tubes which operate with a fixed C bias, grid current flows only for a part of each cycle and hence distortion occurs whenever the grid draws current; here, also, the distortion can be reduced to a negligible value by keeping the input impedance low.

voltage for the first half of the cycle (e_1) will swing the control grid of tube VT_1 positive and a half-wave plate current pulse i_1 will flow through one section of the output transformer primary, inducing a half sine wave voltage in the secondary. No current will flow through tube VT_2 during this half cycle, for its grid will be negative and hence beyond the plate current cut-off point. Similarly, for the other half of the input voltage cycle, plate current i_2 will flow in the opposite direction through the lower section of the transformer primary, inducing in the secondary a half sine wave voltage of opposite polarity to the first, and giving a perfect sine wave output voltage e_S.

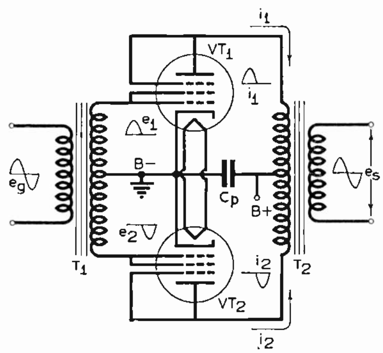

FIG. 17 (above). Push-push amplifier circuit using special high-mu tubes.

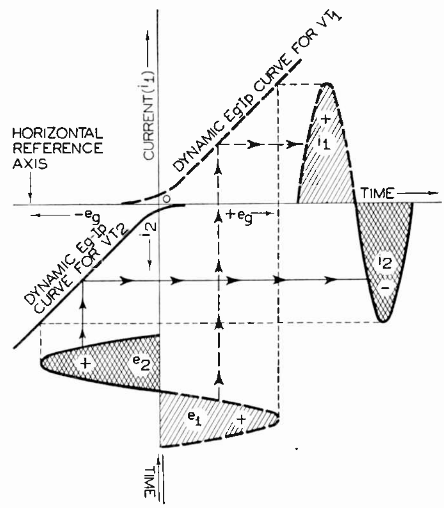

FIG. 18 (at right). This graph explains how a push-push amplifier works. At very low values of grid input voltage, the bend in one dynamic curve is compensated for by the bend in the other, giving the effect of straight line dynamic curves right down to zero plate current.

A graph showing in simplified form the action of a *push-push* stage appears in Fig. *18*. Since only one tube is acting at a time, we can show the action of both tubes on a single combined graph. One dynamic E_g-I_p curve is shown above and the other below the horizontal reference axis, for in this way the combined effects of plate currents i_1 and i_2 can be correctly shown. When the input voltage e_g makes e_1 positive, the grid of tube VT_1 swings over the positive region of the E_g-I_p curve for VT_1, producing the effect of the positive plate current wave i_1; on the other half of the cycle e_2 is positive and swings the grid of tube VT_2 over the positive region of its dynamic curve, producing the effect of plate current wave i_2, which flows in the opposite direction from i_1 through the output transformer and hence is designated "minus." The negative half-cycles of each grid input voltage have no effect upon the circuit and hence are not shown in Fig. *18*.

Distortion. There is no cancellation of either even or odd harmonics in a push-push amplifier, for the harmonics are produced by only one tube at a time. The generation of harmonics can be reduced, however, by using tubes whose dynamic E_g-I_p characteristics are as straight as possible; choosing the proper value of load has much to do with the linearity of the curves. When it is necessary, possibly for economic reasons, to use in a push-push stage those types of tubes which create amplitude distortion (tubes whose dynamic E_g-I_p curves bend either upward or downward in the operating range), the resulting distortion can be canceled out by purposely introducing amplitude distortion of an opposite nature in a preceding stage (by using tubes whose dynamic E_g-I_p curves bend in the opposite direction from the curves for the push-push stage).

Class AB Amplification. When the circuit of Fig. *15* is used with a C bias which is *between* the values required for push-pull and push-push operation, we have an amplifier which will act as a push-pull stage for low grid signal voltages and as a push-push stage for high grid signal voltages. At low signal levels, then, even harmonics are eliminated; distortion caused by harmonics does exist at high signal levels, but is less objectionable at high levels in actual practice. This combination arrangement is known as a *class AB amplifier.* For satisfactory operation the C bias must be obtained in such a way that the plate current has no effect upon its value; in other words, a fixed C bias must be used.

How to Distinguish Between Push-Pull and Push-Push. Here are a few tips which will allow you to determine whether a given circuit is push-pull or push-push. If the C bias resistor R_c has been omitted, if the two tubes have high amplification factors, and if the plate current cut-off point is at zero bias, you have push-push operation. When ordinary output tubes (having a relatively low μ) are used and the C bias voltage is unusually large (approximately equal to the plate voltage divided by the μ of the tube) you likewise have push-push operation. One other fact allows you to identify a *push-push* circuit; the grids swing highly positive and therefore draw current, so the input signal source must be able to supply this power. You will always find a power amplifier stage (single tube, parallel tubes or push-pull type) ahead of a *push-push* stage.

CASCADED AMPLIFIER STAGES (COMPLETE AMPLIFIERS)

In broadcast radio receivers the output of the detector stage may be high enough to drive the power amplifier tube. In television receivers the output of the detector is often high enough to drive an electronic picture reconstructor directly, while in other cases only a single voltage amplifier stage is needed between the detector and the image reconstructor. In public address systems or in the modulation signal amplifier sections of transmitters, however, a great deal of low frequency voltage amplification is required in order to make the final stage deliver its rated power. When more amplification is required than can be obtained with a single stage, several amplifier stages may be used *in cascade.* The entire low frequency amplifier system is then known as a cascaded amplifier.

The circuit diagram of a low frequency amplifier which is capable of delivering 40 watts of undistorted power when the output of a crystal phonograph pick-up is fed to its input is shown in Fig. *19*. An analysis of this circuit, which contains several stages in cascade, will help you to understand the action of complete low frequency amplifiers. The input terminals of the circuit can be fed by any high impedance signal source (sources having an impedance higher than 2,000 ohms); low impedance signal sources can be used if an input transformer is placed between source and amplifier in order to match the impedances. Crystal microphone and phonograph pick-up units have impedances of around 500,000 ohms and hence require no input transformer.

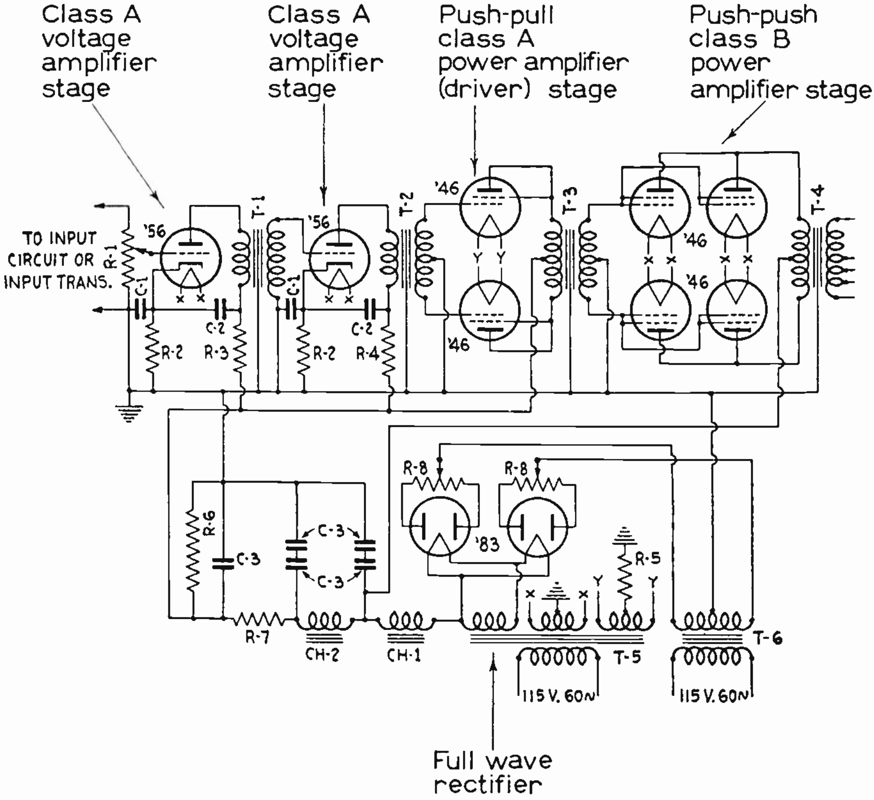

FIG. 19. Schematic circuit diagram of an audio amplifier suitable for public address work; cascaded stages are used to get sufficient voltage amplification, while power tubes are used in parallel in the final push-push power amplifier stage to get 40 watts of undistorted power. Note that the cores of audio transformers T-1, T-2, T-3 and T-4 are grounded; this is accomplished automatically when bolting or riveting the transformers to the chassis.

The signal source feeds into the grid of a type 56 tube acting as a class A voltage amplifier and having transformer *T-1* as a plate load. The plate current of this tube flows through resistor *R-2* in its cathode circuit, thus providing automatic C bias. Condenser *C-1* is a by-pass unit, while condenser *C-2* and resistor *R-3* in the plate circuit serve to keep signal currents out of the power supply leads and at the same time serve to filter out any A.C. ripple which gets past the power pack filter unit. The input A.C. grid voltage in this stage causes an A.C. plate current to flow through the primary of transformer *T-1*, inducing in its secondary an A.C. voltage of similar wave form and of greater magnitude than the input voltage. The maximum possible amplification of this stage is the μ of the tube multiplied by the turns ratio of the transformer.

The secondary of transformer *T-1* feeds into another class A voltage amplifier stage using a type 56 tube; transformer *T-2* is the plate load for this stage, and since its secondary feeds into a push-pull stage, there is a center tap connection on the secondary. Other than this, the two class A amplifier stages are identical.

Turning temporarily to the final stage of this amplifier, we see that it is a push-push arrangement containing four type 46 tubes, each pair of tubes being connected in parallel. The two grids of each tube are connected together to serve as control grid, thus giving the high μ required for push-push operation.*

As you know, a push-push amplifier requires a power stage ahead of it to furnish power to its grid circuit, since the grids draw current. The stage which supplies power to the grids of the final stage is called a *driver stage;* in this circuit the driver contains two type 46 tubes connected in a push-pull arrangement, with the second grid of each tube connected to its plate in order to give the low μ triode required for class A push-pull operation. Notice that both the input transformer (*T-2*) and the output transformer (*T-3*) windings of this driver stage have center tap connections. Resistor *R-5* in the center tap lead of filament transformer *Y-Y* (on *T-5*) provides the required fixed C bias for the push-pull driver stage.

The push-push final stage of course requires no C bias, since its tubes have been connected to give plate current cut-off at zero bias. Two tubes are used in parallel in each half of this final stage in order to secure greater power output. The filaments of these four tubes are all connected in parallel to filament transformer *X-X*, whose center tap is grounded directly. The grid return is also grounded; all this indicates that these tubes have no C bias. Transformer *T-4* has a number of taps on its secondary winding, to permit the use of loads which have different impedances while still reflecting back into the primary winding the correct impedance to give linear dynamic E_g-I_p characteristics for push-push operation.

Incidentally, transformer *T-1* could be replaced by any one of the coupling methods shown in Figs. *8B, 10A, 10C* or *10E*, but the amplification would be reduced somewhat. If greater amplification is required, additional voltage amplifier stages can be used, or the first two stages can be designed for use with pentode tubes.

The power supply for this amplifier contains two type 83 mercury vapor tubes connected to give full-wave rectification. The two plates of each

*In any tube the C bias required for plate current cut-off is approximately equal to the operating plate voltage divided by the μ of the tube. Thus if a tube has a high value of μ, a very low C bias is sufficient for plate current cut-off. With certain high-mu power tubes, satisfactory operation can be obtained with zero C bias.

tube are connected together through resistors *R-8* simply to eliminate internal gas oscillation; if you consider each tube to be a half-wave rectifier, you will have no trouble in analyzing the power pack circuit. Transformer *T-5* supplies the three filament voltage values required for the entire amplifier, while transformer *T-6* supplies the high voltage required by the rectifier tubes. Chokes *CH-1* and *CH-2,* together with condensers *C-3,* form the filter circuit. The filter condensers (*C-3*) are connected in series in two instances in order to permit them to withstand the high voltages encountered. Resistor *R-6* is called a *bleeder resistor* because it draws a small value of current from the power pack at all times. Resistor *R-7* serves to reduce the plate voltage applied to the first three stages. The full rectified output voltage of the power pack is applied to the plates of the output tubes in the final stage by means of a tap between chokes *CH-1* and *CH-2*. The plate voltages of the first two stages are further reduced by voltage-dropping resistors *R-3* and *R-4*.

TEST QUESTIONS

Be sure to number your Answer Sheet 15FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Name the two distinct types of *low frequency* amplifiers.
2. What three forms of distortion may occur in a low frequency amplifier?
3. What type of distortion definitely results in the production of harmonics which are not present in the original signal?
4. Will an increase in the ohmic value of the load resistance for a triode tube make the dynamic E_g-I_p curve for the tube circuit straighter (more linear)?
5. Which *class* of amplifier (A, B, AB or C) has the lowest efficiency?
6. What is the theoretical maximum amplification which can be secured per stage when transformer coupling is used?
7. How can the range over which uniform frequency response is obtained in a resistance-capacitance-coupled amplifier be widened?
8. What device may be used to match two entirely different resistances?
9. What harmonics resulting from amplitude distortion are eliminated by a push-pull circuit?
10. When more amplification is required than can be obtained with a single stage, what can be done?

RADIO FREQUENCY AMPLIFIERS FOR SOUND AND TELEVISION COMMUNICATION

16FR-1

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No matter how hard a person may work for success, there is nothing which can help him if he is always doubting his own ability —if he is always thinking about failure. To be ambitious for wealth yet always expecting to be poor is like trying to get past a vicious dog when afraid of the dog and uncertain of your ability to make friends with him—in each case, fear of failure is almost certain to result in failure.

Never doubt for a moment that you are going to succeed. Look forward to that success with just as much assurance as you look forward to the dawn of another day, *then work—with all that's in you—for success.*

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Radio Frequency Amplifiers for Sound and Television Communication

WHAT R. F. AMPLIFIERS DO

IN sound or television receivers the modulated R.F. carrier current in the antenna circuit is usually not strong enough to be fed directly to the detector (where the sound or picture signals are separated from the carrier). Weak modulated carrier voltages must often be amplified as much as a million times before they can be satisfactorily demodulated by the detector; this can be done by an *R.F. amplifier* consisting of one or more stages.

This R.F. amplifier must not only *amplify* the desired incoming carrier signal, but must also be able to reject all undesired carrier signals which are present in the antenna circuit; the R.F. amplifier must have *selectivity.* Furthermore, the R.F. amplifier must be able to select, when the receiver controls are adjusted, any one of the many carriers which may be present in the antenna circuit; it must be possible to *tune* the R.F. amplifier to a desired carrier frequency.

T.R.F. Receivers. In one very common type of R.F. amplifier, all of the R.F. stages can be tuned to the frequency of the desired incoming carrier signal. A receiver using this type of R.F. amplifier is commonly known as a tuned radio frequency receiver, or simply as a *T.R.F. receiver.*

Superheterodyne Receivers. The most widely used R.F. amplifier is that in which only the first stage (or first two stages) is tuned to the frequency of the incoming carrier. The amplified carrier signal from the first stage then enters a mixer-first detector tube, where it is mixed with an R.F. signal from a local oscillator in such a way that the frequency value of the R.F. carrier is reduced to a lower R.F. value which is known as the intermediate frequency (I.F.). This intermediate radio frequency, still modulated with either the sound or picture signal, is then amplified by I.F. amplifier stages having fixed tuning and therefore giving maximum amplification at one particular frequency. This is the so-called superheterodyne (or super) principle of R.F. amplification, in which the tuning action takes place before frequency conversion and most of the amplification takes place after frequency conversion (in the I.F. amplifier stages, which are also known as low R.F. amplifier stages). Each R.F. and I.F. stage contributes something to the selectivity of the receiver, with the greatest amount of selectivity being secured in the fixed tuned stages (the I.F. amplifier).

Side Bands. Let us review briefly the characteristics of a modulated radio frequency carrier current. As you know, the process of modulating a carrier introduces side frequencies which are above and below the carrier frequency value. The greater the frequency range of a sound or picture signal being transmitted, the farther off from the carrier frequency will be the extreme side frequencies. The frequency range extending from the lowest to the highest side-band frequency is known as the ***band width;***

this naturally varies with the nature of the intelligence being transmitted. In addition to the carrier frequency, then, the R.F. amplifier must therefore handle all of these side frequencies.

Fidelity. The R.F. amplifier in a receiver must be able to reject all signals except the desired R.F. carrier and its side bands, but at the same time it must not be so selective in its operation that it completely or partially rejects any of the side frequencies associated with the desired R.F. carrier frequency.

The fidelity (quality of reproduction) of an R.F. amplifier is impaired when the carrier frequency is amplified more than the side frequencies; distortion likewise occurs if the side frequencies higher than the carrier are amplified more than the side frequencies which are lower than the carrier.

The R.F. amplifier in a sound or television radio receiver must therefore be able to do these four things: *1*, tune to the desired carrier frequency; *2*, amplify the desired carrier frequency; *3*, contribute selectivity by rejecting undesired carrier frequencies; *4*, give uniform amplification for all side frequencies when high fidelity reproduction is required.

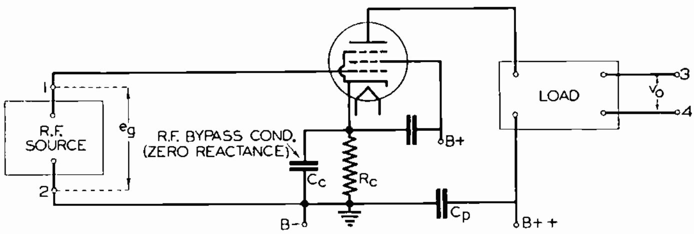


FIG. 1. Simplified schematic circuit diagram of a typical R. F. amplifier stage.

R.F. Amplifiers in Transmitters. In any radio transmitter, regardless of whether sound or picture signals are handled, the R.F. amplifier can be divided into two sections: *1*, the section handling only the unmodulated R.F. carrier currents; *2*, the section handling the modulated R.F. carrier current. The point of division is therefore the stage in which modulation takes place.

The first section of a transmitter creates, by means of an oscillator stage, an R.F. carrier which is amplified by succeeding R.F. stages until the R.F. carrier current is at the power level required for modulation purposes. Since only a single frequency passes through this first section, the R.F. stages may be very selective.

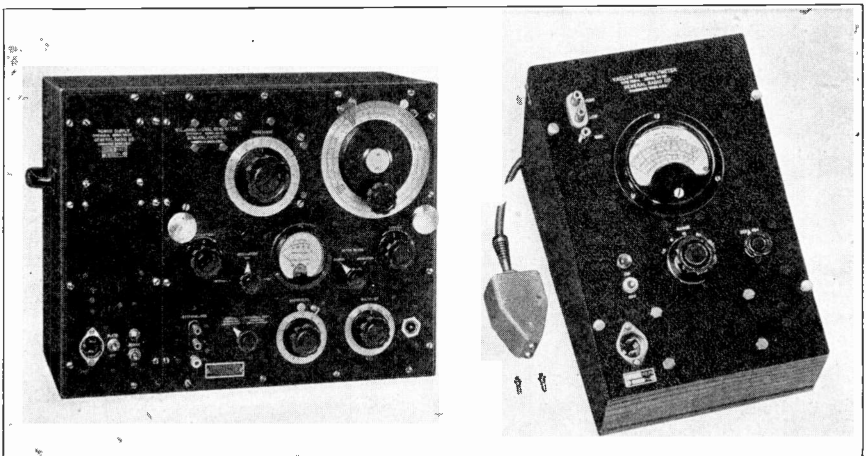
The process of modulation introduces side frequencies as well as harmonics. The second section of a transmitter must therefore pass a definite band width, amplifying all frequencies in this band equally well while raising the power of the modulated R.F. carrier to the desired value.

RESONANCE CURVES

What Is a Resonance Curve? The manner in which the amplifying ability of a tuned R.F. amplifier stage varies for the different frequencies between the lowest and the highest side frequencies is of great importance;

with this information at hand, we can tell how much the stage amplifies, how well it rejects undesired signals, how it amplifies desired signals, and how it amplifies some frequencies more than others in the side bands associated with the desired carrier. All this information about a tuned R.F. amplifier can be presented with a *frequency response curve* which shows in graphical form *the manner in which the amplifier handles or amplifies the various frequencies in its operating range.* Since tuned R.F. amplifiers always contain at least one resonant circuit, this frequency response curve is often called a *resonance curve.*

Typical R.F. Amplifier Stage. The diagram in Fig. *1* presents in simplified form a typical tuned R.F. amplifier stage; after reviewing briefly the



Courtesy General Radio Co.

FIG. 2A (left). General Radio type 605-A signal generator, which consists fundamentally of an R.F. oscillator having a frequency range of 95 kc. to 30,000 kc., and means for varying and measuring the output voltage. There are also provisions for modulating the R.F. signal with an audio note of fixed frequency or with an external modulating signal when a modulated carrier is required; the meter on the panel indicates percentage modulation in this case.
FIG. 2B (right). General Radio type 726-A vacuum tube voltmeter, a multiple-range instrument designed to measure R.F. voltages from .1 to 150 volts with a high degree of accuracy. It is calibrated to read r.m.s. (effective) values of sine wave voltage.

operation of this stage, I will show you how a resonance curve for it can be obtained.

The R.F. source in Fig. *1* feeds to the grid-cathode of the tube (between points *1* and *2*) an R.F. voltage which we will call e_g. As a result of the amplifying action of the tube and the effects of the load, there appears across the output terminals of the load an R.F. output voltage which we will designate as v_o. The net or true voltage amplification of this R.F. amplifier stage (expressed as A) is the output voltage v_o divided by the input voltage e_g. The type of tube used, the operating voltages and the type of load applied determine to a great extent the behavior of this stage as an amplifier.

How a Resonance Curve Is Secured. Although an R.F. amplifier must handle many frequencies (the carrier frequency and the side-band frequencies) simultaneously in actual practice, it is obvious that we cannot study the performance of the amplifier while all these frequencies are passing through; the practical way is to send through only one frequency at a time, a simple sine wave R.F. signal, and measure how much it is amplified. The frequency of this test signal is then changed to other values, and the amplification is measured at each frequency.

Radio engineers use a signal generator like that shown in Fig. *2A* to supply a sine wave R.F. signal whose frequency can be adjusted to the various values required when testing an R.F. amplifier. The large dial in the upper right corner of the panel controls the frequency of the output, the dial at its left changes the frequency range, and other dials change the strength and the modulation percentage of the R.F. output signal when a modulated signal is desired.

To measure the input and output voltages of an R.F. amplifier, engineers use a special voltmeter which employs a vacuum tube as a detector; a typical laboratory type vacuum tube voltmeter (abbreviated V.T.V.M.) is shown in Fig. *2B*. The voltage being measured is applied to the wedge-shaped probe (at the left of the cabinet) in which is an acorn-type tube connected as a rectifier. A shielded cable connects the probe unit to the cabinet on which is mounted a multi-range voltmeter and the control switches. The amplification produced by an R.F. stage at any frequency can be determined simply by dividing the measured output voltage v_o by the measured input voltage e_g.

If the R.F. amplifier stage in Fig. *1* is set to amplify a 1,000 kc. signal, and we desire to obtain a resonance curve for the amplifier at this resonant frequency, we would connect the signal generator in place of the R.F. source and set it in turn at 980, 985, 990, 995, 1,000, 1,005, 1010, 1,015 and 1,020 kc., and for each setting connect the vacuum tube voltmeter across terminals *1* and *2* to measure e_g (if its value is not already known) and across terminals *3* and *4* to measure v_o. We would then compute the amplification A obtained at each frequency, and plot our information on graph paper in the manner shown in Fig. *3* to secure the resonance curve for the R.F. amplifier at 1,000 kc. Notice that as the frequency is increased from the lowest value, the amplification increases and reaches a maximum value at 1,000 kc., the resonant frequency of the stage. Further increases in frequency beyond 1,000 kc. give decreasing amplification, the amplification dropping to zero at about 20 kc. above the resonant frequency. A curve of this nature is called a *single-peaked resonance curve,* for it gives maximum or peak amplification at a single R.F. value.

When a 1,000 kc. R.F. carrier is modulated with a sound signal having a maximum frequency of 5 kc., you know that the side-band frequencies will extend from 995 to 1,005 kc. The amplifier represented by the response curve in Fig. *3* would amplify the carrier frequency about 65 times, but would amplify the lowest side frequency (f_1 in Fig. *3*) only 50 times and the highest side-band frequency (f_2) 58 times.

An amplifier which has a single peaked resonance curve distorts a modulated carrier in two ways. If the corresponding upper and lower side frequencies are amplified equally well *but less than the carrier frequency,* the result after demodulation is comparable to frequency distortion (where the extremely high frequencies in the modulation signal are eliminated). If the corresponding upper and lower side frequencies are, in addition, *amplified unequally,* as is the case in Fig. *3,* there is amplitude distortion as well.

Defining Selectivity. Since the U. S. A. radio stations in the broadcast band are only 10 kc. apart in frequency, it is essential that a receiver tuned to one station does not also pick up the stations 10 kc. away on either side; insufficient selectivity in an R.F. amplifier therefore results in station interference. If the tuned R.F. stage whose performance is represented by Fig. *3* is the only one in a receiver, and it is tuned to a 1,000 kc. station, its carrier signal would be amplified about 65 times, while the carrier signals of adjacent stations (at 990 kc. and 1,010 kc.) would be amplified 15 times and 28 times respectively; this is clearly poor selectivity, for all three stations, if received with nearly equal signal intensity, will be heard at once. What, then, constitutes good selectivity?

Selectivity was formerly found according to the following procedure: The two frequencies at which amplification was 70% of the maximum amplification (the value at resonance) were found; the difference between these frequencies was determined, and the resonant frequency divided by this difference in frequency was said to be a measure of the selectivity of

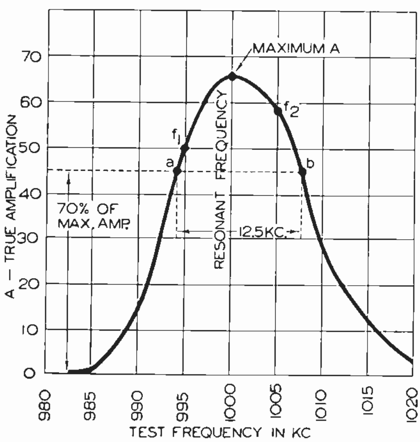


Fig. 3. Conventional resonance curve at 1,000 kc. for an R.F. amplifier stage.

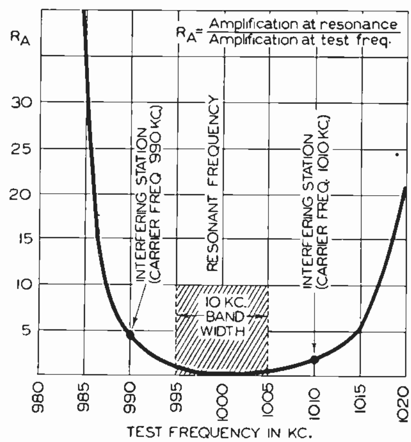


Fig. 4. Ratio resonance curve at 1,000 kc. for an R.F. amplifier stage. R_A is 1 at 1000 kc.

the amplifier. Points *a* and *b* in Fig. *3* correspond to the two frequencies at which *A* is 70% of its maximum value. The difference in frequency between these two points is 13.5 kc., hence the selectivity value for this particular amplifier stage would be 1,000 (the resonant frequency) divided by 13.5, or 74. Incidentally, this value is also the Q factor for the resonant circuit of this amplifier stage.* This older definition for selectivity and Q factor is perfectly satisfactory when applied to simple or single resonant circuits, since all such circuits have essentially identical resonance curve shapes. The response curves of complicated or multi-resonant circuits have widely varying shapes, however, making this old definition of selectivity unsuited for present day use.

The modern definition for receiver selectivity is based upon the fact

* In a series resonant circuit which is tuned to resonance, the ratio of the voltage across the coil or condenser to the applied circuit voltage is the Q factor of the circuit; Q factor is also the reactance of the coil divided by the circuit resistance. In a parallel resonant circuit the ratio of the coil or condenser current to the line supply current at resonance is the Q factor; Q factor is also the resonant resistance divided by the coil or condenser reactance at resonance.

that we are *primarily* interested in how much better the amplification is at resonance than at the nearest undesired frequencies. *For good selectivity, the desired signal frequency and its side frequencies must be amplified at least 1,000 times more than the nearest undesired signal and its side bands.* For fair selectivity this ratio (which we shall designate as R_A) can be about 100, and for excellent selectivity the ratio must be higher than 10,000.

Fidelity is now defined in much the same way as selectivity. *For good fidelity the desired carrier frequency must not be amplified more than 1.25 times the highest side frequency desired with that signal;* in other words, amplification at the highest side frequency must be at least 80% of the amplification at resonance. These figures are by no means fixed, for they are based upon opinions rather than upon precise data, and in addition will vary with the purpose of and use to which an R.F. amplifier is put.

A better picture of the frequency response characteristic of an R.F. amplifier can be obtained by computing R_A, the ratio of amplification at resonance to amplification at the test frequency, for each value of test frequency and plotting these ratios against frequency in the manner shown in Fig. *4*.* A curve like this (called a *ratio resonance curve*) gives us both the fidelity and selectivity characteristics of an amplifier; for example, in Fig. *4* the highest side frequency (for a 5 kc. modulating signal) has a ratio of about 1.1 (at 1,005 kc.), which indicates excellent fidelity since it is considerably less than the maximum allowable value of 1.25. At 1,010 kc., however, the ratio is only about 2.3, indicating that the desired carrier frequency signal will be amplified only about 2.3 times more than the carrier signal of an undesired station at 1,010 kc. if both carrier signals have equal signal strength at the location of the receiver. Thus, fidelity is good but selectivity is very poor in the amplifier represented here.

Amplifiers in Cascade. If one R.F. amplifier stage raises the voltage at the resonant frequency 10 times, another similar stage connected in cascade will amplify the voltage 10 times further, giving a total amplification of 100; the addition of a third identical amplifier stage will boost the voltage 10 times further, giving a total amplification of 1,000. The amplification (gain) of an R.F. amplifier is therefore the product of the gain of each individual stage (the gains are multipled together).

Resonance curves for two and three tuned R.F. amplifier stages in cascade are given in Fig. *5*, with the curve for a single stage shown for comparison. The addition of stages makes the resonance curve sharper and higher in peak value. *Cascading of R.F. amplifier stages thus boosts the amplification and improves the selectivity of an R.F. amplifier.*

The resonance curve for perfect fidelity and ideal selectivity should be flat throughout the desired band width and should have straight vertical sides; adding stages makes the sides of the resonance curve more nearly vertical, giving better selectivity, but lowering fidelity (by making the resonance curve sharper in the band width).

---

* Laboratory engineers sometimes measure R_A directly. At each test frequency they increase the output of the signal generator until the measured amplifier output voltage v_o is the same value as it was at the resonant frequency; the signal generator output at the test frequency divided by the signal generator output at resonance gives the value of R_A.

Fidelity and selectivity characteristics of amplifiers in cascade are more clearly presented by plotting R_A against frequency, as was done in Fig. *4*; this is done in Fig. *6*. Let us analyze these three ratio resonance curves; for convenience I will set down again the practical definitions for selectivity and fidelity.

Good fidelity: R_A is lower than 1.25 at the *highest* side frequency.
Good selectivity: R_A is higher than 1,000 on both adjacent-channel carrier frequencies.

Checking fidelity first, we find that good fidelity is secured with one stage (R_A is less than 1.15 at 1,005 kc.) and with two stages (R_A=1.25),

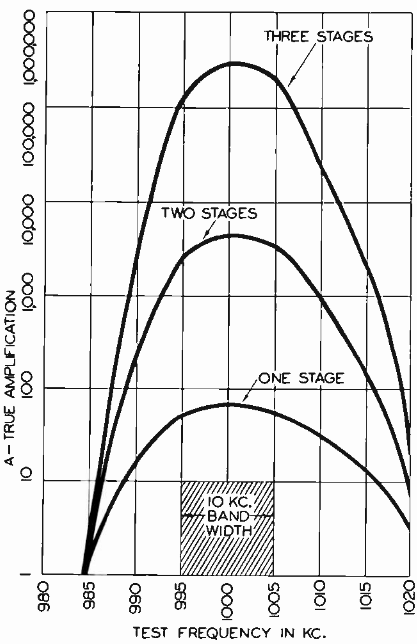


Fig. 5. Resonance curves at 1,000 kc. for one R.F. amplifier stage and for two or three similar stages connected in cascade. Amplification *A* is here plotted on a special condensed scale which corresponds to the response of the human ear. Resonance is at 1,000 kc.

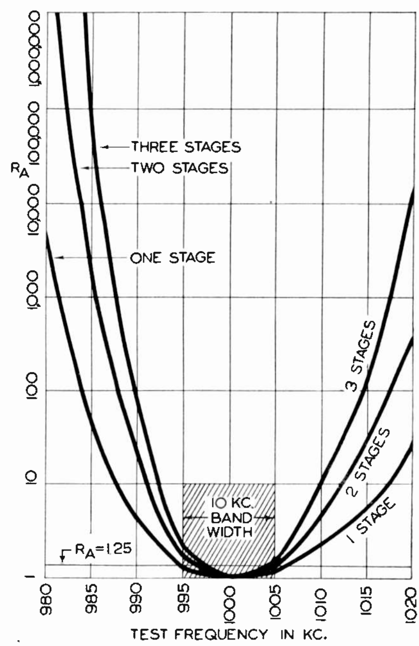


Fig. 6. These three ratio resonance curves give the fidelity and selectivity characteristics of one, two and three of the R.F. amplifier stages in Fig. *1*. The scale at the left gives values of R_A (amplification at resonance ÷ amplification at test frequency). Resonance is at 1,000 kc.

but three stages give poor fidelity (R_A is higher than 1.25). As to selectivity, R_A for three stages is about 100 at 990 kc. and is about 10 at 1,010 kc., these being the adjacent-channel carrier frequencies in the broadcast band. The lowest value governs, and hence selectivity is poor. For one and two stages, the values of R_A at these undesired carrier frequencies are lower, so selectivity is even poorer than for three stages.*

* When peaked R.F. amplified stages have symmetrical response curves, several stages may be connected in cascade to give good selectivity, and the attenuation of the higher modulation frequencies (the poor frequency response) can be compensated for by using an audio (or video) amplifier which will give greatest amplification at the higher frequencies. This fact makes it possible to equalize (adjust) a receiver for high fidelity even though individual stages in it do not have ideal characteristics.

You will notice that the vertical scales in Figs. *5* and *6* are arranged in a different manner from those in Figs. *3* and *4*; this "condensing" was done in order to cover a wide range of values while still showing the nature of the curves clearly at the lowest values, around the resonant frequency. These condensed scales are known as logarithmic scales; they also tell us more clearly what the ear is going to hear, for our ear has this same logarithmic response.

Complete R.F. amplifiers, regardless of whether they are of the superheterodyne or the T.R.F. type, are measured in exactly the same manner as the single stage shown in Fig. *1*, and the results are plotted exactly as is done in Figs. *5* and *6*. The resulting curves allow the radio engineer to study the amplification, selectivity and fidelity characteristics of the entire R.F. amplifier.

Ideal and Practical Ratio Resonance Curves. Ratio resonance curves for four different R.F. amplifiers, each of which contains several stages in cascade, are given in Figs. *7A* and *7B*. These curves give the value of the ratio R_A for different frequencies up to 20 kc. above and below resonance. You can consider R_A in two ways, as the ratio of the amplification at resonance to the amplification at various off-resonance frequencies, or as how much stronger the signal must be off resonance to produce the same output as at resonance. The higher the value of R_A for frequencies off resonance, the more selective is the amplifier.

Before you can study the ratio resonance curve for a particular R.F. amplifier, you must know at least two facts: *1*, the frequency separation in kc. between the stations which are to be picked up by that amplifier; *2*, the R.F. band width in kc. which is required to handle the entire range of frequencies for the audio or video signal being transmitted.

Stations in the broadcast band in the United States, radiating sound signals, are located 10 kc. apart and always have a frequency value ending in zero; thus you may receive stations at 570, 580, 590 kc., etc. For sound signals having a maximum range of 5,000 cycles, the side frequencies will extend 5 kc. above and below the carrier frequency. For good selectivity, then, the value of R_A should be greater than 1,000 at frequencies more than 5 kc. off the desired carrier frequency. To secure good amplification of the side frequencies, however, R_A should be as close to the value 1 as possible throughout the band width of 10 kc.

Curve *1* in Fig. *7A* (the dash-dash curve) represents the ideal ratio resonance characteristics for an R.F. amplifier designed for use with broadcast band apparatus; all frequencies in the band width are amplified equally, while all other frequencies are completely cut off. Curves *2* and *3* in Fig. *7A* and curves *4* and *5* in Fig. *7B* progressively approach this ideal response, curve *5* being about the closest approach to the ideal which can be secured in practice. A radio expert would label curve *2* as "fair fidelity but very poor selectivity"; curve *3* would be designated as "poor fidelity and good selectivity" (this particular response curve might be satisfactory for radio-telegraphy work, where the side frequencies extend very little off resonance). In Fig. *7B*, curve *4* represents an amplifier having good

selectivity and fair fidelity, while curve *5* has excellent fidelity and good selectivity.

Resonance curves very similar to those just studied are used in portraying the abilities of R.F. amplifiers designed for television purposes. Remember, however, that the resonant frequencies here will be in the range extending from 40 to 90 megacycles, the band width will be 5 to 10 megacycles wide and stations will be separated as much as 15 megacycles. The same resonance curves can be used to portray the behavior of R.F. amplifiers which follow the modulated stages in transmitters.

Now we are ready to consider R.F. amplifier circuits in detail; you will learn how their desired features are obtained. A knowledge of how their operation is affected by changes in circuit parts will be of great value when you have to make repairs on incorrectly operating receivers.

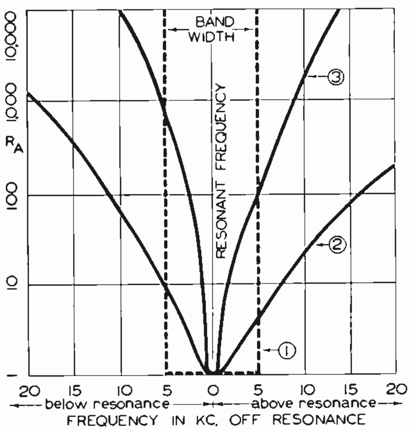


FIG. 7A. Ideal (1) and typical (2 and 3) ratio resonance curves for R.F. amplifiers.

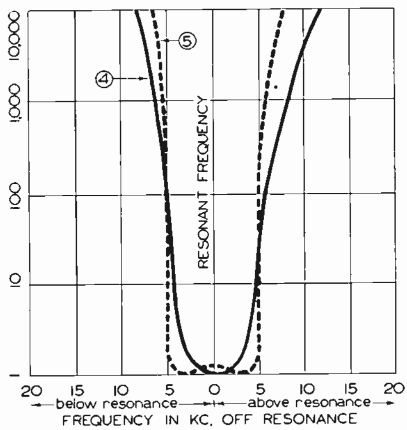


FIG. 7B. Ratio resonance curves of R.F. amplifiers designed to have 10-kc. selectivity. Vertical scale gives values of R_A.

SIMPLE TUNED R. F. AMPLIFIERS

Amplifier Loads. Almost any circuit which uses a vacuum tube having a control grid can be used as an R.F. amplifier provided that the proper plate load is used. If a simple resistor or coil is made to serve as the plate load, we have an untuned R.F. amplifier circuit which will amplify R.F. signals over *a very wide band;* this poor-selectivity characteristic is highly desirable in those cases where other radio devices are used for signal selecting and tuning purposes. If a reasonable amount of voltage amplification is to be secured, the ohmic resistance (or the reactance in the case of a coil) of the plate load (which is untuned) should be greater than the A.C. plate resistance of the tube.

Coil-Condenser Loads. You are already familiar with the fact that a coil and condenser connected in parallel, as in Fig. *8,* behave exactly like a resistor of high ohmic value at the resonant frequency (the frequency at which the coil reactance exactly balances the condenser reactance), but offer a lower reactance at other frequencies. Changing the value of either the coil or the condenser changes the resonant frequency. Thus this parallel coil-condenser resonant circuit is a very desirable load for an R.F. amplifier, giving high amplification of the desired signal, giving low amplification of other frequencies and permitting tuning to a desired frequency.

If coil L in Fig. *8* has an inductance of 250 microhenrys and a resistance R of 20 ohms, and condenser C is adjusted to 100 micro-microfarads (mmfd.), this circuit will act like a 125,000 ohm resistor at its resonant frequency (this can be proved by actual test or by computation with a formula given later in this book). Thus, when this circuit is used as a plate load, a high value of A.C. voltage is produced across terminals *1* and *2* at the resonant frequency, but the circuit acts either as a condenser or coil of low reactance to other frequencies (off-resonance frequencies), with a resulting low A.C. voltage for these frequencies; the circuit therefore possesses selectivity characteristics. Decreasing the inductance of the coil or decreasing the capacity of the condenser *raises* the resonant frequency of the circuit. Another advantage of this coil-condenser tuned load circuit is that it is not seriously affected by capacity between the electrodes of the tube; a high plate-to-cathode capacity simply means C can be smaller.

Fig. 8. A coil-condenser load (a parallel resonant circuit) acts as a resistor of high ohmic value at the resonant frequency of the circuit.

Coil-Condenser Load Connections. There are a number of different ways of connecting a coil-condenser resonant circuit into the plate circuit of a tube; four of the most important of these are shown in Fig. *9*. Remember that a small resistance (that of the coil) is always present in a resonant circuit (it is usually neglected when preparing diagrams, in order to simplify the presentation of resonant circuits).

In Fig. *9A*, resonant circuit *L-C* (often called a tank circuit) is connected directly into the plate circuit, with D.C. plate supply current flowing through coil L. The A.C. voltage which is developed across the tank circuit terminals is impressed upon the grid of the next R.F. amplifier stage through coupling condenser C_K, which has negligible reactance to signal currents. This condenser also prevents D.C. plate current from flowing to the grid of VT_2, the next tube. Resistor R_g has an important function, that of connecting the grid to ground in order that the C bias voltage developed by cathode circuit resistor R_c can act upon the grid of the tube. Obviously the ohmic value of R_g must be much higher than the resonant resistance of the tank circuit if it is not to affect the plate circuit. (Since R_g is in parallel with the plate circuit, a low value of R_g would absorb power, lowering the resonant circuit resistance and thus reducing the net plate circuit resistance; the result would be a reduction in the amplification of the amplifier and a broadening of the resonance curve. This broadening improves fidelity, and is therefore desirable in some cases.)

In Fig. *9B*, choke coil *CH* is used in place of grid resistor R_g. The reactance of this choke coil at any frequency to which the tank circuit may be tuned should be many times greater than the resonant resistance of the tank circuit, in order to secure a large A.C. voltage drop across the tank circuit.

In Fig. *9C* the positions of the choke coil and the tank circuit are interchanged as compared with Fig. *9B*; this arrangement, where the choke coil is in the plate circuit, is known as a shunt fed circuit, for the D.C. power is fed in parallel or in shunt with the *L-C* circuit. When the resistance of R_g in Fig. *9A* and the reactance of *CH* in Figs. *9B* and *9C* are many times greater than the resonant resistance of the tank circuit, the values of *L* and *C* in the tank circuit control the R.F. signal output; the resonant circuit thus becomes the plate load. The following important facts apply to all three circuits:

1. ***The values of L and C determine the resonant frequency of the tank circuit.*** For practical reasons it is customary to tune the condenser; *decreasing* the capacity of the condenser *increases* the resonant frequency of the tank circuit. Coil *L* is still shunted by a capacity, however, when condenser *C* is set at minimum capacity; this residual capacity consists of: *a*, the distributed capacity of coil *L*; *b*, the minimum capacity of the condenser; *c*, capacities between the tube electrodes and between the leads in the circuit. In a well designed practical circuit the minimum or residual tank capacity is about one-ninth of the maximum tank capacity; this means that the maximum frequency to which the tank circuit can be tuned is about 3 times the lowest frequency. An example of this is the average broadcast band receiver, which tunes from about 500 to 1,500 kc. with a single set of coils.
2. ***The effective resistance of the tank circuit at resonance is determined by the inductance of the coil, the capacity of the condenser and the inherent tank circuit resistance.****
3. ***If the tank circuit at resonance has a coil of high inductance and a condenser of low capacity, the resonant resistance will be high.*** Radio men say that a tank circuit with large *L* and low *C* has a high *L/C* ratio. The lower the inherent resistance of the tank circuit, the greater will the resistance of a tank circuit be at resonance.
4. In a single-tube tuned R.F. amplifier stage which uses a parallel resonant circuit as a plate load, the maximum possible amplification is the mu of the tube, and this value is obtained when the resonant resistance of the plate load is many times greater than the A.C. plate resistance of the tube. Triode tubes have relatively low A.C. plate resistances and hence this condition is quite easy to secure, but with tetrode and pentode tubes the load ordinarily cannot be made high enough in value to give maximum amplification.
5. When the tank circuit is tuned to higher frequencies in the usual manner by reducing the value of capacity *C*, the *L/C* ratio increases, raising the resonant resistance of the load.

Tuned Transformer Circuit. In Fig. *9D* is perhaps the most widely used R.F. amplifier circuit, the so-called tuned transformer circuit. The power required for tank circuit *L-C* must be supplied to the primary coil L_p by the tube. When the *L-C* tank circuit acts like a resistor, as at resonance, the reflecting properties of the transformer make coil L_p act like a resistor (the

* There are two formulas for securing the resonant resistance of a tank circuit like that in Fig. 8; the radio engineer uses whichever is more convenient. The formulas are: $R_R = \frac{L}{RC}$, and $R_R = \frac{\omega^2 L^2}{R}$, where R_R is the resonant resistance of the tank circuit in ohms, R is the inherent tank circuit resistance in ohms, ω is 6.28 times the frequency in cycles, L is the inductance of the coil in henrys and C is the capacity of the condenser in farads.

leakage inductance of primary L_p affects this condition, but this inductance is so small that it can be neglected). Facts *1, 2, 3* and *5* brought out in connection with the first three circuits in Fig. *9* hold true also for this circuit, and the following additional facts apply to this circuit only:

1. Increasing the number of turns on primary winding L_p or increasing the coupling between L_p and L raises the reflected resonant resistance appearing between terminals *1* and *2*. We are actually increasing the mutual inductance M of the coils when we add turns or move the coils closer together; thus we can say that increasing the mutual inductance increases the effective resonant resistance of the plate load.

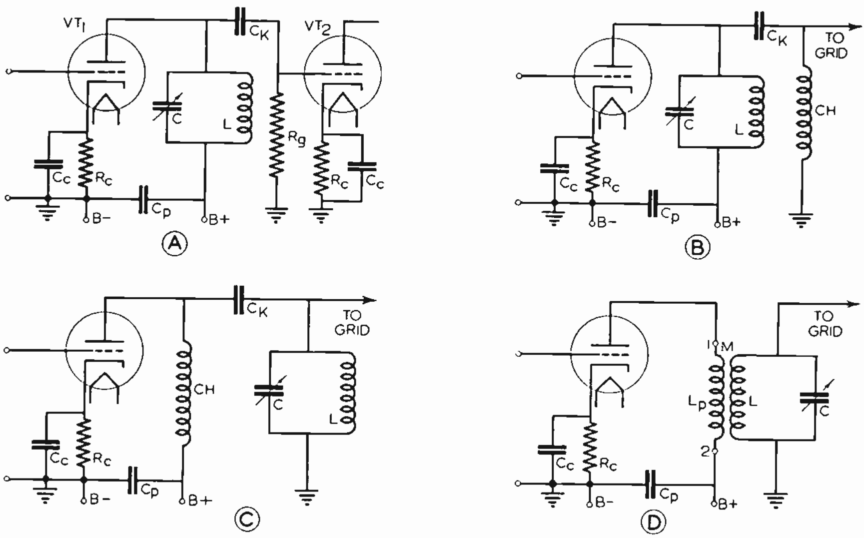


Fig. 9. Four ways of connecting the resonant *L-C* load circuit into an R.F. amplifier stage so it will act as a plate load. These circuits apply also to screen grid and pentode tubes; triodes are shown here merely for simplicity.

2. When a tuned transformer load is used in a single-tube tuned R.F. amplifier stage, maximum voltage amplification is obtained *when the resonant resistance of the tuned load is equal to the A.C. plate resistance of the tube,* for the tank circuit then absorbs the greatest amount of power.

3. Circuit *L-C* in Fig. *9D* is a *series resonant circuit* (because the voltage induced in it acts in series with *L* and *C*), and hence acts as a coil when tuned below resonance and as a condenser when tuned above resonance. The effects at terminals *1* and *2* are opposite, however, because of transformer action.

HOW TUBE CAPACITIES AFFECT R. F. AMPLIFIER CIRCUITS

Inter-Electrode Capacities. When we study an ordinary triode tube in detail, we realize that the grid, plate and cathode are tiny condenser plates which introduce into the tube circuits the three capacities shown by dotted lines in Fig. *10.* These inter-electrode capacities are: *1,* the grid-to-cathode capacity, C_{gk}; *2,* the plate-to-cathode capacity, C_{pk}; *3,* the grid-to-plate capacity, C_{gp}. It is the grid-to-plate capacity, C_{gp}, which prevents the grid and plate circuits from being entirely independent of each other.

In the R.F. amplifier circuit in Fig. *10,* the grid-to-cathode capacity C_{gk} acts simply as if it were an extra condenser connected in parallel with C_1; the plate-to-cathode capacity C_{pk} acts as a condenser connected in parallel with C_2. By-pass condensers C_c and C_p in Fig. *10* are of such high capacity that they act as low reactance paths for A.C. currents, and therefore need not be considered in this discussion.

In Fig. *11* the R.F. amplifier circuit of Fig. *10* has been modified to include only those parts which affect the tube as an amplifier; C_{gk} and C_{pk} have been placed in their effective positions. Capacity C_{gp} can, according to a complicated mathematical analysis which need not be taken up here, be considered as *equivalent* to an extra resistor R_R and an extra condenser C_R, both in parallel with the grid tank circuit C_1-L_1. Remember that R_R and C_R are present *as effects only*, not as actual devices; their exact equivalent values vary greatly with circuit conditions, being dependent upon the capacity of C_{gp}, upon the resonant frequency and nature (resistive, inductive or capacitive) of the plate circuit load, and upon the over-all amplification of the stage.

Coil L_2 in Fig. *11* acts with C_2 and C_{pk} to form a parallel resonant tank circuit which is the equivalent of a high resistance at resonance. When this parallel resonant circuit is tuned below resonance (to a frequency *lower than* that of the incoming signal), the tank circuit will act as if it were a *condenser*. (This is because decreasing the resonant frequency by increasing the capacity of C_2 lowers the reactance of the condenser but does not affect the reactance of the coil; in a parallel circuit such as this it is the *lowest* reactance [the reactance of L_2 or C_2] which governs the nature of the tank circuit off resonance.) Likewise, when this parallel resonant circuit is tuned above resonance (to a frequency *higher than* that of the incoming signal), the tank circuit acts as a coil.*

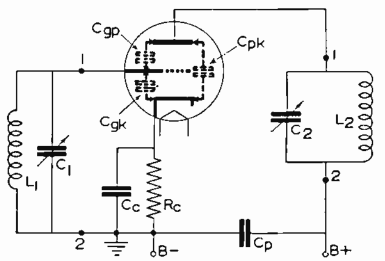


FIG. 10. The three inter-electrode capacities which enter into the operation of an R.F. amplifier are here indicated by dotted lines.

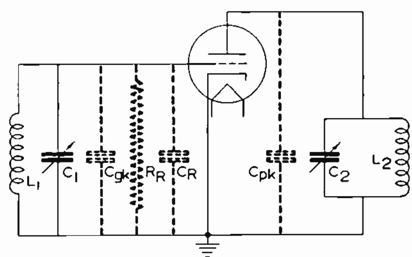


FIG. 11. The circuit of Fig. *10* is here modified to include only those parts which affect the tube as an amplifier. The effects of the grid-to-plate capacity C_{gp} are represented by R_R and C_R.

* When a resonant load circuit is loosely coupled inductively to the plate circuit of a tube, as is done in Fig. *9D*, the tuned secondary *(L-C)* is purely resistive when tuned to resonance. Because of the leakage inductance of primary L_p, however, the effect of the load in the plate circuit (as measured between points *1* and *2*) will be *inductive*. When the *L-C* circuit is tuned off resonance, the reactance which it reflects into primary L_p will always be opposite in nature to the reactance which the *L-C* circuit itself appears to have. Thus, when series resonant circuit *L-C* is tuned above resonance it acts as a capacity and is reflected as an inductance; when tuned below resonance it acts as an inductance and reflects as a capacitance. In order to make the effect of the load purely resistive across terminals *1* and *2*, then, it is necessary to tune the load slightly below resonance, so it reflects a capacitance which will balance out the leakage inductance of the primary; in doing this we are really using the secondary *L-C* circuit to tune the primary L_p (which is in effect the load) to resonance.

The circuit in Fig. *11* possesses a number of interesting and important characteristics, some of which are portrayed by the curve in Fig. *12*. These facts are listed here, for they mean a lot to any one who will work with R.F. amplifiers. The following facts apply equally well to the circuits in Figs. *9* and *10* (if points *1* and *2* in Fig. *9D* are considered as the load terminals).

1. When the load is tuned exactly to the frequency of the incoming signal, the capacity of C_R is a maximum and is equal to the *capacity of* C_{gp} plus a value equal to the *capacity of* C_{gp} *multiplied by the true amplification of the stage.* When the load is tuned either above or below the signal frequency, the true amplification of the stage is greatly reduced and the capacity of C_R therefore decreases rapidly, as is shown in Fig. *12*.

2. When the load is tuned exactly to the incoming signal, the equivalent ohmic value of R_R is so high that it can be neglected.

3. When the load acts as a condenser, the equivalent ohmic value of R_R is greatly reduced. The selectivity response curve of the amplifier is consequently broadened and the amplification of the stage is reduced.

4. When the load acts as a coil, the tube is actually feeding power back into the grid circuit, thus increasing the amplification of the stage and improving selectivity. For convenience this is often explained by saying that the ohmic value of R_R becomes *negative;* a negative resistance in shunt with a real resistance will actually increase the net resonant resistance of L_1-C_1, clearly indicating that the circuit is capable of producing a greater resonant voltage.

5. If the load acts as a coil of sufficiently high reactance, the tube will feed sufficient energy back to the grid to make the circuit oscillate at a frequency determined essentially by the values of L_1, C_1, C_{gk} and C_R.

Practical Considerations. The curve in Fig. *12* also contains the answers to some very practical questions concerning the operation of amplifiers in general, including audio or video amplifiers. Keep the following facts in mind when you work with amplifiers and you will have no difficulty in finding causes and cures for annoying squeals or for poor fidelity.

1. In an audio or picture frequency amplifier, a high plate load resistance or reactance will give high amplification and make C_R very high in capacity. The higher frequencies in the audio or picture signal will therefore be attenuated (by-passed to ground before they reach the grid). A low-impedance load gives less attenuation.

2. If high plate load impedance in an audio or picture frequency amplifier stage is accompanied by an inductive plate load condition, undesirable oscillation may take place.

3. In an R.F. amplifier using a triode tube, any stage having plate and grid circuits arranged as in Fig. *10* will go into oscillation whenever the plate tank circuit is made sufficiently *inductive* by tuning it above the signal frequency. Two R.F. signals, the incoming signal and the oscillating frequency, will then reach the grid and be amplified by the tube; these two frequencies will be mixed together by the detector stage, and if the difference in their frequencies is in the audio range, an annoying squeal will be heard in the loudspeaker.

4. Oscillations can take place even without an incoming signal if the resonant frequency of L_2-C_2, the plate load, is considerably higher than the resonant frequency of L_1-C_1 in the grid circuit, for under this condition the plate tuned circuit will be *inductive* at the resonant frequency of the grid tuned circuit. These being R.F. oscillations, they will not ordinarily be heard in the loudspeaker. If, however, this condition for R.F. oscillation exists in two different stages, two R.F. signals may go through the system and beat with each other at the detector, producing an A.F. note which will be heard as a squeal. This explains why some receivers produce squeals even when not tuned to a station; the remedy simply involves adjusting one or more of the tuned circuits.

GETTING RID OF FEED-BACK

When triode tubes are used in amplifier circuits, it is the grid-to-plate capacity which is of vital importance; the other two inter-electrode capacities, C_{gk} and C_{pk}, simply reduce the tuning range of the amplifier slightly at the highest frequencies.

Grid Suppressors. The oscillation or regeneration caused by the grid-to-plate tube capacity in a triode tube is an especially serious problem in single dial receivers, for these have no provisions for tuning out an annoying squeal at a particular setting of the tuning dial. Since only triode tubes were available in the early days of radio, engineers were compelled to develop a number of solutions for this regeneration or feed-back problem. One of these involved loading the grid tank circuit (L_1-C_1 in Fig. *10*) with a resistor which made the resonant resistance of the grid tank circuit less than the ohmic value of the equivalent negative resistance R_R. (Engineers have proved that R_R, in addition to being negative must be lower in ohmic value than the resonant resistance of the grid tank circuit before oscillation can occur.) Another feed-back-killing scheme involved inserting a re-

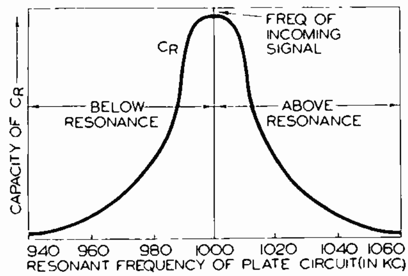


FIG. 12. This curve shows how the equivalent capacity C_R of the circuit in Fig. *11* varies when the plate tank circuit of an R.F. amplifier is tuned to, above and below the frequency of an incoming signal.

sistor in the grid lead, as at point *1* in Fig. *10*; the resistor was in this case known as a *grid suppressor*. Lowering the amplification of the stage, such as by using a low L/C ratio in the plate tank circuit, was another way of preventing regeneration.

Neutrodyne Circuits. In the early days of radio, neutrodyne receivers were "all the rage"; these used an ingenious method of preventing regeneration while retaining all of the amplification of a stage. An A.C. voltage taken from the plate circuit of the R.F. amplifier was fed back into the grid circuit out of phase to balance out, buck out or *neutralize* the undesirable feed-back voltage caused by grid-to-plate capacity.

Figure *13A* is an example of one of these early neutrodyne circuits; regeneration occurred here because the A.C. voltage across coil L_1 fed back to the grid tank circuit through inter-electrode capacity C_{gp}. To offset this, coil L_2 was coupled with and connected to coil L_1 in such a way that the voltage which it fed through neutralizing condenser C_N to the grid was out of phase with the undesired feed-back voltage; the two voltages therefore bucked each other and, when C_N was adjusted to make the two voltages equal, they exactly cancelled each other and eliminated regeneration effects.

Figure *13B* gives another neutrodyne circuit; no additional coil winding was needed here, for the required out-of-phase A.C. voltage was secured by tapping the secondary winding of the R.F. transformer. There were many variations of these two neutrodyne circuits, but all were essentially the same in their operation. Neutrodyne circuits were not entirely practical, for they were easily thrown out of adjustment. Any changes in the circuit parts, or the installation of a new tube, made it necessary to readjust neutralizing condenser C_N.

Engineers realized that the grid-to-plate capacity in the tube was the real cause of all their regeneration troubles, and finally called in vacuum tube engineers to design a tube which had negligible grid-to-plate capacity. The screen grid or shielded grid tube, which you know as the tetrode, was the result; we will consider this tube next.

THE SCREEN GRID TUBE

As you know, it is current flowing from the plate through inter-electrode capacity C_{gp} to the grid which results in regeneration in amplifier circuits. If an additional grid is placed between the control grid and plate of a triode, and this new grid, which we call the *screen grid*, is connected to

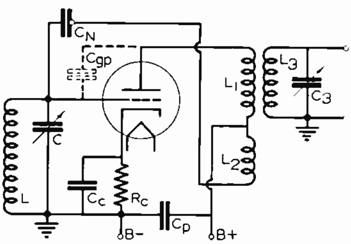


FIG. 13A. Early neutrodyne R.F. amplifier circuit, in which a special coil L_2 provides the required neutralizing voltage.

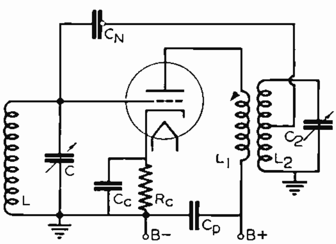


FIG. 13B. A tap on coil L_2 in this neutrodyne circuit gives the required out-of-phase feed-back voltage.

ground, the feed-back current will flow to the screen grid and then to ground, and will not reach the control grid at all. Tube engineers also realized that this new grid could be made to aid the plate in pulling electrons out of the space cloud near the cathode. The resulting circuit arrangement, in which the screen grid is at zero potential for A.C. and at a high positive potential with respect to the cathode for D.C., can be seen in Fig. *14A*. The screen grid is connected directly to one terminal of the power supply, and the plate is connected to a higher voltage terminal ($B{+}{+}$), while by-pass condenser C_2 is placed between screen grid and ground to provide a path to ground for the A.C. feed-back currents. The capacity of C_2 must be much higher than the capacity existing between screen grid and control grid in order to make the feed-back current take the desired path to ground.

Now you can readily see that if the screen grid by-pass condenser in an R.F. amplifier (such as C_2 in Fig. *14A*) should open, as it often does in radio equipment, the feed-back current will flow past the screen grid to the control grid, and *oscillation will occur,* resulting in a squeal in the loud speaker output. Replacement of the screen grid by-pass condenser (C_2) will eliminate the squeals.

The effect of the screen grid in reducing the grid-plate capacity of a tube can be determined from any tube chart. A comparison of the inter-electrode capacity values for a typical triode and a typical tetrode tube is given below:

Type 27 (triode) — $C_{gp}=3.3$ mmfd.; $C_{gk}=3.1$ mmfd.; $C_{pk}=2.3$ mmfd.
Type 24A (tetrode)—$C_{gp}=.007$ mmfd.; $C_{gk}=5.3$ mmfd.; $C_{pk}=10.5$ mmfd.

Observe that in the tetrode the introduction of the screen grid has reduced the grid-to-plate capacity about 470 times, an amount which is more than sufficient to prevent regenerative feed-back. C_{gp} cannot be entirely eliminated, however, for there is always a little leakage current from plate to grid. Surrounding the plate completely with the screen grid eliminates a great deal of this leakage, at the same time increasing the plate-to-cathode capacity, but increasing C_{pk} does not appreciably affect the performance of a tuned R.F. amplifier; it simply means that less capacity will be needed in the plate circuit variable condenser, and a reduction in the highest frequency to which the T.R.F. amplifier can be tuned.

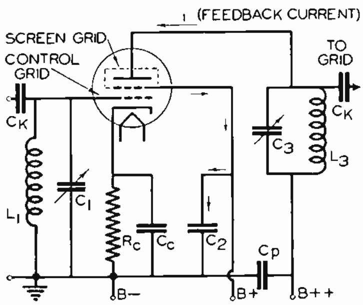


Fig. 14A. R.F. amplifier circuit using a screen grid tube. In such screen grid tubes as the 24A, the screen grid completely surrounds the plate, as indicated by the light dotted lines, but the schematic diagram for a screen grid tube generally shows only the heavy lines here indicated.

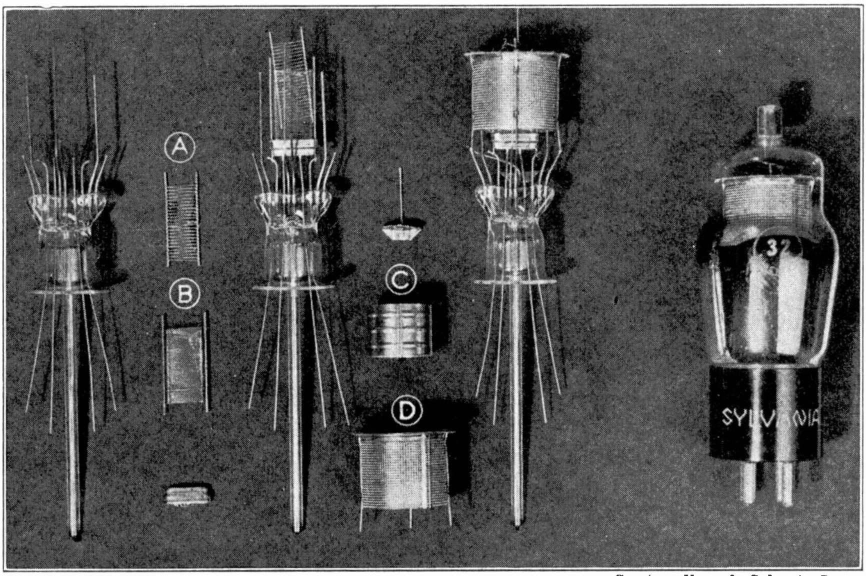
With the troublesome grid-to-plate capacity out of the way, radio tube engineers proceeded to build greater amplification into the screen grid tube by moving the control grid closer to the space cloud and moving the plate farther away from the cathode. While this did not materially increase the electron flow to the plate, it did increase the A.C. plate resistance. The screen grid tube therefore has a high amplification factor, a high A.C. plate resistance and an average value of mutual conductance; the following table gives a comparison of these values, together with rated plate current values for a triode and a tetrode:

Type 27 (triode): $\mu=9$; $g_m=1{,}000$ micromhos; $r_p=9{,}000$ ohms; $I_p=5.0$ ma.
Type 24A (tetrode): $\mu=400$; $g_m=1{,}000$ micromhos; $r_p=400{,}000$ ohms; $I_p=4.0$ ma.

Details of construction of a typical screen grid tube, the type 32, are shown in Fig. *14B*; note how completely the plate is surrounded by the screen grid.

The Performance of a Screen Grid Tube. The behavior of a tetrode or screen grid tube as an amplifier is expressed by the family of E_p-I_p curves given in Fig. *15*; these curves give average characteristics for the RCA Radiotron type 24A screen grid tube. Notice that plate current is referred to as I_b instead of I_p. In securing data for these curves, the tube was operated at a normal filament voltage of 2.5 volts (either A.C. or D.C.) and normal screen grid voltage of 90 volts D.C., and the plate voltage was varied from zero to a maximum for each value of D.C. control grid voltage (for 0, –1.5, –3.0, –4.5 and –6.0 volts).

For any one value of control grid voltage, plate current rises quite rapidly at first, as the plate voltage is gradually increased from zero. The screen grid has such tremendous electron-pulling power, however, that electrons approach it at very high speeds, pass right through its widely spaced wires and hit the plate with terrific impact, knocking electrons out of the plate; this effect is known as *secondary emission.* Some of these secondary electrons return to the plate, but a great number of them are attracted to the screen grid, which also is at a high positive D.C. voltage.



Courtesy Hygrade Sylvania Corp.

FIG. 14B. Construction of a typical screen grid tube, a type 32 tetrode. The control grid is at *A*. The inner part of the screen grid (mounted between the plate and the control grid) is at *B*, while the outer part of the screen grid (which surrounds plate *C*) is at *D*. At the right is the completed tube.

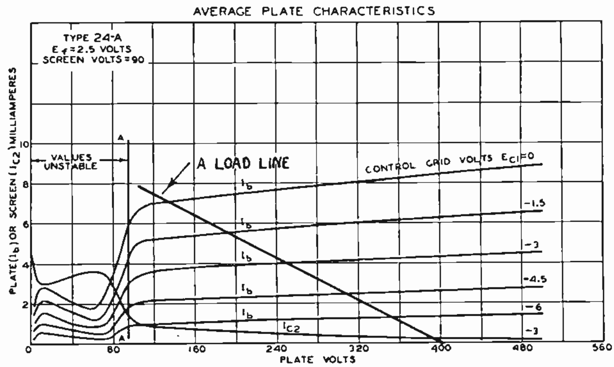
Curve I_{C2}, representing screen grid current, shows you that for low plate voltages the screen grid current is actually higher than the plate current, indicating that the screen grid collects a high proportion of the electrons which "bounce" off the plate and also attracts electrons directly (the screen grid is at a higher potential than the plate in the region to the left of line *AA*). It is for these reasons that in the region between zero and 90 volts (labeled "VALUES UNSTABLE" in Fig. *15*), increases in plate voltage actually cause the plate current to go down. For plate voltages above 90 volts, plate current rises and screen grid current decreases gradually to a very low value.

When the plate tank circuit in an R.F. amplifier contributes its resonant-produced A.C. voltage to the D.C. plate voltage, it makes the plate-to-cathode voltage swing from high to low values. In order to show how plate current varies under this condition, we can use the load line in Fig. *15*; this load line gives us plate current and plate voltage values directly, making it unnecessary to compute the voltage drop across the load.

The plate voltage of the screen grid tube in Fig. *15* cannot be allowed to swing below the screen grid voltage (90 volts in this case) if distortion is to be prevented. Incidentally, if the plate voltage in an R.F. amplifier circuit like Fig. *14A* should swing down to about 40 volts, the circuit will act as an oscillator instead of an amplifier; under this condition the screen and plate possess a negative resistance characteristic and supply power to the plate tank circuit. A screen grid tube gives better results than a triode in an R.F. amplifier provided that we limit the plate voltage swing to the linear portion of the E_g-I_p characteristic curve.

THE SUPPRESSOR GRID TUBE

Tube designers quickly realized that some means of forcing secondary electrons to return to the plate in a screen grid tube instead of going to the screen grid would greatly improve the amplifying characteristics of the tube at low plate voltage. One scheme for accomplishing this, actually tried in the type 48 power tetrode tube, involved attaching thin metal fins



Courtesy RCA Mfg. Co., Inc.

Fig. 15. Family of E_p-I_p characteristic curves for a typical screen grid (tetrode) tube, a type 24A tube. (I_p is here designated as I_b.)

around the inside of the plate electrode, as shown in Fig. *16A*. These fins exert control over the secondary electrons for a considerable distance after they have bounced off the plate. The fins attract far more secondary electrons than does the screen grid, and these electrons then travel back along the fins to the plate. The chief objection to this method is that the fins are expensive to construct; electrical means for accomplishing the same results have been developed.

The introduction of an extra grid between the plate and the inner section of the screen grid proved to be the electrical answer to the problem of driving secondary electrons back to the plate. This extra grid is known as the suppressor grid, for it actually *suppresses* the effects of secondary emission.

Here is how a suppressor grid acts: First of all, it is connected to the cathode or to a terminal which is more negative than the cathode. When an electron bounces off the plate and tries to flow to the positively charged screen grid, it is repelled just enough by the suppressor grid to be forced back to the plate. Even when the suppressor grid is at zero or cathode potential, its action is sufficient to make secondary electrons prefer the plate to the screen grid.

Why is it that the suppressor grid has very little effect upon the electrons flowing from the cathode to the plate, but a great deal of control over those which reverse their direction at the plate? *Speed* is the answer; an electron moving from the cathode through the control grid and the screen grid to the plate has developed so much speed by the time it reaches the suppressor grid that it goes right through the coarse wire mesh without slowing up at all, but secondary electrons coming from the plate have very little speed. We might compare the suppressor grid to a thin sheet of steel, which is easily pierced by a bullet from a high powered gun but which is able to stop a slow speed bullet from a small rifle. This one-way action of the suppressor grid is so efficient that it is even possible to operate the screen grid at the same potential as the plate, improving the electron flow to the plate without affecting secondary emission.

Figure *16B* shows a typical circuit for a suppressor grid or pentode tube. Notice that the suppressor grid is connected directly to the cathode. The screen grid is often connected to the same power supply terminal as the plate; thus terminals *1* and *2* may be connected together in some circuits, as they usually are when power pentode (suppressor grid) tubes are used.

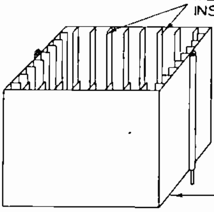


Fig. 16A. Sketch of plate electrode in a type 48 tube, showing metal fins used to limit screen grid current.

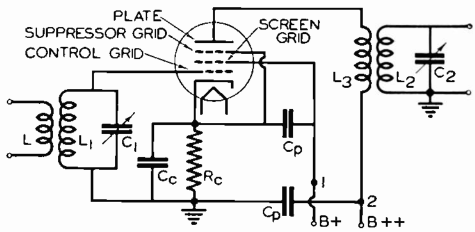


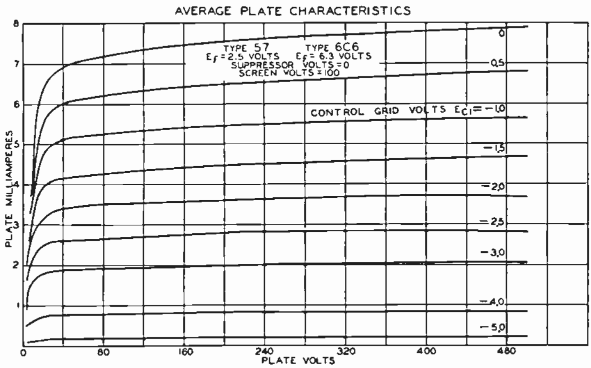
Fig. 16B. R.F. amplifier circuit using a suppressor grid tube. In most pentode tubes like this, the screen grid does not cover the outside of the plate.

The quality of a radio tube is judged entirely by its characteristics. A family of E_p-I_p characteristic curves for a pentode tube designed for R.F. amplification is given in Fig. *17*; notice that the suppressor grid has eliminated the unstable region below the screen grid voltage value which was present in the screen grid tube characteristic curves in Fig. *15*. The plate current of this pentode tube practically reaches its full value at low plate voltages, indicating that secondary emission is not depriving the plate of its current. A tube with characteristics like this can be made to swing over wide plate current and plate voltage values, giving maximum amplification and maximum power output for the tube.

VARIABLE-MU OR SUPER-CONTROL TUBES

You may already have heard of *variable-mu tubes,* also called *super-control tubes,* for they are quite commonly used in amplifier circuits where the gain (the amplification) is varied by varying the C bias voltage of the tube. These tubes solve the problem of controlling volume by providing a mutual conductance (and therefore an amplification factor μ) which can be varied *by changing the setting of the C bias voltage.* But let us first see what happens when we try to control volume in this way with ordinary tubes.

Cross-Modulation. When two stations are heard at the same time on a radio receiver, one being a weak station to which the receiver is tuned and the other being a powerful local station, and this is observed for a number of other desired weak stations as well, *cross-modulation* exists.



Courtesy RCA Mfg. Co., Inc.

FIG. 17. Family of E_p-I_p characteristic curves for a typical suppressor grid (pentode) tube, the type 57 and its equivalent in the 6-volt series, the 6C6.

Here is what happens: The weak signal is amplified in the normal manner by the first R.F. amplifier stage, but because of poor selectivity the strong signal also reaches the amplifier tube and is demodulated *because it swings the grid of the first tube beyond the linear region of the E_g-I_p characteristic curve.* Plate current thus varies *at the modulation frequencies of the strong station,* just as in any detector, and these A.F. variations serve to modulate the desired R.F. carrier. This carrier, now having both the desired and the undesired modulation signals, goes through the receiver in

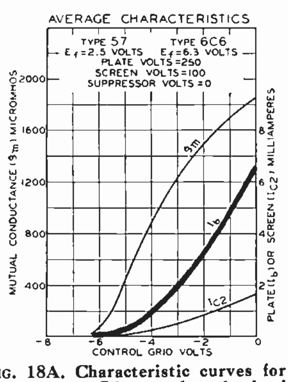


FIG. 18A. Characteristic curves for a type 57 or 6C6 pentode tube having both screen and suppressor grids.

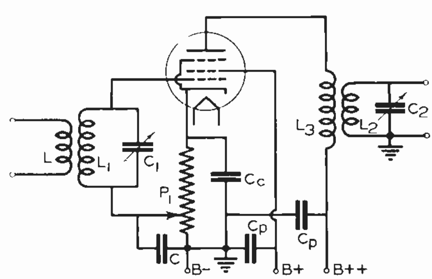


FIG. 18B. R.F. amplifier circuit using a pentode tube. Volume control P_1 varies the automatic C bias value.

the normal manner and both modulation signals are demodulated together.

The characteristic curves for a typical R.F. amplifier tube are given in Fig. *18A;* let us consider an actual example of cross-modulation, where the tube represented by these curves is placed in the R.F. amplifier circuit of Fig. *18B.* A normal C bias of –3 volts can be obtained for this tube by adjusting P_1. If the desired signal has a peak voltage of one-half volt, it will swing the grid over a linear portion of the grid voltage-plate current characteristic curve (I_b) and the signal will be amplified in a normal manner. If any undesired signal greater than 3 volts gets into this stage, however, it will swing the grid down beyond the bend in the I_b curve or even beyond the plate current cut-off point. The resulting rectification of the undesired signal causes cross-modulation.

Modulation Distortion. The E_g-I_p curve (curve I_b in Fig. *18A*) for an ordinary screen grid tube has a very pronounced bend in the region of cut-off; the result is that signal voltages which swing the control grid *more positive* cause *large changes* in plate current, whereas signal voltages which swing the grid *more negative* give only *very small changes* in plate current. The harmonics produced under this condition can be partially filtered out by resonant circuits, but the more serious effect, distortion of the wave form of the modulation accompanying the carrier, is difficult to remedy; *modulation distortion* is the term applied to this operating defect of a screen grid tube.

In order to eliminate cross-modulation and modulation distortion effects yet still control volume by means of the C bias voltage, we need a tube which will reduce its mutual conductance as the C bias is made more negative, but which will not have a *sharp* bend in its E_g-I_p curve at low current values; we need a tube which requires a very high negative C bias to produce plate current cut-off.

An ordinary screen grid tetrode or pentode tube has a sharp plate current cut-off and, since the control grid wires are close together and near the cathode, only a small negative C bias is needed to drive the plate current to zero. This construction, as you know, gives a high amplification factor. If, now, we modify the construction so that some of the control grid wires are farther away from the cathode than others or so some of the control grid wires are closer together than others, we get a tube which has the desired characteristics. The variable spacing scheme is illustrated in Fig. *19A*; this is the arrangement commonly used for variable-mu tubes, since it simplifies construction problems.

This variable spacing of control grid wires gives to the tube two distinct characteristics, one for each spacing, as you would expect. At small negative C bias voltages the action of the tube is essentially the same as if all grid wires were uniformly spaced at the maximum distance, but at high negative bias values the closely wound turns block electron flow; electrons continue to pass through the widely spaced grid turns to the plate until the highly negative cut-off bias is reached, and thus we obtain the desired remote cut-off characteristic.

The mutual conductance and plate current curves for a representative variable-mu tube are given in Fig. *19B*, with the plate current curve (E_g-I_p curve) for an ordinary screen grid tube (the type 57) shown for comparison. If you compare the plate current cut-off points and the bends in the two I_p curves, you can verify the statements just made concerning variable-mu tubes.

Ordinarily screen grid and pentode tubes are quite satisfactory for those circuits where the C bias is such that the A.C. signal swings over a linear part of the E_g-I_p characteristic, but only a very limited variation in g_m is permissible if cross-modulation and modulation distortion are to be eliminated. Variable-mu screen grid tubes and variable-mu pentodes (often called super-control pentodes) permit considerable variation in their values of g_m; these tubes are well suited for those stages of a well designed amplifier where a C bias type of gain control is used, for they will reduce cross-modulation and modulation distortion.

PRACTICAL R. F. PENTODE CIRCUITS

Amplifier circuits containing ordinary pentode tubes or super-control pentode (variable-mu) tubes are basically the same as the triode amplifier circuits shown in Fig. *9*. Remember, however, that pentode tubes have a very high A.C. plate resistance; this means that the conditions for maximum amplification (a load resistance many times higher than the A.C. plate resistance if an ordinary resonant circuit is used as load, or a load resistance equal to the A.C. plate resistance in the case of a tuned trans-

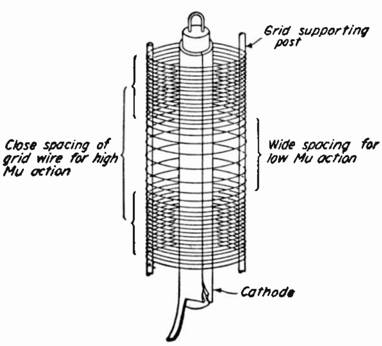


FIG. 19A. This sketch shows the variable spacing used for the control grid wires in a variable mu tube.

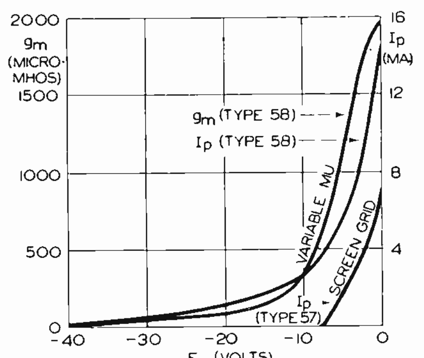


FIG. 19B. Characteristic curves for a variable mu pentode tube (type 58), with plate current curve for ordinary pentode (type 57) shown for comparison.

former load for a single-tube stage) are seldom if ever secured. A tank circuit load which is designed for a triode tube is purposely given a low resonant resistance, so obviously a triode load will not be satisfactory in a pentode circuit.

A two-stage R.F. amplifier using pentode tubes and containing a number of different types of R.F. circuits is shown in Fig. *20*. The first tube is an ordinary pentode; a 1,500 ohm cathode-to-ground resistor supplies it with an essentially constant automatic C bias. Condensers marked *.1* (.1 mfd.) serve as low-reactance paths for A.C. currents. The second R.F. amplifier stage, containing a super-control pentode tube, is coupled to the first stage by condenser *C*, which is used both as a D.C. blocking condenser and as an A.C. coupling condenser. The capacity of *C* is quite low, being about 10 mmfd.; this capacity generally is secured simply by twisting two insulated wire leads together once or twice.*

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* When the R.F. choke and the tank coil are constructed as a single unit (but with no inductive coupling between them), a stiff wire is sometimes connected to the upper end of choke *RFC* and looped partly around the grid end of the tank coil L_2 to provide the required low coupling capacity *C*.

The type 58 super-control pentode tube feeds into its load through a transformer having a tuned primary. The gain of this R.F. amplifier is controlled by varying the negative C bias which is applied to the type 58 tube; potentiometer *P* in the voltage divider network provides a means of varying this C bias. Choke coil RFC_1 in the plate supply lead of the super-control pentode prevents A.C. signal currents from entering the power supply circuit.

Pentode R.F. amplifiers of the type just described are used for all frequencies. With R.F. values between 100 kc. and 20 megacycles it is simply necessary to design the resonant circuit to respond to the desired frequency and to have a resonant resistance which gives sufficiently high amplification for desired results. By-pass condensers and choke coils must, of course, be of the proper values to keep A.C. signals in their proper paths. At the ultra-high frequencies, however, such as those used in television systems, the grid-to-cathode, grid-to-plate and plate-to-cathode capacities in the tubes become appreciable in value, especially in stages which are designed for high voltage gain; in these cases acorn-type tubes, which have no bases and are so designed that leakage and inter-electrode capacities are a minimum, are used.

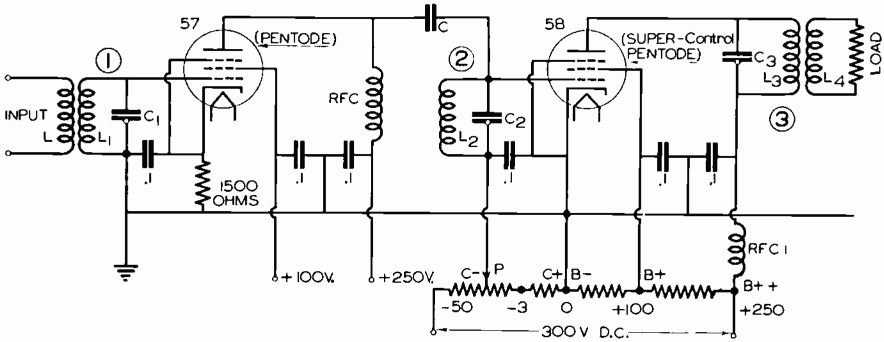


Fig. 20. Circuit of a two-stage R.F. amplifier using pentode tubes. The small circle on a condenser symbol indicates that the condenser is adjustable. Numerals alongside a condenser represent its capacity in microfarads. All .1 mfd. condensers are by-pass condensers.

BAND-PASS R. F. CIRCUITS

All of the R.F. circuits which you have just studied have had single peak frequency response curves like that shown in Fig. *7A;* these are, of course, perfectly satisfactory where the side-band frequencies involved are within narrow limits. In order to approach the ideal flat response curve shown in Fig. *7B*, multiple resonant circuits are required. It is possible to flatten the curve produced by a single tuned circuit if the tank circuit is shunted by a resistance, but this reduces the gain considerably and simply gives an approach to the ideal response.

When a number of tuned circuits are used in cascade, as they are in Fig. *20,* it is possible to secure an approach to an ideal response curve by tuning one or more circuits off the incoming signal frequency. For example, circuit *2* could be tuned to the desired 1,000 kc. signal, circuit *1* could be tuned to about 995 kc., and circuit *3* could be tuned to about 1,005 kc. The over-all response curve is the product of the responses of each stage. By careful adjustment, very nearly ideal response, with three more or less pronounced peaks, like those shown in Fig. *21*, can be obtained. Considerable gain is of course sacrificed in order to secure this response; another disadvantage is that two tubes are required to provide the three tuned circuits.

It is possible, however, to obtain flat response with only a single R.F. stage; several such stages can be used to give the desired amount of amplification, for the gain of the stages is cumulative. Double and sometimes triple tuned circuits are used in place of single resonant circuits; a typical double tuned circuit which is widely used in the I.F. amplifiers of superheterodynes is shown in Fig. *22*. Circuits L_1-C_1 and L_2-C_2 are usually identical circuits, coupled to each other by mutual inductance M. When both resonant circuits are tuned to give maximum output, a single peak response curve is obtained; if each tuned circuit has low circuit resistance, the frequency response curve will be pointed or peaked, whereas high circuit resistance gives a broad, rounded curve. When circuit L_1-C_1 is tuned to a frequency *above* the incoming signal (by reducing the capacity of C_1) and circuit L_2-C_2 is tuned *below* the incoming signal (by increasing the capacity of C_2), the resulting resonant curve will have a double hump. The

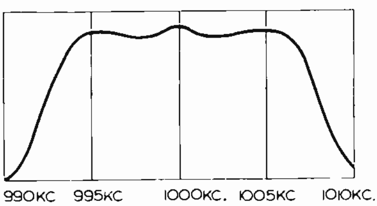


FIG. 21. When the three tuned circuits in the amplifier of Fig. 20 are properly adjusted for band-pass operation, the over-all response characteristic will be as shown here.

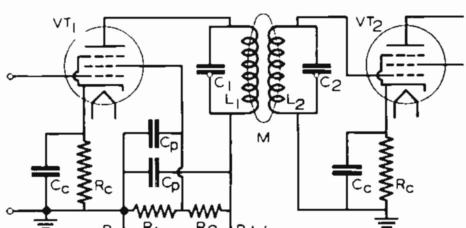


FIG. 22. A double-tuned band-pass radio frequency amplifier circuit, with inductive coupling between the two tuned circuits.

primary could just as well be tuned *below* resonance and the secondary *above* resonance for band-pass results.

The use of three resonant circuits, each coupled to the next and each adjusted to a different frequency, as the load of an R.F. amplifier gives a triple hump response curve. Of course, each extra coil wastes a certain amount of power, lowering the effective value of plate load resistance and consequently reducing the gain, but this loss in gain can be compensated for by using several such R.F. stages in cascade. A tuned amplifier having two or three tuned circuits obviously cannot give as much amplification, even when each circuit is tuned to resonance, as a single tuned circuit because of the losses in the extra coils. Single tuned circuits are therefore often referred to as high gain R.F. amplifiers.

Figure *23* shows another way of using two resonant circuits to give a double peak response curve; capacity C here couples the two circuits together, for the voltage developed across C by the L_1-C_1 circuit becomes the source voltage for circuit L_2-C_2. Coil L_1 is tuned by condensers C_1 and C in series, while coil L_2 is tuned by condensers C_2 and C in series. Since condenser C is usually fifty to one-hundred times as large as either C_1 or C_2, its tuning effect is negligible.

Condenser C can be replaced with a coil if desired, giving an inductively coupled circuit; the inductance of coils L_1 and L_2 should then be fifty to one-hundred times that of the coupling coil. The band width of a double tuned coupled circuit like this is roughly dependent upon the reactance of the coupling device; this reactance increases with frequency when inductive coupling is used, but decreases with frequency when capacitive coupling is used. Thus, in Fig. *22*, where inductive coupling is used, the frequency response curve will be broadest when the circuit is tuned to the higher frequencies, while for the circuit in Fig. *23*, which has capacitive coupling, the frequency response curve will be broadest at the lower frequencies to which the circuit is tuned. Quite often both inductive and capacitive coupling are used in order to secure a constant band width, especially when a circuit is to be tuned over a wide range of frequencies.

The question of band width is highly important in high fidelity sound receivers and especially in television receivers. In high fidelity sound receivers the band width is generally between 10 and 20 kc., while in television receivers the band width may be as much as 6,000 kc. The greater the band width of an amplifier, the less attenuation there is of the higher side frequencies, and the better is the fidelity of response.

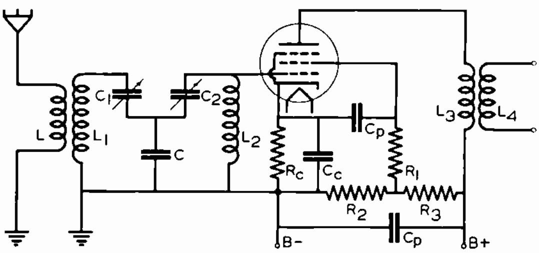


FIG. 23. The resonant circuits here couple the antenna circuit to the grid circuit of the first R.F. amplifier stage, giving a double-peak response characteristic.

FIXED R. F. AMPLIFIERS

At one time in the development of the radio industry, the tuned radio frequency amplifier patents were available only to a few radio manufacturers. This compelled other manufacturers to develop fixed R.F. amplifiers in order to get around these patents; tuning was accomplished with a resonant circuit placed ahead of the amplifier. In fixed R.F. amplifiers it was possible to use resistance-capacity coupled circuits, especially with triode tubes which had a low A.C. plate resistance; if screen grid tubes were used, however, a high plate load resistance and extremely high plate supply voltage were required.

A more practical solution to the problem of designing a fixed R.F. amplifier was found in the untuned air core transformer having a primary and secondary which were tightly coupled together; in fact, primary and secondary were wound simultaneously on a single coil form. The resulting circuit, shown in Fig. *24*, gave excellent results with triode tubes. The coupling between the primary and secondary windings in the transformer was sometimes made even closer by using pulverized iron cores. Fixed R.F. amplifiers are seldom used today, as patents on tuned R.F. amplifier circuits, which give much better results, are available to practically all receiver manufacturers.

POWER R. F. AMPLIFIERS

Maximum power amplification in any single-tube R.F. amplifier stage is obtained when the A.C. plate resistance of the tube is equal to the resonant resistance of the plate tank circuit. When maximum power is desired in the tank circuit, the tubes should have a high mutual conductance. In power R.F. amplifiers, especially those used in transmitters, the circuit must be designed to make maximum use of plate power; since it is ordinarily not feasible to design tank circuits which will have resonant resistances comparable to the A.C. plate resistances of ordinary tetrode and pentode tubes, special power R.F. amplifier tubes have been designed, these having a low A.C. plate resistance which is secured by reducing the amplification factor of the tube and by raising the cathode emission. The use of special tubes is the essential difference between power R.F. amplifiers used in transmitters and those used in receivers. Some power amplifier circuits are designed for peak response at a single frequency, while others (such as circuits handling modulated R.F. currents) are designed for band-pass operation.

Efficiency. In high power R.F. amplifiers such as are used in transmitters, the A.C. power in the tank circuits may be hundreds or even thousands of watts; in cases like these the efficiency of operation of the tube is of vital importance.* When

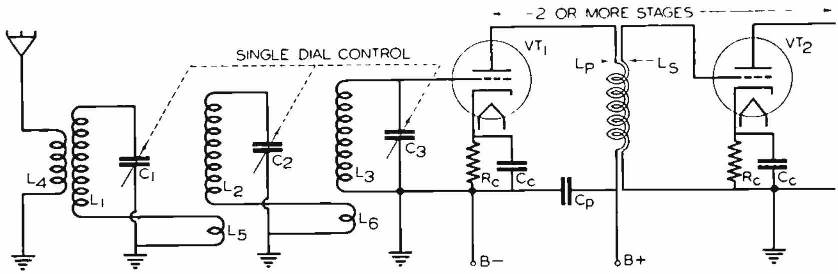


FIG. 24. A fixed R.F. amplifier circuit, with tuning being accomplished by the three resonant circuits which precede the first triode tube.

the C bias of an R. F. amplifier is set to make the input signal swing over a linear portion of the dynamic E_g-I_p curve, so the tube is operating as a *class A amplifier*, an efficiency of about 30 per cent is obtained even if the grid is driven positive for a part of each cycle.

The plate resistance of the tube is to blame for the greatest part of this wasted power, for all plate current must flow through this plate resistance. Greater efficiency can be obtained by cutting down the time during which plate current flows; by setting the C bias for plate current cut-off, no plate current will flow at normal plate voltage when there is no excitation, and plate current will flow only for one-half of each cycle when grid excitation is applied; this condition, where the tube is operating as a *class B amplifier*, is shown graphically in Fig. 25. Efficiencies of 50% are possible with this circuit. Observe that although the grid excitation voltage e_g is a perfect sine wave in form, the plate current i_p is a half sine wave; thus power is being supplied to the plate load circuit for only half of each cycle.

Engineers have proved, both by calculation and experiment, that the half sine wave plate current i_p in Fig. 25 is made up of a direct current component and an A.C. component having *even* (second, fourth, sixth, eighth, etc.) *harmonic components;* all these components are trying to flow through the *L-C* plate tank circuit. The D.C. component readily flows through coil *L* to the power supply, but the fundamental A.C. component encounters a high resonant resistance; part of this A.C. component is absorbed by the tank circuit, and the remainder by the tube.

* The efficiency of an R.F. amplifier is the A.C. power output (in the tank circuit) divided by the D.C. power supplied to the plate circuit; multiply this ratio by 100 to get per cent efficiency. The power supplied to the plate circuit is, of course, the D.C. plate voltage multiplied by the D.C. plate current.

The harmonic components find condenser C to be a low reactance path; since only the tube is offering impedance to the harmonic currents, the entire harmonic power is wasted in the tube. A tank circuit having a high Q factor will have an unusually high fundamental A.C. component flowing through both L and C.

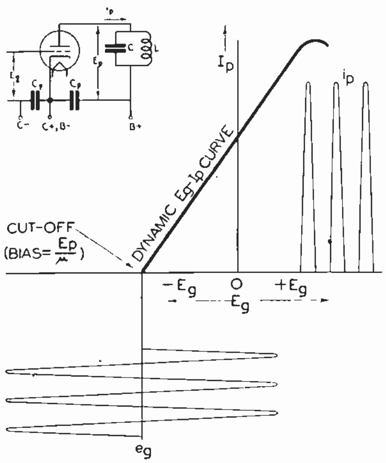


FIG. 25. Circuit diagram and characteristic curve for a typical triode tube operating as a class B amplifier.

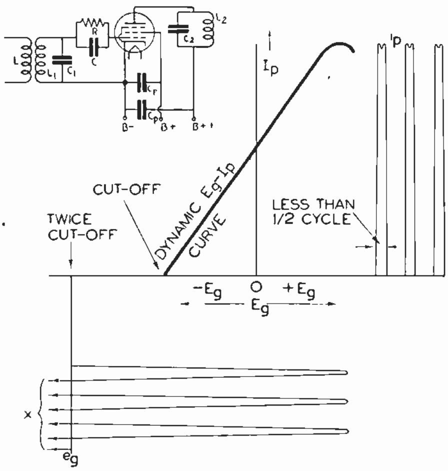


FIG. 26. Circuit diagram and characteristic curve for a typical pentode tube operating as a class C amplifier. The negative half-cycles at x have been omitted to conserve space on the drawing.

Even greater operating efficiencies (as high as 85%) can be obtained by making the C bias more negative than the cut-off value (usually about twice the cut-off value, as in Fig. *26*) and increasing the grid excitation until the maximum possible plate current is obtained; the tube is here operating as a *class C amplifier*. Notice that the resulting plate current pulses in Fig. *26* are almost rectangular in shape, and flow for considerably less than a half cycle. Experiments have shown that

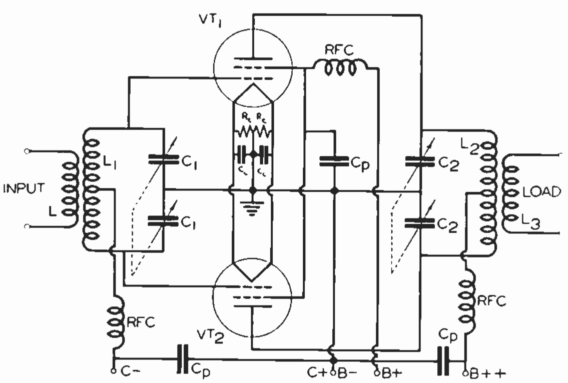


FIG. 27. Typical push-push power R.F. amplifier circuit.

with this wave form, more of the desired A.C. power is absorbed by the tank circuit.

Class C operation is widely used in power R.F. amplifiers where high efficiency and a large amount of power are desired. With both class B and class C operation, coupling the load to the tank circuit coil insures that the load will be fed with power at the fundamental frequency.

Self-Biased R.F. Amplifier Circuits. Although a separate C bias supply (like that in the circuit of Fig. *25*) is generally used in power R.F. amplifiers, a self-biased circuit like that in Fig. *26* is occasionally used. Here a pulsating rectified D.C. grid current flows through grid resistor R when the grid is driven positive by the excitation, thus making that resistor terminal negative which is closer to the grid. Condenser C in Fig. *26* provides a low reactance path for the A.C. excitation being applied to the grid and at the same time smooths out the pulsating direct current flowing through R, making the C bias voltage constant in value.

Power Amplification. Since the grid in the circuit of Fig. *26* is drawing current, power is being absorbed by the grid-cathode path in the tube; this power must be supplied by the grid excitation source. The power delivered to the plate tank circuit divided by the power fed to the grid gives what is known as the *power amplification* of a high-power R.F. amplifier stage. The power amplification value is usually about 10, which means that in order to get 1,000 watts out of a power R.F. amplifier, you must furnish about 100 watts of power to its grid.

Push-Push Power R.F. Amplifiers. In *audio frequency* amplifiers, a circuit containing two tubes arranged for push-pull or push-push operation is widely used to secure large power outputs, as you already know. These same two-tube circuits can, with slight modifications, be used to deliver high power output as R.F. amplifiers. A typical push-pull or push-push R.F. amplifier circuit is shown in Fig. *27*. Split-stator condenser C_1 divides the input voltage between the two tubes. A fixed C bias voltage is applied to the grids through an R.F. choke and coil L_1. Each tube feeds into the resonant load circuit made up of center-tapped coil L_2 and split stator condenser C_2.

TEST QUESTIONS

Be sure to number your Answer Sheet 16FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. What four things must the R.F. amplifier do in a sound or television radio receiver?
2. What does a frequency response curve (or resonance curve) for a tuned R.F. amplifier show?
3. In the modern definition for good selectivity, how many times more should the desired signal frequencies be amplified than the nearest undesired signals?
4. How does the cascading of R.F. amplifier stages affect the amplification and selectivity of an R.F. amplifier?
5. When a tuned transformer load is used in a single-tube R.F. amplifier stage, under what condition is maximum voltage amplification obtained?
6. Of the four circuits shown in Fig. *9* (*A, B, C* and *D*), which one uses a series resonant circuit?
7. Which inter-electrode capacity in a triode tube causes regeneration or oscillation?
8. In an R.F. amplifier like that shown in Fig. *14A*, what happens when the screen grid by-pass condenser C_2 opens?
9. What does the suppressor grid do in a vacuum tube?
10. Will variable-mu or super-control pentode tubes reduce cross-modulation and modulation distortion?

HOW TUNED CIRCUITS FUNCTION; COUPLING RADIO CIRCUITS

9FR-2

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

FIRST IMPRESSIONS

First impressions mean a lot in this busy world. An applicant for a job has a pretty tough time making the grade if his appearance and first few words do not make a favorable impression on the employment manager. A salesman likewise gets the "cold shoulder" if there is anything about him which annoys the prospect. The impression received when thumbing rapidly through the pages of a magazine on a newsstand or a book at a store determines, in nine cases out of ten, whether a sale will be made. And there are hundreds and hundreds of other instances where first impressions count.

With technical material of any kind, however, first impressions can be very treacherous. Oftentimes a technical book will contain a number of apparently complicated diagrams, charts, graphs, sketches or tables; since we glance mostly at illustrations when inspecting a book, we are apt to get a misleading impression.

You yourself have very likely encountered already in this Course a number of diagrams which seemed "all Greek" at the start but which proved to be surprisingly simple and easy to understand once you started studying them. Possibly you also found paragraphs, pages or entire lessons which seemed difficult during the first reading, but which became almost magically clear during the second or third reading.

If first impressions of a required task are favorable, fine and dandy; if unfavorable, be not discouraged, but wade right into the work and give it a chance to prove that *first impressions don't always count.*

J. E. SMITH.

WASHINGTON, D.C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

FM25C441 Printed in U. S. A.

How Tuned Circuits Function

WHAT IS A TUNED OR RESONANT CIRCUIT?

SO far in this Course you have studied resistors, coils and condensers separately, as well as coils or condensers acting with resistors. There remains, then, the *combination of a coil and condenser* to consider; this combination, whether used with or without a resistor, is known as a *tuned circuit* or *resonant circuit,* and is one of the most important and most widely used of all basic radio circuits.

In this lesson you will learn how resonant circuits behave under various conditions; you will discover that when the reactance of a coil in a resonant circuit completely balances out the reactance of the condenser at a particular frequency, the circuit is tuned to *resonance* and gives a desirable increase or step-up of signals. When you *tune* a radio receiver to a particular station, you are actually adjusting condensers in *tuned circuits* so that these circuits will be tuned to resonance and will respond to the desired signal frequency.

EXPERIMENTING WITH SERIES RESONANT CIRCUITS

There are two distinct types of resonant circuits, each having its own peculiar behavior. In a *series resonant circuit,* the source of voltage, the coil and the condenser are all *in series.* In a *parallel resonant circuit,* the source of voltage, the coil and the condenser are all *in parallel.* We will consider series resonant circuits first.

A simple experiment will show us the important characteristics of a series resonant circuit. Assume that we have at hand several A.C. ammeters and voltmeters, 10 and 100 millihenry coils, various condensers ranging from .1 to 10 mfd., a 0-200 ohm rheostat and a 500-cycle, 110-volt source of A.C. which can be varied in frequency from 0 to 1,000 cycles if desired and which delivers an essentially constant voltage.

Let us set the rheostat at 120 ohms and connect it across the 110-volt, 500 cycle source, inserting an A.C. ammeter in series as in Fig. *1A* to measure the A.C. current being drawn. (A 500-cycle source frequency was selected for this experiment simply because a low frequency such as this is convenient to use, but any other reasonable value of frequency, even R.F. values, would give essentially the same results.) The ammeter reads .92 ampere. (Note: All values given in this lesson are approximate.) Placing an A.C. voltmeter across the rheostat, we get a 110-volt reading. From our study of resistors we know that this A.C. voltage is always in phase with the current through the circuit.

Having completed these preliminary tests we are ready to begin the experiment. First we will insert the 100 mh. coil in this circuit, as in Fig. *1B.* The ammeter reading promptly drops to about .32 ampere. This shows us that a 100 mh. coil, when inserted in an A.C. circuit, offers considerable opposition to the flow of current; we say that the coil has a certain *reactance* in ohms. (The reactance in ohms of a coil or condenser depends upon the frequency of the applied A.C. voltage as well as upon its electrical value; the reactance of a coil or condenser is therefore different for each frequency.*) Now we will check the voltages in the circuit with A.C. voltmeters. Across the coil we get 103 volts, and across the rheostat the voltmeter reads 39 volts. Why, they add up to more volts than there are in the source! But wait—didn't we learn, in our study of coils, that voltages cannot be added as simply as this in A.C. circuits containing coils or condensers? That explains the mystery; the voltage across the coil is *out of phase* with the circuit current (actually, the coil voltage *leads* the current by 90 degrees), while the voltage across the resistor is *in phase* with the current.

Knowing how a coil acts in our circuit, let us replace it with condensers of various sizes until we find one which makes the ammeter read exactly the same value as it did for the coil; we find that a 1 mfd. condenser "will do the trick," making our circuit like that in Fig. *1C*. The voltmeters show that the voltages are exactly the same *in value* as were obtained with the coil; this proves that the reactance of this condenser is exactly equal in ohmic value to the reactance of the coil in Fig. *1B*. We know also that the voltage across the condenser *lags* the current by 90 degrees, while the resistor voltage is in phase with the current.

Individually, the coil and the condenser offer considerable opposition to A.C.—but look what happens when we place them both in series with the rheostat, as in Fig. *1D!* The ammeter reading is almost as high as it was with L and C both out. Clearly something unusual is taking place, for the opposition effects of L and C appear to be cancelling each other. It is a *series resonant circuit* which we now have, for the condenser, the coil, the rheostat and the 500-cycle source of voltage are all in series.

A check-up of the voltages in Fig. *1D* will tell us what is going on in this resonant circuit. The rheostat voltage is 109 volts, practically equal to the 110-volt source. Now put the voltmeter across the coil—why, 290 volts exists here! And the same voltage exists across the condenser! We are pretty sure now that these two voltage drops balance or cancel each other, for how else could the rheostat get almost full voltage? (Technically speaking, one voltage leads the current by 90 degrees and the other lags 90 degrees; consequently there is a 180-degree phase difference between the two voltages, and they do exactly cancel as far as the source is concerned. A voltmeter connected between points x and y would indicate zero voltage.)

*The reactance of a coil is obtained by multiplying the inductance of the coil (in henrys) by the frequency of the source (in cycles per second), then multiplying the result by 6.28. The reactance of a condenser is obtained by dividing the number 159,000 by the capacity of the condenser in microfarads, then dividing the result by the frequency in cycles.

Resonance. We intentionally made the reactances of L and C exactly equal at 500 cycles, and therefore the series resonant circuit in Fig. *1D* is *tuned to resonance* at the frequency of the source, which is 500 cycles; this is the only frequency at which resonance and maximum current will be obtained with the chosen values of inductance and capacity. In a practical circuit, we must usually adjust either L or C until their reactances cancel; this is called *tuning the circuit to resonance.*

At resonance in a series resonant circuit we always have these conditions: Circuit current is a maximum; the voltages across the coil and the condenser are equal and are at a maximum value (but opposite in phase); the L-C circuit as a whole (between points x and y) acts exactly like a resistor of *low ohmic value,* this resistance being almost entirely in the coil.

Resonant Voltage Step-Up. Perhaps the most astonishing fact about the series resonant circuit in Fig. *1D* is that the voltage across either

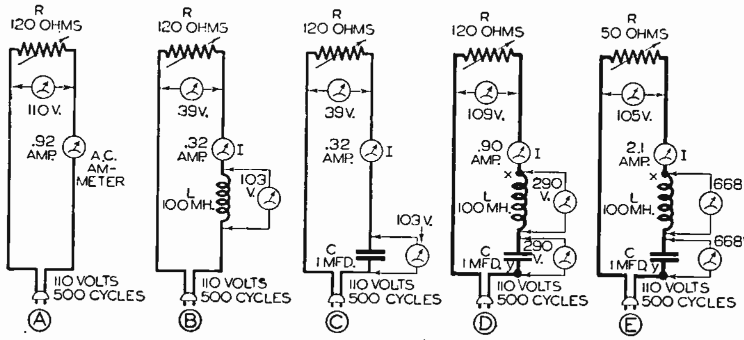


Fig. 1. The simple experiments represented by these diagrams show you the actual behavior of a series resonant circuit.

the coil or condenser is higher than the source voltage. This is our first meeting with *resonant voltage step-up—the ability of a series resonant circuit to deliver a voltage several times as great as that fed into it.* Here, for example, we feed in 110 volts at 500 cycles and get 290 volts, or more than two and one-half times as much.

Varying R. Continuing with our experiment, let us set rheostat R at 50 ohms, giving the circuit arrangement of Fig. *1E.* Doing this makes the circuit current jump up to 2.1 amperes. This greatly increased current, flowing through the same values of inductive and capacitive reactance as before, is the reason why the voltages across L and C are now 668 volts. Lowering the ohmic value of R below 50 ohms would increase these voltages even more, making it evident that the lower the resistance in a series resonant circuit, the greater will be the resonant voltage step-up of the circuit at resonance. Coil L always has some resistance, however, and it is this which limits the current flow and the amount of resonant voltage step-up when the rheostat resistance is reduced to zero. Remember: The lower the value of R, the higher will be the circuit current at resonance, and the higher will be the voltage developed across L and C by this current. In other words, lowering the value of R increases the step-up in voltage.

Varying C. The true experimenter is not satisfied until he has determined the effects of variations in each part of his circuit. Let us, therefore, vary the value of C (by inserting condensers of different sizes) while leaving the source, the coil and the resistor just as they are in Fig. *1D*. We are particularly interested in the circuit current I, since it determines what the voltage across L or C will be.

With condensers smaller than 1 mfd., circuit current I drops rapidly; the smaller the value of C, the lower the current. The reason is quite simple; reducing the electrical value of C increases its reactance above that of L, and that portion of this capacitive reactance which is not balanced out by L is effective in limiting current flow.

Incidentally, when we tune our series resonant circuit away fron resonance by varying C in this way, the circuit will act like that reactance *which is the larger or is predominant.* Lowering the value of C here makes the capacitive reactance the larger, and the series resonant circuit therefore acts like a condenser.

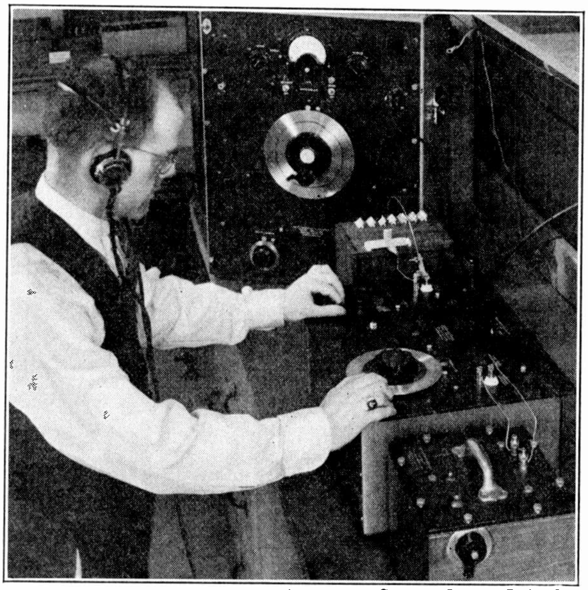
With condensers larger than 1 mfd., the ammeter reading likewise drops; increasing the electrical value of the condenser makes the reactance of C lower than that of L, with the result that a portion of the inductive reactance is left over to limit current flow.

Varying L. If we varied inductive reactance (instead of capacitive reactance) by inserting various values of L in the series resonant circuit, similar results would be obtained, for it is the amount of reactance left over (not balanced out) which governs the current.

Varying Frequency. With our series resonant circuit having the values indicated in Fig. *1D,* let us see what the results will be when the frequency of the source voltage is varied. Look—as we increase frequency from a low value, circuit current gets higher and higher, reaching a maximum value at 500 cycles and gradually decreasing again as we go higher.

Changing the value of either L or C throws the circuit off resonance as far as our 500-cycle source is concerned, but further experimentation will show that the circuit will be at resonance again for some other frequency. We could determine this frequency experimentally simply by varying the frequency of the source until we secured a maximum ammeter reading, then measuring the source frequency. We will find these facts to be true: *Increasing the value of either L or C lowers the resonant frequency of a series resonant circuit. Decreasing the value of either L or C raises the resonant frequency of a series resonant circuit.*

Varying Both L and C. Now we naturally wonder if resonance can be obtained at a given frequency with different values for L and C. With a 500-cycle source, we know that resonance can be obtained with a 1 mfd. condenser and 100 mh. coil; let us use a 50 mh. coil and try various values of C until we get resonance (maximum current) again. We find that a 2 mfd. condenser is required. This brings to light an interesting and important fact; multiplying together the values of L and C gives exactly the same number in both cases, for 100×1 is 100 and 50×2 is 100. This will hold true for all other values of L as well; multiplying together the values of L in millihenrys and C in microfarads at resonance will always give the number 100 for a 500-cycle source (this statement is sufficiently accurate for practical purposes). The larger the value of L, the smaller will be the value of C required for resonance.



Courtesy General Radio Co.

Resonant circuits play important roles in the method by which this General Radio engineer is measuring with extreme accuracy the capacity of a standard laboratory condenser.

If we changed the source frequency and repeated this part of our experiment, we would secure another number when multiplying together L and C; in other words, there is one number corresponding to each resonant frequency. Tables are available giving these numbers for different frequencies, so an engineer who is assembling a resonant circuit need only look up this number for the frequency in question, then choose values of L and C which when multiplied together will give this number. (Although this number is equal to L times C, engineers for convenience often omit the word "times" and simply call it the LC value.)

The above-mentioned relationship between L and C at any resonant frequency makes it easy for engineers to predict beforehand what values of L, C and frequency will give resonance in a particular circuit; knowing any two of these values, they can find the third either by means of a chart, a table or a mathematical formula.*

If you watch the ammeter while trying various values of L and C with the 500-cycle source, you will see that it reads just about the same *at resonance* for all of the coils. This is because at resonance the reactances of L and C cancel, regardless of what their values may be, and only the rheostat set at 120 ohms and to a lesser extent the coil resistance are limiting current flow.

You will also observe that with a 50 mh. coil the voltages across L and C are considerably lower at resonance than with the original 100 mh. coil. This is quite to be expected, for the smaller the coil, the lower is its reactance and therefore its voltage.

Graphs for Series Resonant Circuits. If we plot the results of our experiment on graphs like those in Figs. *2A* and *2B*, we can get an even more complete picture of what happens when changes are made in a series resonant circuit.

The manner in which the current in a series resonant circuit (like that in Fig. *1D*) varies when the condenser capacity is varied above and below the at-resonance value is clearly shown by the graph in Fig. *2A*. We see that as capacity is increased to get resonance, the rise in current is much more sudden than when capacity is decreased from a high value; this means that if we use series resonant circuits in a radio receiver, a station will come in suddenly as we tune to it from one direction, but will come in gradually over a greater number of dial divisions when tuning from the opposite direction.

Varying the inductance instead of capacity would give a perfectly symmetrical curve (having the same shape on either side of resonance), but for economical and practical reasons it is generally more satisfactory to vary capacity in actual radio circuits.

A curve like that in Fig. *2A* is commonly called a *resonance curve*, for it shows how circuit conditions change as we pass through resonance.

The most important characteristic of a resonant circuit used in radio work is how much better it accepts the desired resonant frequency than the undesired frequencies on either side. In radio receivers, for example, we want the resonant circuits to tune in a desired carrier frequency signal while rejecting the adjacent undesired carriers. Only a resonance curve obtained by plotting current against source frequency will give this information. Three such curves for series resonant cir-

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*For those who are interested in mathematics, this formula is: $f = 159{,}000 \div \sqrt{LC}$

In this formula, f is the resonant frequency in cycles, L is the inductance of the coil in microhenrys (1 millihenry = 1,000 microhenrys) and C is the condenser capacity in microfarads. This formula applies to both series and parallel resonant circuits.

cuits, often called selectivity curves, are shown in Fig. *2B*; let us see how much they can tell.

Curve *A* in Fig. *2B* is for the series resonant circuit in Fig. *1D*; it was obtained by keeping the source voltage constant while varying the frequency and measuring the circuit current. You can see that there is quite a drop in circuit current as you go above and below the resonant frequency of 500 cycles. The sharper the curve at resonance, the greater will be this drop in current, or, as radio men say, the better will be the selectivity of the circuit. You will learn later in the course, however, that a certain amount of broadness in the curve at resonance is also desirable in order to keep distortion at a minimum. Let us see how we can get a more peaked curve and a broader curve.

You will recall that the rheostat (*R*) was set at 120 ohms in Fig. *1D*;

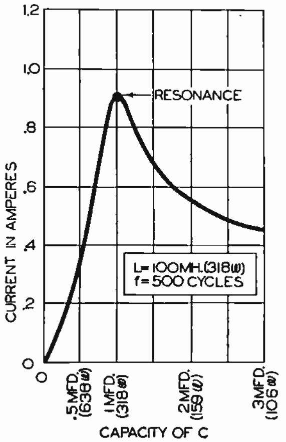


Fig. 2A. This graph shows how the current varies in a series resonant circuit when the value of capacity *C* is varied from 0 to 3 mfd. The capacitive reactances in ohms corresponding to each value of *C* are given in parentheses on the horizontal scale. Note that resonance and maximum current occur when the capacity of *C* is 1 mfd., making its 318-ohm capacitive reactance equal to the 318-ohm inductive reactance of *L*.

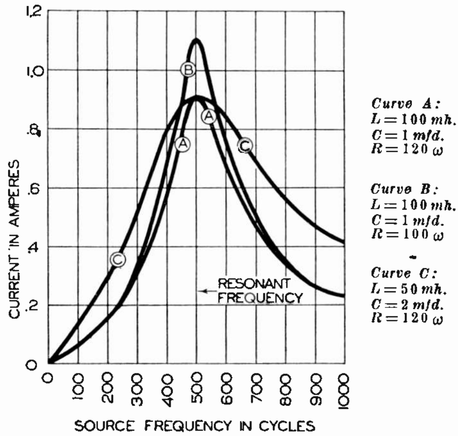


Fig. 2B. Here is what happens when you vary the frequency of the source in a series resonant circuit. These curves prove that for any given set of values for *L* and *C*, there is only one frequency at which resonance and maximum current will be obtained. (These curves and that in Fig. *2A* could also represent voltage across rheostat *R*, coil *L* or condenser *C* if the proper vertical scale of voltage were substituted for the current scale.)

if we change the setting to 100 ohms, the circuit resistance at resonance will be lower and we will secure a more peaked resonance curve. This is evident in Fig. *2B;* clearly, curve *B* for 100 ohms has a higher and sharper peak than curve *A* for 120 ohms. Lowering the resistance in a series resonant circuit thus improves selectivity.

Suppose we use a 50 mh. coil and a 2 mfd. condenser, re-setting *R* to 120 ohms. We still get resonance at 500 cycles, for the *LC* value of 100 has not been changed, but now curve *C* in Fig. *2B* represents conditions in the circuit. Note that this curve is considerably broader at resonance; this indicates that a wider range of frequencies around the resonant value will be passed equally well. If we experimented further in this same way, we would find that the lower the value of *L* while circuit resistance is kept constant, the broader will be the current resonance curve obtained when source frequency is varied. Incidentally, resonance or selectivity curves like those in Fig. *2B* are also known as *frequency response curves* or simply as *response curves.*

EXPERIMENTING WITH PARALLEL RESONANT CIRCUITS

When the source for a resonant circuit is connected directly in parallel with both the coil and the condenser, we have a *parallel resonant circuit.* We can use an actual experiment to show how this resonant circuit behaves. The first three steps in this experiment, represented by Figs. *3A, 3B* and *3C,* are the same as for the series resonant circuit.

Now we place the coil across the condenser as shown in Fig. *3D,* to form a parallel resonant circuit; the circuit current drops rather than

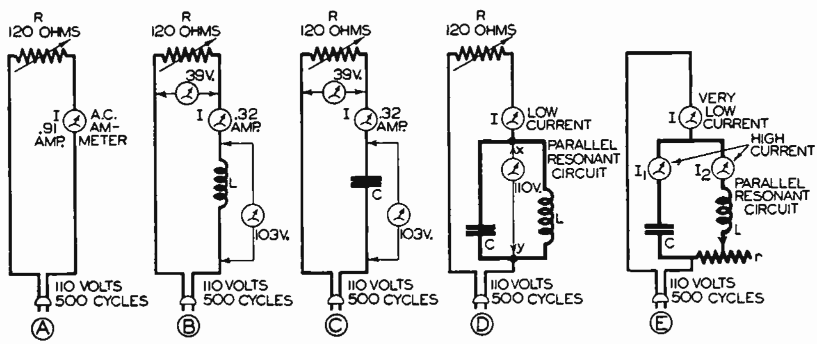


FIG. 3. The experiments represented by these diagrams show the actual behavior of a parallel resonant circuit. At resonance, a parallel resonant circuit behaves like a *resistor of high ohmic value.* This resonant resistance *decreases* when the resistance of the coil is increased.

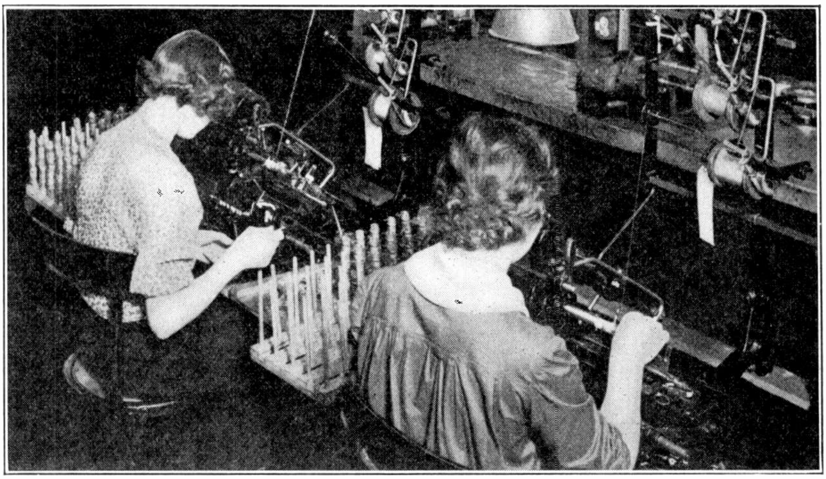
increases—another surprise! Our voltmeter readings tell us that practically all of the line voltage is across *L* and *C,* leaving none for the rheostat.

With no current flowing through the rheostat, we can remove it, as in Fig. *3E,* without appreciably affecting our circuit. Now let us insert A.C. ammeters in series with *L* and *C,* to see if they can solve this parallel resonance mystery. Look! There's plenty of current in the resonant circuit itself; both meters read practically the same as they did in the circuits of Figs. *3B* and *3C*! Truly this is just as "tricky" as a series resonant circuit.

Clearly this resonant circuit is for some reason acting like a very high resistance *across its terminals* (*X* and *Y* in Fig. *3D*), and at the same time is offering normal opposition to current flow *in the resonant circuit itself* (the circuit made up of *L, C* and the two ammeters). Can it be that the coil and condenser are storing energy on alternate half cycles and passing it back and forth inside the resonant circuit to make meters

I_1 and I_2 give high readings? In this case the source would only have to supply enough current to make up for the very small power losses in L and C. We shall learn shortly that this explanation is quite correct.

Behavior at Resonance. Whenever a coil and condenser are in parallel in an A.C. circuit, regardless of whether or not their reactances are equal, one will be feeding current back into the line when the other is drawing current, and the line current at any instant will be the difference between the two currents, phase being taken into account. When the reactances are equal, as at resonance, the line current is a minimum, while the coil and condenser each draw a current determined by its reactance and the voltage across the resonant circuit (essentially line voltage in most cases). At resonance, then, a parallel resonant circuit



Courtesy Universal Winding Co.

Coils for resonant circuits in the R.F. and I.F. stages of radio receivers are wound at high speed on special machines like these, which weave the wire back and forth to give a cross-wound coil. The criss-crossed windings have lower capacities between turns and hence such coils have a wider frequency range when tuned by variable condensers.

behaves like *a resistor of high ohmic value,* reducing line current almost to zero. The resistance of a parallel resonant circuit at resonance is known as the *resonant resistance* of the circuit.

Resonant Current Step-Up. You have just seen that the current through either the coil or condenser in a parallel resonant circuit is very much higher than the line current at resonance. This is *resonant current step-up*—the ability of a parallel resonant circuit to circulate a current many times greater than the current fed into it. This particular characteristic is very useful in Radio circuits, as you shall soon see.

Varying the Coil Resistance. Since all coils have a certain amount of resistance acting in series with their inductance, let us see how increases in this resistance affect the parallel resonant circuit in Fig. *3E.* Instead of using coils with the same inductance and various values of resistance, we can simply place a 100-ohm rheostat r in series with our coil and get the same effects. Starting with zero resistance for r in Fig. *3E*, we gradually increase the resonant circuit resistance while watching all three ammeters. The coil current goes down only a little, the condenser current remains the same, but up goes the line current. This means that when the resistance of the coil in a parallel resonant circuit is increased, *the resonant resistance is decreased;* this allows more line current to flow, and makes the line current value more nearly equal to the condenser current. (The insertion of a resistance in any resonant circuit does not ordinarily change the resonant frequency of the circuit.) We can conclude, then, that inserting resistance in a parallel resonant circuit decreases the resonant current step-up ratio (the ratio of coil current to line current), as well as decreases the resonant resistance.

Varying C. With the parallel resonant circuit in Fig. *3E* tuned to resonance, r being at its zero resistance setting, let us try different condensers for C and note the effects on line current while the source frequency is kept constant at 500 cycles. We will be duplicating a practical action here, for most parallel resonant circuits used in radio work have variable condensers.

We start with a very small value of capacity for C, and find that condenser current is practically zero, while coil and line currents are both about .35 ampere.

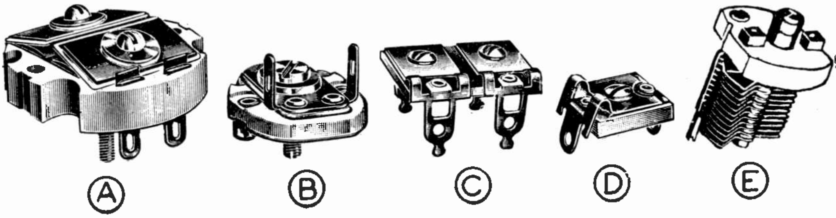
Gradually we increase the capacity of C, and note that condenser current goes up, line current goes down and coil current remains unchanged. Coil and condenser currents become more nearly equal as the capacity of C approaches its resonant value, and finally we reach the at-resonance condition already described, where line current is at its minimum value and the coil and condenser currents are equal.

Increasing the capacity of C above the resonance value causes line current to go up again, while condenser current continues to increase and coil current still remains unchanged. With a very high capacity for C the reactance of C becomes so low that coil current becomes negligible in comparison with the extremely high condenser current, and meters I and I_1 read almost the same values. Unless protected by fuses, these meters would be damaged if the experiment were actually carried out this far.

By varying C in this manner, we have actually been tuning our parallel resonant circuit to various frequencies. Off resonance, a parallel circuit acts like that part (L or C) which has the lowest reactance; it can therefore act either as a coil or a condenser. As a result of this experiment we find that lowering the capacity of C does these things: *1,* raises the resonant frequency of the circuit; *2,* makes the reactance of L lower than that of C, so that L predominates and the parallel resonant circuit acts like a coil. Raising the capacity of C does this: *1,* lowers the resonant frequency of the circuit; *2,* makes the reactance of C lower than that of L, so that the parallel resonant circuit acts like a condenser.

Varying L. If we varied inductive reactance (instead of capacitive reactance) by using different sizes of coils for L while keeping the source frequency constant, we would find that low values of L had the same effect as low values of C, and high values of L gave the same results as high values of C. In actual radio apparatus it is generally more convenient to vary C than L, but you can see that either procedure gives the same results.

Varying Frequency. And now let us return to the circuit shown in Fig. *3E*, set r to zero resistance and vary the frequency of the source without changing its voltage or the coil and condenser values. Suppose we start with a very low frequency (less than one cycle per second); this is very nearly the equivalent of direct current, and you know, then, that C will



Condensers like these, known as trimmer condensers, are widely used in the resonant circuits of radio receivers for the purpose of making small changes in the resonant frequency (as when aligning or band-passing a receiver). Unit *A* has two condensers, independently adjustable, for the two resonant circuits in a double-tuned I.F. transformer in a superheterodyne receiver. Unit *B* is most commonly used in a single-tuned I.F. transformer. You will often see units like those at *C* and *D* mounted on variable tuning condensers, where they serve to make all of the resonant tuning circuits (controlled by the sections of the ganged condenser) tune to the same frequency. These first four units have mica as a dielectric; that at *E* has only air as a dielectric, and is really a midget tuning condenser intended for use in tuned I.F. transformers of advanced design such as are required for precision amateur and commercial high-frequency communication receivers where frequency drift due to normal fluctuations in temperature and humidity must be negligible. The capacity of a trimmer condenser may be anywhere from about 10 to 500 mmfd., depending upon the number of plates used and upon the setting of the adjusting screw.

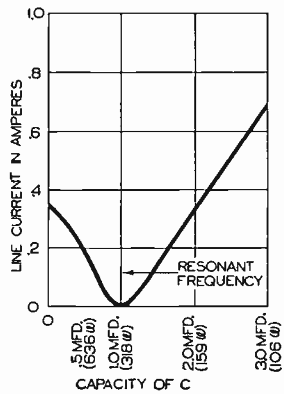
act like an open circuit (very high reactance), while L will act like a short (very low reactance). This means that the same very high current will flow through the coil and ammeters I and I_2, damaging them if they are not protected by fuses.

Increasing the frequency gradually from zero up to 500 cycles makes the reactances of L and C more and more nearly equal, with the parallel resonant circuit acting like a coil (because below 500 cycles the reactance of L is lower than that of C). Line current drops down to almost zero at 500 cycles, and condenser current increases gradually, being equal to the coil current at 500 cycles.

When the source frequency is 500 cycles, we of course have the resonance condition already described.

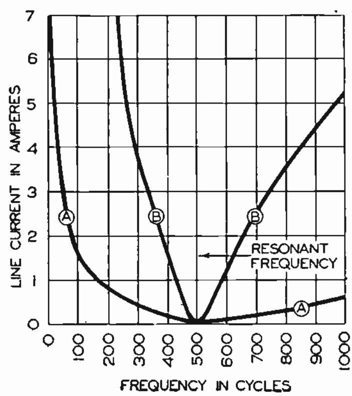
As the source frequency is increased above 500 cycles, coil reactance goes up and condenser reactance goes down, making our parallel resonant circuit behave like a condenser, with line current increasing again to supply the extra current drawn by the condenser. At a very high frequency, the reactance of L will be so high that it will act as an open circuit, but the reactance of C will be practically zero, and line current will be just as high as for very low frequencies.

Varying Both L and C. If we continue with this experiment by inserting various values of L in Fig. *3D* and use the correct values of C to give resonance at 500 cycles, we will find in each case that the same number is obtained by multiplying together the values of L and C; in other words, the product LC is a constant for a given frequency, just as it was for series resonant circuits. Furthermore, the formula for determining the resonant frequency when L and C are known (already given you in a previous footnote) applies to parallel resonant circuits as well as series resonant circuits.



$L = 100$ *mh.*; $f = 500$ *cycles*; $R = 0$; $r = 0$

FIG. 4A. This graph tells you how the line current changes when you vary the capacity of the condenser (C) in a parallel resonant circuit. Values of capacitive reactance corresponding to each value of C are given in parentheses.



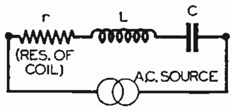
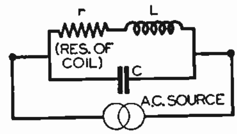
Curve A: $L = 100$ *mh.*; $C = 1$ *mfd.*; $L/C = 100$; $r = 0$; $R = 0$
Curve B: $L = 10$ *mh.*; $C = 10$ *mfd.*; $L/C = 1$; $r = 0$; $R = 5$

FIG. 4B. The effects of variations in frequency on the line current for a parallel resonant circuit are given on this graph for two different L/C ratios. (Instead of stating exact values of L and C when discussing a resonant circuit, engineers often divide the value of L by the corresponding value of C and speak of the resulting number as the L/C ratio of the circuit.)

Graphs for Parallel Resonant Circuits. If we recorded the line current readings when varying the capacity of C in the parallel resonant circuit of Fig. *3E*, then plotted the results, we would secure a curve similar to that in Fig. *4A*. This shows at a glance all the things we observed when carrying out this part of our experiment—that line current is a minimum at resonance, and increases when the capacity of C is made higher or lower than its resonant value.

A more important curve for our parallel resonant circuit is that secured by plotting frequency against line current, as in Fig. *4B*. When L is 100 mh. and C is 1 mfd., curve A is secured, while when L is 10 mh. and C is 10 mfd., curve B is the result. In parallel resonant circuits, then, lower values of L make line current increase more rapidly off resonance.

COMPARISON OF SERIES AND PARALLEL RESONANT CIRCUITS

Series Resonant Circuits	Parallel Resonant Circuits
	
1. The coil, the condenser and the A.C. voltage source are all in series.	1. The coil, the condenser and the A.C. voltage source are all in parallel.
2. Resonance occurs when the reactance of *L* is equal to the reactance of *C*.	2. Resonance occurs when the reactance of *L* is equal to the reactance of *C*.
3. At resonance, source current is a *maximum* (very high).	3. At resonance, source current is a *minimum* (very low).
4. At resonance, a series resonant circuit acts like *a resistor of low ohmic value*.	4. At resonance, a parallel resonant circuit acts like *a resistor of high ohmic value*.
5. At resonance, the voltages across *L* and *C* are equal in magnitude but 180 degrees out of phase with each other.	5. At resonance, the voltages across *L*, *C* and the source are all the same in magnitude and phase.
6. At resonance, the same current flows through the entire circuit.	6. At resonance, the currents through *L* and *C* are essentially equal in magnitude but 180 degrees out of phase with each other.
7. At resonance, the voltage across either *L* or *C* may be greater than that of the source, giving resonant voltage step-up.	7. At resonance, the current through either *L* or *C* is greater than the source current, giving resonant current step-up.
8. At resonance, increasing the value of coil resistance *r* lowers the circuit current, thereby *lowering* the resonant voltage step-up.	8. At resonance, increasing the value of coil resistance *r* increases line current, thereby *lowering* the resonant current step-up.
9. Off resonance, the circuit acts like that part which has the *highest* reactance.	9. Off resonance, the circuit acts like that part which has the *lowest* reactance.
a. Increasing *C* above its at-resonance value makes the circuit act like a coil.	a. Increasing *C* above its at-resonance value makes the circuit act like a condenser.
b. Reducing *C* below its at-resonance value makes the circuit act like a condenser.	b. Reducing *C* below its at-resonance value makes the circuit act like a coil.
c. Increasing *L* above its at-resonance value makes the circuit act like a coil.	c. Increasing *L* above its at-resonance value makes the circuit act like a condenser.
d. Reducing *L* below its at-resonance value makes the circuit act like a condenser.	d. Reducing *L* below its at-resonance value makes the circuit act like a coil.
10. The product *LC* is constant for any given resonant frequency.	10. The product *LC* is constant for any given resonant frequency.
11. Increasing *L* or increasing *C* lowers the resonant frequency.	11. Increasing *L* or increasing *C* lowers the resonant frequency.
12. Decreasing *L* or decreasing *C* raises the resonant frequency.	12. Decreasing *L* or decreasing *C* raises the resonant frequency.
13. The Q factor of the circuit is essentially equal to the coil reactance divided by the A.C. resistance of the coil.	13. The Q factor of the circuit is essentially equal to the coil reactance divided by the A.C. resistance of the coil.

Q FACTOR OF RESONANT CIRCUITS

Q Factor of a Coil. We have seen that the lower the resistance in any resonant circuit, the greater is the resonant voltage step-up or resonant current step-up. Since a high step-up ratio is generally desired, and since resistances increase the circuit losses, engineers seldom insert resistances intentionally in resonant circuits. Any resonant circuit, however, has a certain amount of loss due to the effective A.C. resistance of the coil, the condenser and the wiring in the circuit; in practically all cases it can be assumed that this loss is concentrated in the coil. This coil will have a certain reactance at a given frequency, and this *coil reactance divided by the A.C. resistance of the coil* gives a number which is known as the *Q factor* of the coil. It is also the Q factor of the resonant circuit containing the coil.

This Q factor, which is simply a number or rating, has a very important meaning in connection with each type of resonant circuit. When a coil is used alone, the impedance of the circuit is essentially the reactance of the coil; this circuit impedance is *reduced Q times* by placing in series with the coil a condenser which tunes the circuit to resonance; furthermore, the circuit current is *increased Q times* the value with the coil alone, and the coil voltage is *increased Q times.* Since with a coil alone the coil voltage is the line voltage, the coil voltage in a series resonant circuit which is tuned to resonance is Q times the line voltage.

In a parallel resonant circuit, the current through the coil at resonance is Q times the line current, with the result that the resonant resistance is Q times the reactance of the coil alone.

A high Q factor is oftentimes quite desirable for a resonant circuit. It is secured by using a high value of inductance and at the same time keeping the A.C. or R.F. resistance of the coil as low as possible.

USES FOR RESONANT CIRCUITS

Distinguishing Between Series and Parallel Resonant Circuits. One question often asked even by experienced radio men is, "How can I tell whether a resonant circuit is of the series or parallel type when I see it in a circuit diagram or in radio apparatus?" First I am going to give you a few simple rules as an answer to this question, then I shall illustrate these rules with a number of practical examples. I suggest you go through the following simple procedure when identifying a resonant circuit:

1. Locate the coil and the condenser which are always associated with a resonant circuit.
2. Locate the source of A.C. voltage for this resonant circuit. Typical sources will be receiving antennas, plate circuits of vacuum tubes and voltages induced from other circuits.
3. If the source for the resonant circuit is in series with the coil and the condenser, you have a series resonant circuit.
4. If the source for the resonant circuit is connected *directly in parallel with both* the coil and the condenser, you have a parallel resonant circuit.

Using a Parallel Resonant Circuit as a Wave Trap. When a radio receiver is located so near a powerful short-wave or broadcast band transmitter that signals of local stations interfere with those of stations broadcasting on adjacent frequencies, a wave trap similar to that shown in Fig. *5A* is quite often used to weaken the signal of the undesired local station before this signal gets into the amplifying section of the receiver. A parallel resonant circuit made up of coil *L* and condenser *C* is inserted in the antenna lead-in wire and tuned to resonance at the frequency of the undesired signal. This circuit acts as a very high resistance to signals at its resonant frequency, reducing the strength of these signals to the point where they no longer cause interference. The wave trap circuit acts as a fairly low reactance to signals of all other frequencies, however, allowing desired signals to pass through to the receiver.

A coil and condenser connected to form a parallel resonant circuit which can be used as a wave trap are shown in Fig. *5B*. The trimmer type condenser need be adjusted only once, at the time when the wave trap is installed by the serviceman.

Using a Series Resonant Circuit as a Wave Trap. A series resonant circuit, when connected to the antenna and ground terminals of a re-

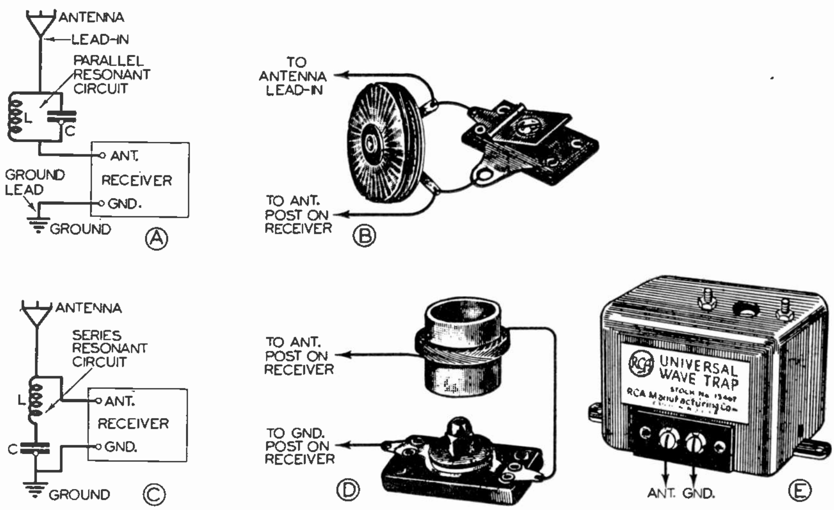


FIG. 5. If a single station causes interference, a wave trap can be used to keep the undesired signal out of the receiver. A parallel resonant circuit used as a wave trap is illustrated at *A* and *B*, while a series resonant circuit serves as wave trap at *C*, *D* and *E*.

ceiver in the manner shown in Fig. *5C*, also serves as a wave trap. The antenna and ground constitute the signal source, just as they did in Fig. *5A*, but you can see that in Fig. *5C* the coil and condenser are connected in series with their signal source, and the receiver gets the voltage which is developed across the combination of *L* and *C*. The wave trap, when tuned to the frequency of the offending station, acts as a very low resistance to currents of that frequency, in flowing through the wave trap to ground, then, the undesired signal current produces only a very small voltage drop across *L* and *C*, and this has little effect upon the receiver. At all other signal frequencies the impedance of the series resonant circuit which forms the wave trap is very much higher, and the voltage drop produced by a desired signal current flowing through *L* and *C* is more than high enough to affect the receiver.

The actual connections of a coil and condenser used as a wave trap of the series resonant type are shown in Fig. *5D*. A completely assembled wave trap in a neat metal housing is illustrated in Fig. *5E;* this is of the series resonant type, with connections like that in Fig. *5C*, and hence its two terminals are connected directly to the antenna and ground terminals of the receiver. The condenser is adjusted with a screwdriver inserted through a hole in the top of the housing.

Wave Trap Data. Wave traps of the parallel resonant type* generally give best results on receivers which have a low input A.C. resistance, while those of the series resonant type* will work best with receivers having a high input A.C. resistance. When the A.C. resistance of the receiver input is unknown, the practical radio man usually tries both types, selecting the one which reduces interference the most.

Adjusting a wave trap is a simple matter; connect it to the receiver in the proper manner, tune the receiver *to the offending station,* and then adjust the condenser in the wave trap until the offending signal is as weak as possible. If more than one station interferes, use one wave trap for each interfering station. Many all-wave superheterodyne receivers have built-in wave traps, which can be adjusted by the serviceman to tune out offending low frequency code stations.

Parallel Resonant Circuits in R.F. Amplifiers. Tuned or resonant circuits are widely used for feeding radio frequency signals from one tube to another, as in tuned R.F. amplifiers. The tuned-impedance or high-gain amplifier circuit shown in Fig. *6A* is an example; we are interested primarily in the action of the *L-C* circuit drawn in heavy lines, since the other parts of this circuit will be taken up in detail later in the Course.

The plate current of the tube is fed directly to both coil *L* and condenser *C*; this indicates clearly that we are dealing with a *parallel* resonant circuit, which has a very high resistance at resonance.

With any R.F. amplifier circuit, the greater the resistance of the load, the greater will be the voltage developed across the load and the less will be the voltage in the tube. The *L-C* circuit in Fig. *6A* is the load for tube VT_1; if we adjust *C* to bring this circuit to resonance at the frequency of the incoming signal, the load will have the desired high resistance, and the signal voltage developed across the load will feed through coupling condenser C_K to the grid of tube VT_2. For all other frequencies the *L-C* circuit will act as a low reactance, and currents at undesired frequencies will pass through this circuit and through by-pass condenser C_p to the chassis and ground without developing a voltage large enough to affect the grid of tube VT_2.

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*Since wave traps of the parallel resonant circuit type are used ***in series*** with the signal source, as shown in Fig. *5A*, they are often called ***series traps.*** Wave traps of the series resonant circuit type are used ***in parallel*** with the load, as shown in Fig. *5C*, and are for this reason often called ***parallel traps.*** Remember that these terms apply only to the method of connection, and not to the type of resonant circuit employed.

A parallel resonant circuit thus passes on signal voltages at the frequency to which it is tuned, and rejects voltages at all other frequencies. In other words, the circuit possesses selectivity characteristics which make it very valuable for separating R.F. signals which have nearly the same carrier frequencies.

The picture diagram in Fig. *6B* shows you the actual connections for a parallel resonant circuit, just as you might find them in the chassis of an R.F. amplifier. Notice how much simpler it is to draw the schematic diagram (Fig. *6A*) than the picture diagram. Except for keeping certain leads (such as grid and plate leads) as far apart as possible, the manner in which parts are connected together is generally not important as long as the proper terminals are connected together electrically.

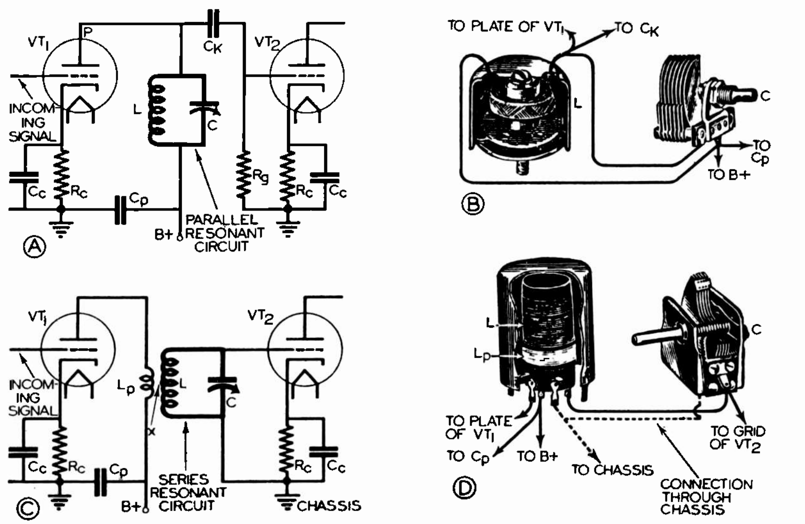

FIG. 6. Series and parallel resonant circuits are shown here (in heavy lines) as they are used in vacuum tube amplifiers. Actual chassis connections for the resonant circuits are shown alongside each diagram for comparison.

Series Resonant Circuits in R.F. Amplifiers. Another typical R.F. amplifier which uses a resonant circuit is shown in Fig. *6C*. There is no difficulty here in recognizing the resonant circuit made up of condenser C and coil L, but the question is: Where is the source of voltage for this circuit? We must locate this source before we can tell whether the circuit is of the series or parallel type.

The answer to this question lies in the transformer made up of coils L_p and L; the R.F. signal current supplied by the plate of tube VT_1 flows through coil L_p and induces an R.F. voltage of corresponding wave form in coil L. This induced voltage exists *in* the coil just as if it were at point x in coil L, and not across the coil. Consequently we must consider the induced voltage to be in series with coil L; it is therefore also in series with condenser C, and we have a ***series resonant circuit.***

When L and C in this series resonant circuit are tuned to the frequency of the induced signal voltage, they act as a resistance of very low ohmic value. A large R.F. curent therefore flows through the series resonant circuit, developing a correspondingly large voltage across condenser C, and this voltage acts on the grid and cathode of tube VT_2. At all other frequencies, the L-C circuit acts as a high reactance; the R.F. currents at these other frequencies are therefore low, the voltages developd across C are low, and undesired signals are suppressed. A series resonant circuit thus improves selectivity in addition to giving resonant amplification of the desired signal. Chassis connections as they might be for a series resonant circuit in an R.F. amplifier are shown in Fig. *6D*.

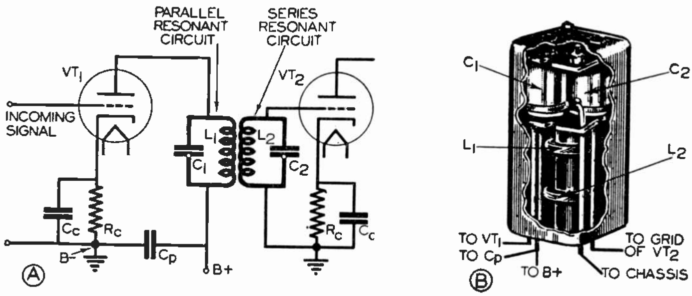

FIG. 7. The I.F. amplifier section of a superheterodyne receiver, the circuit diagram of which is given at *A*, is a practical example of an amplifier circuit which uses both series and parallel resonant circuits. The I.F. transformer consists of parts L_1, C_1, L_2 and C_2. The actual connections to both resonant circuits appear at *B*.

Resonant Circuits in a Superheterodyne Receiver. You have just seen how series and parallel resonant circuits each contribute a certain amount of selectivity. In superheterodyne receivers, series and parallel resonant circuits are often connected together in the manner shown in Fig. *7A* in order to secure even greater selectivity., together with resonant amplification at the desired frequencies. Again the resonant circuits are shown in heavy lines.

First consider only circuit L_1-C_1; clearly this is a parallel resonant circuit like that shown in Fig. *6A*, for tube VT_1 is its signal source. At resonance, then, a large current flows through coil L_1 and condenser C_1.

Now let us bring the L_2-C_2 circuit into our picture. The R.F. current flowing through coil L_1 induces in coil L_2 an R.F. voltage which acts in series with L_2 and C_2, just as in Fig. *6C*, and thus L_2 and C_2 form a series resonant circuit. The actual chassis connections for this double resonant circuit might be as shown in Fig. *7B*.

Coupling Radio Circuits

PRACTICAL ANTENNA COUPLING METHODS

Now that we are well acquainted with resonant circuits and with a few of their applications, we are ready to take up the different ways in which one resonant circuit can be coupled (connected) to another resonant circuit or to some other type of radio circuit.

The antenna circuit of a radio receiver is one of the simplest and best-known applications for coupling systems, so we will use it as our practical example in connection with this study of coupling methods.

Coupling the Antenna to One Resonant Circuit. Here is a very practical radio problem. Suppose we had an antenna and a ground, and wanted to connect or couple them to the resonant or tuned circuit which feeds the first R.F. stage of a radio receiver. We must remember that an ordinary antenna has impedance, and this lowers the signal voltage applied to the resonant circuit. What are the different coupling methods

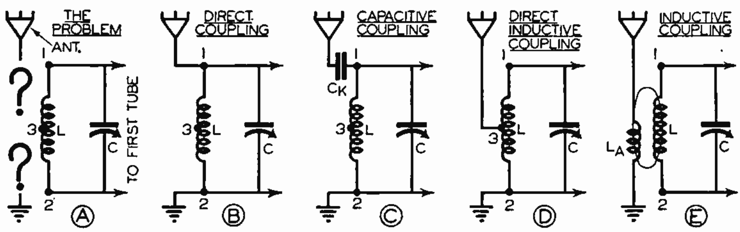

FIG. 8. Four simple ways of coupling an antenna system to the first resonant circuit of a radio receiver are shown here.

which will serve as a satisfactory solution to our problem? There are four simple methods of coupling an antenna to a single resonant circuit, as follows: *1,* Direct coupling; *2,* capacitive coupling; *3,* direct inductive coupling; *4,* inductive coupling. Let us consider them one by one.

Our problem is shown in diagram form in Fig. *8A*; the antenna picks up many R.F. signals, of which only one is desired at any one time in the tuned circuit made up of L and C.

1. Direct coupling, as shown in Fig. *8B,* is the first and simplest solution to this problem. The entire antenna voltage is applied across our L-C circuit, making it a *parallel resonant circuit.* We know from our previous experiments that this tuned circuit will act as a resistance of high ohmic value to a signal having the resonant frequency to which L and C are tuned; at this desired frequency, then, the resistance of the input circuit is much higher than the antenna impedance, and the greatest part of the signal voltage will exist across the resonant circuit and be passed on to the grid of the first tube. At all other frequencies, however, this resonant circuit will act as a low impedance, and only a negligible voltage will be developed across it.

2. Capacitive coupling, as illustrated in Fig. *8C,* is the second method. As you can see, it is simply direct coupling with a low-capacity condenser C_K inserted in the antenna lead-in. There are several reasons why this condenser is desirable. Suppose that the antenna wire broke in a storm and fell across a power line; if condenser C_K were not present, a heavy current would flow through coil L, burning it out. The condenser blocks this current entirely if it is D.C., and limits it to a negligible value in the case of 60-cycle A.C. If made variable, this condenser can also be used to tune the antenna itself to a desired signal frequency. Maximum signal will be delivered by the antenna at this frequency, while other signals, such as that of a strong undesired local station, will be reduced in strength. To secure this result, however, it is necessary to readjust C_K each time a new station is tuned in. Capacitive coupling can be made to improve both selectivity and gain.

3. Direct inductive coupling of the form shown in Fig. *8D* applies the antenna voltage to only a part of the resonant circuit. This connection can boost the gain considerably, for antenna current flowing in section *3-2* of coil L induces in the rest of the coil a much higher voltage; this induced voltage acts in series with the coil and therefore undergoes resonant voltage step-up. The position of point *3* can be varied to secure maximum gain with fair selectivity or low gain with good selectivity, as desired.

4. Inductive coupling, shown in Fig. *8E,* is perhaps the most widely used of all methods for coupling the antenna system to a resonant input circuit; inductive coupling is also known as transformer coupling or sometimes as indirect inductive coupling. Antenna current flowing through coil L_A sets up a varying magnetic flux which links coil L and induces in it a voltage which acts as if it were in series with L. We thus have a series resonant circuit, with the voltage undergoing resonant step-up. Inductive coupling can be designed to give very high gain, to give high selectivity or to give a satisfactory compromise between the two, as desired, by varying the number of turns in coil L_A and its position with respect to coil L.

Coupling the Antenna to Two Resonant Circuits. In building radio receivers, selectivity is often desired more than voltage step-up, for the high-gain amplifier tubes now available make it easy to get the required gain. Furthermore, it may be highly desirable to secure this extra selectivity ahead of the first R.F. amplifier tube. The solution obviously lies in making the incoming signals pass through two or more resonant circuits one after another, so each resonant circuit can contribute to selectivity. We will now consider three practical methods for connecting two resonant circuits to each other (in what is known as a *cascade arrangement*) and to the antenna system. The problem is shown in diagram form in Fig. *9A*.

First of all we must couple our antenna system to the first resonant circuit. Any of the methods shown in Fig. *8* may be used for this purpose; let us use the inductive coupling method of Fig. *8E* where antenna current flowing through extra coil L_A induces a voltage in series with the first resonant circuit.

Coupling together the two resonant circuits is the next problem. One method for doing this is shown in Fig. *9B*; coupling coil L_M is so connected that it is common to both resonant circuits, giving *direct inductive coupling*. Now coil L_1, coil L_M and condenser C_1 are all in series with the induced voltage, and our first resonant circuit acts as a series

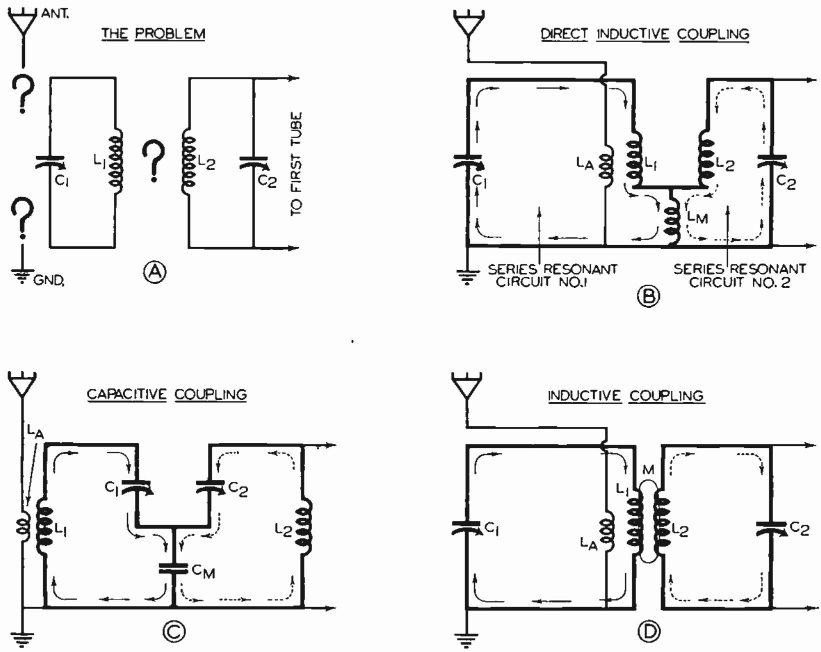

FIG. 9. Here are three ways of coupling together an antenna system and two resonant circuits for the purpose of securing extra selectivity.

resonant circuit. At resonance we have maximum current circulating in this first resonant circuit, as shown by the solid arrows in Fig. *9B*. This current produces across coupling coil L_M a voltage drop which serves as the source voltage for our second series resonant circuit, consisting of L_M, L_2 and C_2. The current flow through this circuit, shown by dotted arrows, produces across C_2 the voltage which is fed to the first tube in the receiver.

If we replace coil L_M with a condenser, as is done in Fig. *9C*, much the same results are secured, but now we have what is known as *capacitive coupling*. Condenser C_M is common to both series resonant circuits, with each circuit contributing to selectivity. There may or may not be any resonant voltage step-up, depending upon the values of the parts in the circuits.

When *inductive coupling* is used to transfer the signal from one resonant circuit to the other, we have the arrangement shown in Fig. *9D*. Again we have two series resonant circuits, for induced voltages always act *in series with coils*.

Coupling Two Vacuum Tube Circuits Together. The coupling methods shown in Figs. *8* and *9* for antenna circuits are essentially the same as those you will encounter in a host of other radio applications, the most common of which is the coupling together of the plate circuit of one tube and the grid circuit of the following tube. Let us look back to the amplifier circuits shown earlier in this text, and see if we can identify the type of coupling used in each.

In Fig. *6A*, condenser C_K is clearly serving as a signal path between the two tubes, and this therefore is capacitive coupling like that shown in Fig. *8C*. Condenser C_K also serves an extra function here, that of preventing direct current from flowing from the plate supply (B+) through coil L to the grid of VT_2.

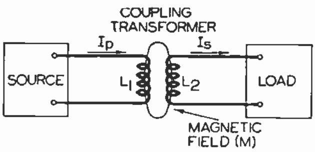

Fig. 10A. Any inductively coupled circuit can be represented by this simplified circuit.

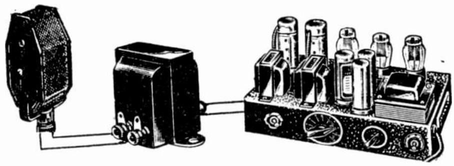
FIG. 10B. In this practical application of inductive coupling, the microphone transformer (center) couples together the velocity microphone and the public address amplifier unit.

In Fig. *7A* we have two resonant circuits in cascade, and again inductive coupling serves to transfer the signals from one circuit to the other. The arrangement is like that in Fig. *9D* except that instead of inductive coupling between the signal source and the first resonant circuit, we have a direct connection.

HOW INDUCTIVE COUPLING WORKS

The average radio man who encounters inductive coupling accepts it simply as a process whereby an alternating current in one coil induces an A.C. voltage in the other coil. But there is a lot more about inductive coupling which I want *you* to know, because I want you to be a better-than-average radio man.

Simplified Circuit. Any inductively coupled circuit can be simplified to the three essential parts shown in Fig. *10A*; a source, a coupling transformer, and a load. The source may or may not have appreciable impedance, and may be delivering either an A.F. or R.F. signal voltage. The transformer may be of the air core type, where its two windings (coils) are separated only by air or some other insulating material, or the transformer may be of the iron core type. The load may likewise have impedance. Either the source, the load or both may be resonant circuits. Here is what happens: The source, "feeling" the effects of the load through the coupling transformer, sends through the transformer primary (coil L_1) a current I_P which induces in coil L_2 a voltage that acts directly on the load, making current I_S flow through the load.

Practical A.F. Application. A very common and practical low-frequency application of inductive coupling is that shown in Fig. *10B*, where a microphone serves as a source of A.F. signals, an audio amplifier serves as load, and an iron-core coupling transformer serves to make the source "feel" the effects of the load. This coupling transformer can be designed to deliver maximum voltage or maximum power to the load.

Practical R.F. Application. A radio frequency application of inductive coupling is the little "pill-box" you see connected between the two halves of some short-wave antennas in an arrangement similar to that shown in Fig. *11A*. A close-up view of this box appears at Fig. *11B*; generally, all you will find inside it are two coils forming an air-core transformer, connected between the two halves of the antenna and the

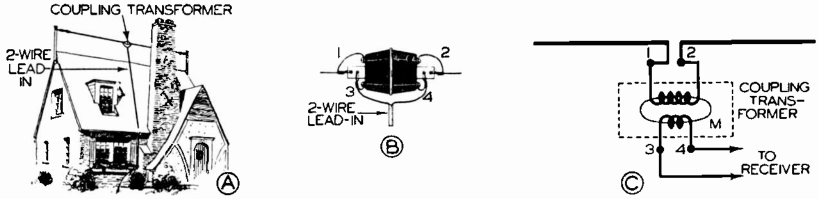

FIG. 11. Illustrated here is a well-known R.F. application of inductive coupling, the type of coupling transformer used with a doublet short-wave antenna.

two-wire lead-in (transmission line) in the manner shown in Fig. *11C*. The use of inductive coupling here makes it possible to secure maximum transfer of power from the antenna to the receiver.

Types of Inductive Coupling. The action of a coupling transformer, as you already know, depends upon the fact that current flowing through the primary winding produces a varying magnetic flux. *When all of the magnetic flux produced by the primary winding links with (passes through) the entire secondary winding,* we have the condition necessary for *unity coupling,* and the load will be "felt" the most by the source. Unity coupling is seldom if ever attained in actual transformers, however, so when engineers secure the closest practical approach they can to unity coupling, they say that they have *tight coupling*. When only a part of this magnetic flux links with all of the secondary winding, the coupling is said to be *loose* or *weak,* and the load will have less effect upon the source. If none of this magnetic flux links with the secondary winding, there is *zero coupling*. Let us consider how tight or weak coupling can be secured in actual coupling transformers, then find out how each type of coupling behaves in actual circuits.

Tight Coupling. When the two wires which form the primary and secondary windings of a coupling transformer are wound side by side on the coil form, as indicated in Fig. *12A*, we have tight coupling, for now practically all of the flux produced by the primary winding must link with or pass through the entire secondary winding. In ultra-high frequency apparatus, the same result is often secured by using one or more turns of copper tubing as the primary coil, and threading an insulated wire through this tubing to serve as the secondary coil; this is illustrated in Fig. *12B*. When an iron core is used, as in Fig. *12C*, tight coupling is secured without the necessity for having the turns of the two windings close together; in fact, the primary and secondary may be two separate coils placed one inside or alongside the other, as long as all of the magnetic flux passes through both coils. Iron cores are most extensively used in coupling transformers designed for audio amplifier circuits.

How Tight Coupling Behaves. We know that a source can "feel" the presence of a load to which it is connected by a coupling transformer, but exactly what does the source "feel" when the coupling is tight and various loads are used? This is quite an important question, for it determines how much current the source will have to deliver.

Let us consider a resistance load first; experiments show that a resistance load connected across the secondary of a coupling transformer as in Fig. *13A* acts the same as a resistance connected across the primary (Fig. *13B*). The value of this primary resistor R_P may be quite different from the value of R in some cases.

When a coil L is used as load, we have the circuit of Fig. *13C*. This inductive load acts the same as a condenser connected across the primary (Fig. *13D*).

When a condenser C is used as load, we have the circuit of Fig. *13E*. This capacitance load acts the same as a coil L_P connected across the primary (Fig. *13F*).

When the effects of a load are transferred through a coupling coil in this way, engineers say that the load is *reflected* into the primary circuit. Thus a resistance load reflects as a resistance, a condenser load reflects as a coil, and a coil load reflects as a condenser. With tight coupling, the primary and secondary coils are out of the picture as far as direct effects on the source are concerned, for the secondary coil reflects into the primary as a condenser whose reactance cancels out the reactance of the primary coil.

If the load is some combination of R, L and C, then each component of the load will be reflected in the manner described above. When the load contains both L and C in series, and their reactances are equal, we have a series resonant circuit which acts as a resistor at resonance and will therefore be reflected as a resistor. If these reactances are not exactly equal, they will only partially balance each other, and that which is the larger will be reflected in the usual way.

Loose Coupling. Radio frequency transformers built for radio receivers commonly use loose coupling. The two coils are generally arranged in one of the two ways shown in Fig. *14,* so there is considerable space between the coils. Only a small fraction of the magnetic flux thus links with the secondary coil.

How Loose Coupling Behaves. When two coils are loosely coupled to each other, we really have the condition where a small part of the primary coil is *tightly coupled* with a small part of the secondary coil. This leaves us in the primary circuit an entirely separate coil which is smaller in effective size than the original primary coil; in the secondary circuit we have another separate coil (not coupled to anything) which is

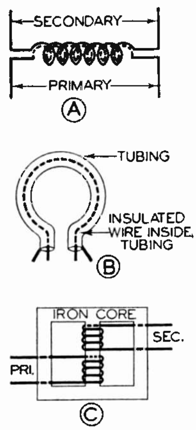

FIG. 12. Three examples of tight coupling.

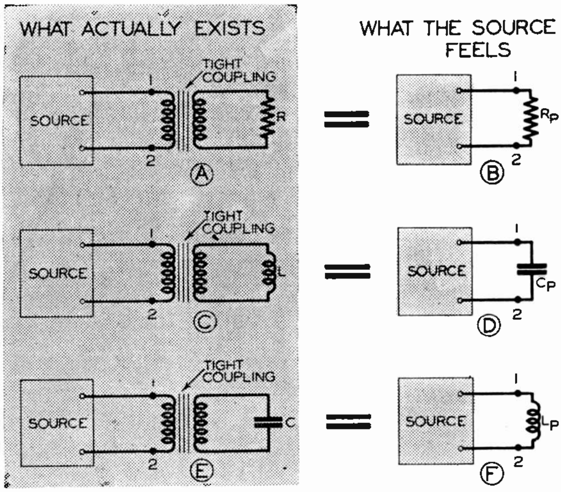

FIG. 13. These diagrams tell you what the source feels when various loads are connected across the coupling transformer in the case of tight coupling.

smaller than the original secondary coil, and our two circuits are coupled together by a tightly-coupled transformer. These extra inductances, each acting alone, are known as the *primary leakage inductance* and the *secondary leakage inductance* because they are due to the magnetic flux which *leaks off* without linking the other coil.

In Fig. *6C* we have an excellent example of a circuit which uses loose coupling. Here the reactance of *C* is adjusted to cancel the secondary leakage inductance, so all we have left in the secondary circuit is the resonant resistance. This load resistance is, of course, reflected into the primary circuit as a resistance of different value, where it acts in series with the primary leakage inductance (usually negligible) as the effective load for the signal source.

As you learn more about radio apparatus, you will see how important is this left-over or leakage inductance in the actual operation of radio circuits which employ loose coupling. You will discover, for instance, that moving the original coils closer together increases the coupling, reduces the values of these leakage inductances, and affects the operation of the circuit in many other ways.

Ratings for Coupling Transformers. Although a knowledge of *how* coupling transformers act under various conditions is generally sufficient for ordinary radio work, there is a possibility that some day you may want to know *how much* voltage you can secure, or *how much* better one coupling transformer will be than another for a particular purpose. I can explain in a few words the ratings which tell you this information for any type of inductive coupling; you will find that they are very similar to the already-familiar ratings for ordinary coils.

You know that when a current of *one ampere* is sent through an ordinary resistor, the resulting voltage drop across the resistor will be exactly equal to its *resistance in ohms.* (This is Ohm's Law: $R = E \div I$, and I here is 1, so $R = E$.)

Furthermore, you know that when an alternating current of *one ampere* is sent through a perfect coil, the resulting voltage drop across the coil will be exactly equal to the *inductive reactance in ohms* of the coil (Ohm's Law for A.C. circuits). Dividing this inductive reactance by the frequency in cycles and then by the number 6.28 gives the *inductance in henrys* of the coil.

Likewise, when an alternating current of *one ampere* is sent through the primary coil of a coupling transformer, the voltage across the secondary coil will be equal to what is known as the *mutual reactance* in ohms of the coupling transformer. Dividing this mutual reactance by the frequency in cycles and then by the number 6.28 gives the *mutual inductance* in henrys of the coupling transformer.

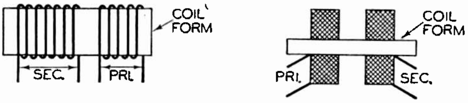

FIG. 14. Two types of loose coupling.

The mutual inductance rating, expressed in henrys, millihenrys or microhenrys, expresses the characteristics of a coupling transformer independently of frequency. Knowing the mutual inductance in henrys, you need only multiply together its value, the primary current in amperes, the frequency in cycles and the number 6.28 to get the secondary voltage.

The mutual inductance (commonly designated as M) of a coupling transformer depends upon the inductances of the two coils and upon how good the coupling is between them. Separating the coils weakens the coupling, thus lowering the value of M. The *coefficient of coupling* is a term commonly used to tell how good the coupling is; with perfect coupling (all flux linking both coils) this coefficient of coupling K is *1*, and it reduces gradually to zero as the coils are separated. The fact may be of value to you at some time; the coefficient of coupling K is actually the mutual inductance of a coil divided by the maximum possible mutual inductance (tight or unity coupling).

VARIABLE INDUCTANCES

The tuning of radio circuits is such an important matter for practical radio men that I want you to know how it is actually accomplished. You know that a circuit can be tuned either by varying the capacity of the condenser or the inductance of the coil, but how do we actually go about varying these things? You are already familiar with variable condensers, since they have been fully covered earlier in the Course, so I will concentrate upon the design, construction and adjustment of variable inductances.

Methods of Varying the Inductance of a Coil. You will recall that anything which increases or decreases the magnetic flux linkage per ampere of current flowing through a coil will increase or decrease the inductance of the coil; for example, increasing the number of turns on the coil increases its inductance, and increasing the amount of flux flowing through the coil likewise increases its inductance. One way of building a variable inductance, then, is to use a coil which has the number of turns required to give the maximum desired inductance for a circuit, and provide some means for using fewer turns in order to reduce the inductance in the circuit. One scheme which has been widely used for this purpose is shown in Fig. *15A*; here various turns on the coil are connected by means of wire leads (taps) to metal contacts over which a contact arm moves, thus permitting the operator to select as many or as few turns as he requires.

Earlier radio receivers used this tapped inductance extensively, while a variation of it is still being used in transmitters. Figure *15B* shows a

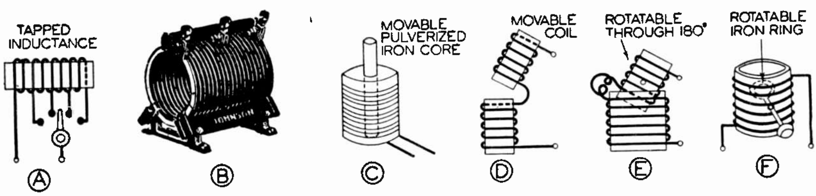

Fig. 15. Methods of varying the inductance of a coil.

transmitting coil with movable clamp type contacts which can be placed on any desired turns. Only those turns which carry current are effective in producing flux linkages.

You can increase flux through a coil and thereby increase its inductance by placing inside the coil a material which offers less opposition than air to the flow of magnetic lines of force. Iron and steel are good magnetic conductors; sometimes silicon, another material, is mixed with the iron or steel to improve its magnetic characteristics. Thus the inductance of an air-core coil will increase when an iron rod is placed inside the coil.

The high inductance of iron-core coils is secured in this way; for low frequencies, iron and steel in either solid or laminated form are satisfactory, but for radio frequencies, solid and laminated cores act like a multitude of tiny short-circuited secondary coils which serve to reduce the useful magnetic flux. Radio manufacturers are getting around this difficulty by pulverizing the steel core material and mixing this steel powder with liquid bakelite (a good insulator). The resulting mixture can be molded into a core of the desired shape for use with radio frequency coils, as the metal particles are insulated from each other by the bakelite. If the core is so designed that it can be moved in and out of the coil, as indicated in Fig. *15C,* we have another form of variable inductance.

Two coils are often connected together in series. If the coils are some distance apart, so that there is no mutual inductance between them, their combined inductance is the sum of the separate inductances. As the coils are moved closer to each other, so that the flux of one links the turns of the other, the combined inductance will increase if the two fluxes are in the same direction and will decrease if the two fluxes are in opposite directions. This is illustrated in Fig. *15D*; by making one of the coils smaller and mounting it on a shaft inside the other, as shown in Fig. *15E,* it is possible, by rotating the inner coil, to vary the combined inductance from a value almost equal to twice the sum of the individual inductances to a value equal to about twice the difference between the individual inductances. When the coils are so arranged that their currents flow in the same direction, the fluxes will be in the same direction and the combined inductance will be high; when the coil is turned half way around (180 degrees) so that the currents flow in opposite directions, the fluxes will oppose each other and the inductance will be greatly reduced. Rotating the inner coil varies the combined inductance from the minimum to the maximum value. A variable inductance of this type is known as a *variometer.*

You can measure the mutual inductance between any two coils having a fixed relation to each other by measuring their combined inductance when connected in series, measuring the inductance again when the connections to one of the coils are reversed, finding the difference between the two measured values and dividing this difference by 4 to get the mutual inductance at that setting.

Another method of constructing a variable inductance is illustrated in Fig. *15F.* A rotatable metal ring is mounted in the center of the core; when this ring is at right angles to the axis of the coil, it acts as a short-circuited secondary winding having one turn, and produces a flux which partially balances out the coil flux, reducing the inductance of the coil. Rotating the ring lessens the amount of flux which can induce a voltage in the ring, thus reducing the "bucking" effect of the flux produced by the ring and increasing the coil inductance. A metal disc will work equally as well as a ring in this variable inductance, for a disc really consists of a great many rings, one inside the other. A very important fact to remember is that the presence of any conducting material near a coil, such as a metal shield surrounding a coil, will reduce the inductance.

Looking Forward. Now that we have a general understanding of resistors, coils, condensers, vacuum tubes and tuned circuits, we can proceed to connect all these into actual vacuum tube circuits and study their operation in connection with tubes. This we will do in our next lesson, in which I will introduce you to a number of typical circuits actually being used in radio receivers and other radio apparatus. I have an idea that you will be greatly surprised, after you have completed your study of this next lesson, at how much you have learned from the first ten lessons in your Course.

TEST QUESTIONS

Be sure to number your Answer Sheet 9FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Name the two distinct types of resonant circuits.
2. What is meant by the resonant voltage step-up of a series resonant circuit?
3. Will increasing the value of either L or C lower the resonant frequency of a series resonant circuit?
4. What well-known radio part does a parallel resonant circuit behave like at resonance?
5. What happens to the resonant resistance of a parallel resonant circuit when the resistance of the coil is increased?
6. When the source for a resonant circuit is connected directly in parallel with both the coil and the condenser, what type of resonant circuit do we have?
7. Name the four simple methods of coupling an antenna to a single resonant circuit.
8. What condition is necessary for unity coupling in a transformer?
9. Is loose coupling commonly used in the radio frequency transformers built for radio receivers?
10. What will happen to the inductance of an air-core coil when an iron rod is placed inside the coil?

RADIO AND ELECTRONIC TUBES AT WORK IN TYPICAL CIRCUITS

10FR-3

PIONEER HOME STUDY RADIO SCHOOL

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WASHINGTON, D.C.

ENTHUSIASM

Starting work in a new field of endeavor just naturally arouses an intense and eager interest in what you are doing—an enthusiasm which not only makes study and work a pleasure, but also betters the chances for success.

My students have enthusiasm for their Course of training because it is preparing them for a definite goal—an independent business or a good job. Those who have already had experience with radio and electricity are continually finding, in the lessons studied, explanations for mysteries which they have encountered; discovering immediate uses for fundamental facts keeps their enthusiasm high. Many find that the experimental units supplied with the Course give inspiration in themselves by proving the truths of the basic radio principles given in the lesson texts.

A real and lasting enthusiasm for radio will make your study and work as pleasant as play, and will make your life much happier.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
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Radio and Electronic Tubes at Work in Typical Circuits

TUBES OPERATE ONLY IN CIRCUITS

AN electronic tube demands two things in order to do its work—the correct operating voltages and *a suitable circuit.* There is a particular tube circuit for each purpose in radio and television receivers and transmitters and in photoelectric control systems; some tube circuits are best at amplifying voltages, while others are designed to amplify power, generate A.C. currents, change A.C. to D.C. or mix a sound or picture signal with (or separate it from) an R.F. carrier.

In this lesson I have two purposes in mind—to show you the importance of circuits in making tubes accomplish desired functions, and to explain how certain characteristics of tubes make them suited for particular jobs. Although tubes with two, three and four grids are better than single grid (triode) tubes for certain purposes, the extra grids do not change the basic operating features of a circuit. In this lesson, therefore, I will consider only *diode* and *triode* tubes, in order that you can concentrate upon the important features of each circuit without becoming confused by extra grids.

The superheterodyne receiver proves ideal for study in this lesson, since it contains examples of almost every one of the common jobs for electronic tubes. After giving you a sort of "bird's-eye view" of the entire receiver, I will take up in detail each tube circuit; then, when I assemble the various circuits into a complete diagram again, you will have made a start towards mastering one of the most important circuits in radio. I will also take up a few special tube circuits not found in superheterodynes.

Block Diagram of a Superheterodyne Receiver. The block diagram in Fig. *1* shows that the essential sections or stages of a superheterodyne receiver are the same for television as for sound reception. The antenna-ground system intercepts the radio waves (which are modulated with either a sound or picture signal) and feeds a modulated R.F. carrier current into the first section, the *R.F. amplifier.* This section not only amplifies (strengthens) the desired carrier but also tunes out or rejects, to a certain extent, all other carriers (coming from different transmitting stations) picked up by the antenna.

This amplification and tuning of the carrier signal could, of course, be repeated in additional similar R.F. amplifier stages, but much better results can be obtained with amplifier circuits operating at *lower radio frequencies,* especially if all signals are amplified at *one fixed low radio frequency.* Briefly, the important function of a superheterodyne circuit is: *The superheterodyne circuit mixes an incoming A.C. signal with a local*

A.C. signal in order to produce a lower frequency signal which can more readily be amplified by the intermediate frequency (I.F.) amplifier section.

The modulation (the sound or picture signal) can be made to ride on a lower radio frequency by mixing the modulated R.F. carrier with another R.F. signal (produced in the receiver) and sending the mixture of signals through a detector circuit. Out of the detector come many different signal frequencies but only one of these, the low R.F. signal which is equal to the *difference* between the two signal frequencies fed to the detector, is selected for further amplification.

The block diagram in Fig. *1* illustrates how this frequency reduction process is carried out; the mixer-first detector section gets the modulated R.F. signal from the R.F. amplifier, and gets the other R.F. signal (unmodulated) from the *local R.F. oscillator* stage. (The mixer-first detector and the R.F. oscillator are together known as the *frequency converter;* in

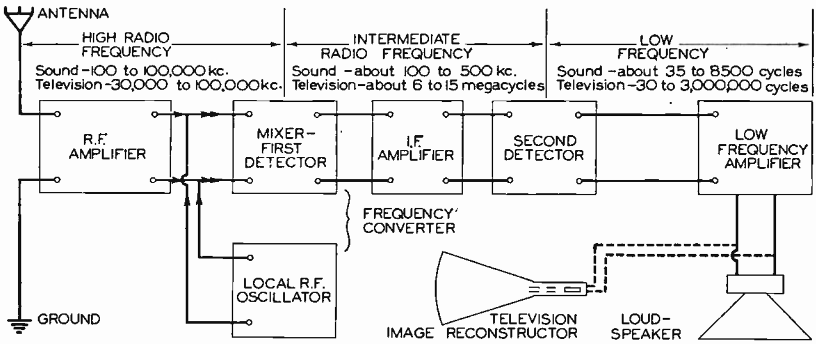


FIG. 1. Block diagram of an ordinary superheterodyne receiver, showing range of frequencies present in each stage. A television receiver has the same operating principle as a sound receiver, except that in the television receiver both the carrier and the modulation signals for the video and the carrier for the audio signal are much higher in frequency than the signals encountered in sound receivers. The image reconstructor is often connected directly to the output of the detector, as it requires merely a high voltage swing (variation) and very little power. The tubes in each section must be supplied with A.C. or D.C. filament power and the electrodes supplied with D.C. voltages.

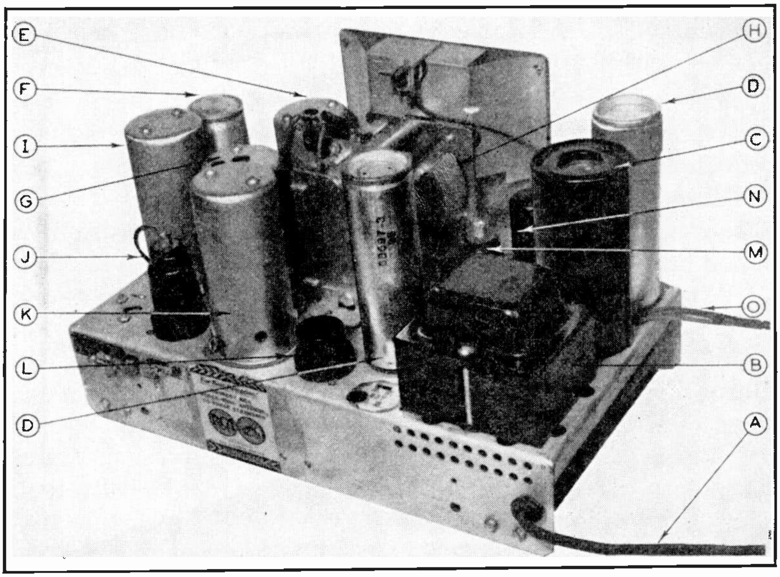
many superheterodynes a single tube, a pentagrid converter, serves both functions and is therefore called a frequency converter tube.) The R.F. amplifier and the local oscillator are tuned together by a single control (which rotates the gang tuning condenser), making the modulated low R.F. output of the mixer *the same value* regardless of the frequency of the transmitter to which the receiver is tuned; this fixed value is known as the *intermediate frequency* (abbreviated I.F.). The I.F. is always the difference between the two R.F. values.*

The *I.F. amplifier* may contain a number of I.F. stages, each adjusted to the *selected I.F.* value (which generally is a frequency between 100 kc. and

*Here is an example: If the local oscillator of a certain receiver generates a 1,175 kc. signal when the R.F. section of the receiver is tuned to a 1,000 kc. station, the output of the first detector will contain two new signals, 2,175 and 175 kc.; the latter, the 175 kc. difference frequency, which is further amplified, is called the I.F. value.

500 kc. in ordinary sound broadcast receivers). Finally, when the modulating signal has been given the desired boost in strength while "riding" on the I.F. carrier, it is fed into the *second detector,* a stage which removes (*demodulates* is the technical name) the sound or picture signal from the I.F. carrier.

Only the sound or picture signal is allowed to leave the second detector circuit; if this signal is still a bit too weak to operate a loudspeaker or television image reconstructor, it is first fed through an audio or video *frequency amplifier* containing one or more tube circuits adjusted to act only on the sound or picture signal frequencies.



The chassis of a six-tube all-wave superheterodyne receiver. *A*—110 volt A.C. line cord; *B*—power transformer; *C*—type 80 rectifier tube; *D*—electrolytic filter condensers; *E*—antenna coil; *F*—type 6A8 frequency converter tube (hidden by coil shields); *G*—oscillator coil; *H*—gang tuning condenser; *I*—first I.F. transformer; *J*—type 6K7 first I.F. amplifier tube; *K*—second I.F. transformer; *L*—type 6H6 second detector and AVC tube; *M*—type 6F5 first audio amplifier tube; *N*—type 6F6 power amplifier tube; *O*—loudspeaker cable.

Thus, each section of a "super" contains one or more stages, and each stage contains an electronic tube and its associated circuit. Each tube requires A.C. or D.C. power for its filaments, and pure D.C. voltages for its other electrodes; these voltages are furnished by the power pack (not shown in Fig. *1*).

In addition to showing the important sections of superheterodyne receivers, Fig. *1* also gives the frequencies of the signals usually handled by each section. The variations in construction required by these differences in frequency will be taken up later in the Course; for the present we will concentrate upon the basic features of individual circuits. As you study the following pages, which explain how tubes operate in circuits, keep in mind that you are studying both television and sound receivers.

POWER PACK CIRCUITS

The primary purpose of the power pack in A.C. operated radio or television apparatus is to convert the A.C. line voltage to the various A.C. and D.C. values required by the different electrodes of each tube used. The power pack in the average superhetrodyne receiver has four important parts, each performing a particular job.

1. ***The power transformer,*** **which changes the A.C. line voltage to a higher A.C. value for the rectifier tube and to lower A.C. values for the filaments of all tubes in the apparatus.**
2. ***The rectifier tube,*** **which converts the stepped-up A.C. voltage into a D.C. voltage of a pulsating nature.**
3. ***The filter section,*** **which smooths out or filters the variations in the pulsating D.C. voltage.**
4. ***The voltage divider,*** **which divides the resulting D.C. voltage into the various values required by the grids and plates of individual tubes.**

A typical power pack circuit appears in Fig. *2;* if the superheterodyne receiver represented by Fig. *1* is to operate from an A.C. outlet, this power pack circuit could very well be used. The four important parts of a power pack will now be considered in greater detail.

1. The Power Transformer. An A.C. voltage can very easily be raised or lowered in value by an iron core transformer known as a *power transformer.* When A.C. line voltage (usually 110 volts) is applied to the primary winding (P_1 in Fig. *2*), the voltage induced in a secondary winding will depend upon the number of turns in that winding; if a secondary has more turns than the primary, its voltage will be higher, and if a secondary has fewer turns than the primary, its voltage will be lower than the primary voltage. If three different voltages are required, three secondary windings are generally used. Thus, in Fig. *2* secondary S_1 provides 440 volts A.C., secondary S_2 provides 5.0 volts A.C. for the diode rectifier tube filament *FF,* and secondary S_3 provides 6.3 volts A.C. (across terminals *X* and *Y*) for the filaments of all other tubes in the receiver, these filaments being connected together in parallel.* Graph *A* in Fig. *2* represents the A.C. voltage across the transformer primary, and graph *B* shows the voltage across one of the secondary windings, S_1.

2. The Rectifier Tube. The simplest and easiest way of converting A.C. to D.C. is by means of a diode (two element) tube; under normal operating conditions this tube allows electrons to flow from its cathode *K* to its plate *P* when the A.C. voltage makes the plate *positive,* but completely *blocks* the flow of electrons when the A.C. voltage *reverses its polarity.* The current flow through the tube is therefore as shown at *C* in Fig. *2,* a pulsating direct current.

A rectifier tube is often considered as a special kind of resistor, having a low ohmic value for electrons flowing from cathode to plate, but a very high ohmic value for electrons which try to flow in the opposite direction. For

*These voltage values were selected only for purposes of illustration and will vary in different receivers.

example, in one particular diode rectifier tube (the type 81), the low ohmic value is about 500 ohms and the high ohmic value is about 5,000,000 ohms.

3. The Filter Section. The ability of certain combinations of coils and condensers to filter the variations in a pulsating current or voltage is made use of in power pack circuits; the combination shown in Fig. *2,* consisting of choke coils L_1 and L_2 together with condensers C_1, C_2 and C_3, has proven especially effective. You will note that while the voltage across condenser C_1, shown at *D*, has a pronounced ripple, the voltage at *E* (across C_2) has much less ripple, and that at *F* (across C_3) is practically a pure direct current. As you will learn in other lessons, it is "teamwork" between

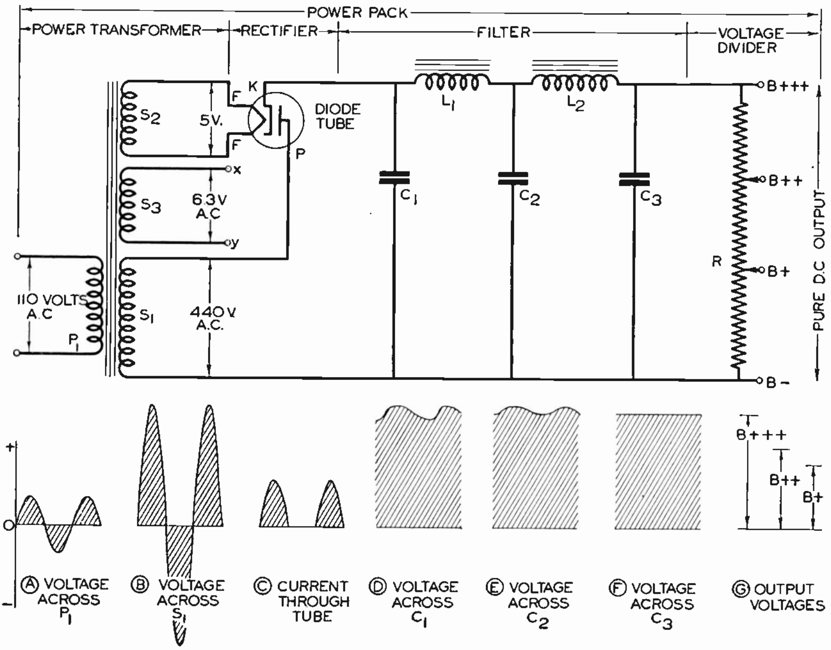


FIG. 2. Schematic circuit diagram of the power pack section of an A.C. operated receiver; half-wave rectification is provided by the diode tube. The series of graphs below the diagram show the wave form of the voltages in each section of the power pack.

coils and condensers which accomplishes this action; the coils block the fluctuations and the condensers "guide" them back to the transformer (by-pass them).

4. The Voltage Divider. A resistor *R* with several taps, connected across the output of the filter, is often used to divide the D.C. output voltage into the required values. The arrangement is shown at the right in Fig. *2,* and the voltage division is represented by graph *G*. The voltage available at any tap depends essentially upon the distance of that tap from the B— end of the voltage-dividing resistor. It is customary, when a power pack has several output voltages, to mark "B+" on the circuit diagram that terminal which has the lowest positive voltage; the next highest voltage is indicated by "B++," the next by "B+++," etc.

ELECTRONIC TUBES AS AMPLIFIERS

Although a superheterodyne receiver contains many different amplifier circuits—R.F., I.F., and audio or picture frequency amplifiers, these tube amplifiers can be divided into two basic types: *1, voltage amplifiers; 2, power amplifiers*. Even these two groups of amplifiers have several things in common, for amplifier tubes do much the same sort of work in any of their circuits.

Voltage Amplifiers and Power Amplifiers. Amplifiers can have one of two purposes: *1,* If an amplifier makes the variable (A.C.) voltage across its load resistor (across R_L in Fig. *3*) much larger than the A.C. grid voltage e_g, it is called a *voltage amplifier; 2,* if an amplifier makes the power in the load resistor as large as possible, it is being operated as a *power amplifier.* The circuits are the same in either case; we can get either large A.C. voltage changes or large A.C. power changes by adjusting the value of load R_L.

Signal Sources for Amplifiers. The signal source which feeds into the grid-cathode terminals of a tube used as a voltage amplifier may be any device capable of supplying a variable voltage which, for purposes of study, can be considered to have a sine wave form.

Photoelectric cells might be signal sources for electronic control amplifiers. *Microphones* are, of course, the signal sources for transmitters, public address amplifiers and for sound recording amplifiers, while *television pick-up tubes* feed A.C. signal voltages to television transmitter amplifiers. The *oscillator,* as you learned in the first part of this text, is a local signal source for superheterodyne receivers; oscillators also serve as signal sources in transmitters and in radio servicing apparatus. *Audio transformers* and *R.F. transformers* are used for coupling amplifiers together or for coupling an amplifier to some load; they therefore do double duty, as loads and as signal sources for amplifiers.

Amplifier Loads. In practical radio circuits you can generally assume that the load on an amplifier, whatever it may be, is *equivalent to* an ordinary resistor.

Resistors themselves often serve as loads for amplifiers, especially in test apparatus and in television circuits. Pilotless airplanes or boats, controlled by radio from a remote location, use *relays* as amplifier loads; the use of *loudspeakers and television image reconstructors* in connection with radio and television receivers respectively is already familiar to you. The *audio transformer* is used as a load where the signal is of an audio (sound) frequency; likewise, the *R.F. transformer* can be a load when R.F. signals are involved.

Similarity of all Amplifiers. Any amplifier, regardless of whether it is used to amplify the grid voltage or to produce a large power change in the load, can be simplified to the circuit in Fig. *3,* even if it contains screen grid or pentode tubes, because the principles of operation of all amplifiers are essentially the same as for this simple triode amplifier circuit. We are most interested in *how the plate current of an amplifier circuit can be changed,* for the more we can change this current, the greater will be the voltage or power change in the load resistor.

A Simple Amplifier Circuit. A study of the typical amplifier circuit given in Fig. *3* will bring out a few of the things which amplifiers have in common and will at the same time serve as an introduction to tube characteristic ratings. First of all, notice that there are two voltages acting upon the grid—the fixed D.C. voltage E_g, supplied by the C battery and called the *operating grid voltage* or the *C bias voltage,* and the A.C. *signal voltage* e_g, supplied by the signal source; together these grid voltages serve to produce a *pulsating direct current* i_p in the plate circuit. This current produces, across load R_L in the plate circuit, a pulsating voltage whose A.C. component v_L has the same wave form as the A.C. signal voltage e_g. Con-

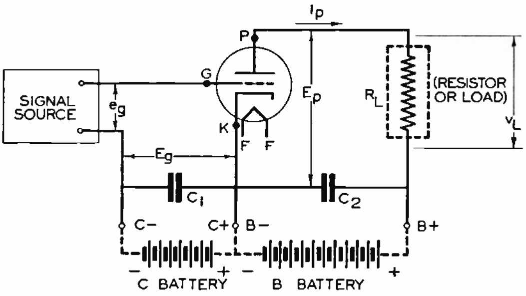


FIG. 3. A simple voltage amplifier circuit feeding into a resistance load. Since the filament of the tube serves only to heat the cathode, its connections to a power supply are not shown and no attention need be given it.

densers C_1 and C_2 simply provide low impedance paths to the cathode for the A.C. currents, keeping these currents out of the batteries. Incidentally, a power pack could be used in place of the B and C batteries if desired.

Let us consider the actual effect of the signal voltage e_g on the grid of the tube in this basic amplifier circuit (Fig. *3*). Since the A.C. signal voltage has a sine wave form and varies from a maximum positive value to a maximum negative value, a little thought will show you that e_g acts as a variable voltage which alternately increases and decreases the effect of the C battery voltage E_g upon the grid. In studying an amplifier circuit, we can vary the grid bias voltage E_g in steps and get the same plate current variations as would be produced by the A.C. signal voltage; the variations will, however, be in "slow motion."

A Tube Testing Circuit. We cannot effectively study the behavior of a tube by placing it in an amplifier circuit like Fig. *3,* for the resistance load R_L in this circuit would give effects which are not wanted when studying only the tube. The test circuit in Fig. *4,* having no load, is far better for study purposes; after the desired tube performance data has been secured by means of this circuit, the load can be taken into account with no difficulty, as you will shortly see.

A Family of E_g-I_p (Grid Voltage-Plate Current) Curves. If we assemble a tube testing circuit in the manner shown in Fig. *4*, we can secure some very valuable data on the behavior of the tube as an amplifier. With P_2 fixed, giving a definite plate voltage, we can vary the *grid voltage* from zero to a maximum negative value by moving P_1 from *1* to *2*, and measure (with the meters shown) the value of plate current for each new grid voltage. By plotting the results on a graph, we get the E_g-I_p characteristic of the tube for one value of plate voltage; this E_g-I_p characteristic curve tells you directly *how the plate current will vary when the grid voltage is varied.* If the testing procedure is repeated for other values of plate voltage by changing the position of P_2, a series or *family* of E_g-I_p *characteristic curves* is obtained, as shown in Fig. *5A*.

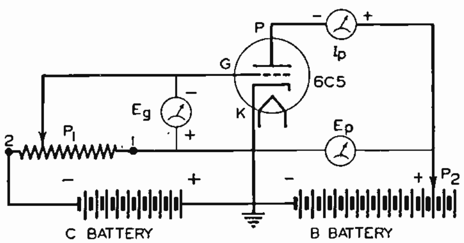


FIG. 4. A simple circuit for measuring the characteristics of the 6C5 all-metal triode (or any other triode vacuum tube).

A Family of E_p-I_p (Plate Voltage-Plate Current) Curves. Some radio designers prefer to know how *plate voltage* (rather than grid voltage) causes plate current to vary; a family of curves giving this information can also be secured with the circuit of Fig. *4*. With P_1 set to a definite value, readings of plate current are taken as P_2 is adjusted to vary the plate voltage from zero to its maximum value; by repeating this procedure for representative values of E_g, sufficient data can be obtained to plot a family of E_p-I_p *characteristic curves* simliar to that shown in Fig. *5B*. An E_p-I_p curve tells directly how the plate current will vary when the plate voltage is varied.

With a family of E_g-I_p or E_p-I_p characteristic curves, you can quickly determine the three important and inter-related electrical values of an amplifier circuit: *1, the D.C. grid bias voltage E_g; 2, the D.C. plate current I_p; 3, the D.C. plate voltage E_p.* If any two of these values are known, the third must be the definite value which is given by either family of curves. For example, if you know that E_g is —10 volts and E_p is 250 volts for a 6C5 tube, either Fig. *5A* or *5B* will tell you that I_p is 4.6 ma., *P* being the operating point.

TUBE CURRENTS AND VOLTAGES

It is important that you have a clear understanding of how changes in grid voltage produce changes in the plate current of an amplifier tube, and how A.C. values of voltage and current enter into the study of tube circuits.

Effect of Grid Voltage on Plate Current. Any tube used as an amplifier must have an operating C bias (a D.C. grid voltage) which, when a definite D.C. plate voltage is applied, determines what the D.C. plate current (the operating plate current) will be when no A.C. signal is applied to the grid. The application of an A.C. signal to the grid makes the resulting grid voltage alternately more or less negative than the operating *C* bias; we actually have a pulsating D.C. voltage on the grid. Figure *6* illustrates these facts; point *S* on the E_g-I_p curve shown in Fig. *6B* is the *operating point* in this

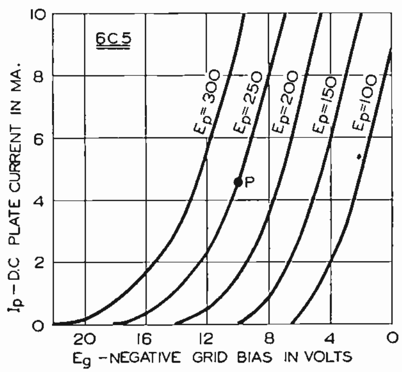


FIG. 5A. Family of E_g-I_p characteristic curves for a 6C5 radio tube.

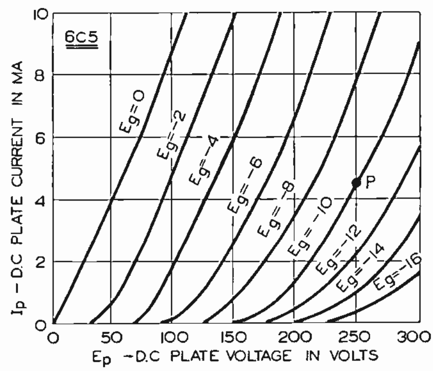


FIG. 5B. Family of E_p-I_p characteristic curves for a 6C5 radio tube.

example and corresponds to an operating C bias of —3.5 volts. If the sinusoidal* A.C. voltage shown in Fig. *6A* is applied to the grid, the resulting pulsating grid voltage will be made up of *x*, the D.C. or fixed component, plus or minus *y*, the A.C. or varying component at a particular instant.

Naturally this varying grid voltage will cause the plate current to vary also; the E_g-I_p curve in Fig. *6B* can tell how it will vary. Starting at point *1* in Fig. *6A*, trace vertically upwards to the corresponding point *1* (or *S*) in Fig. *6B*, and move horizontally from here to point *1* in Fig. *6C*. Now, if you change the grid voltage by moving from point *1* to point *2* in Fig. *6A*, you can determine the effect of this upon plate current by tracing up to point *2* in Fig. *6B*, then over to point *2* in Fig. *6C*. This procedure can be repeated for other values of grid voltage, such as those for points *3*, *4* and *5*. You will see that the plate current also varies sinusoidally (provided the E_g-I_p characteristic is linear—is a straight line between points *2* and *4*, the limits of the operating range). Another important point to observe is that the plate current is a pulsating direct current (which varies in value above

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***Having a sine wave form.**

and below its operating value but never changes its direction), having v as the D.C. component and w as the A.C. component at any instant.

Practical radio men usually consider A.C. values of grid voltage and plate current to be of sinusoidal wave form, because sine waves are simpler to study and because currents and voltages produced by the signal generators used for testing are sinusoidal in form. Although I have, up to this point, only considered sine wave signals in connection with the study of tubes at work, I have included the diagram in Fig. 7 to show you what takes place in a practical case. The signal voltage e_g, a complex signal which is irregular in wave form but is actually made up of a large number

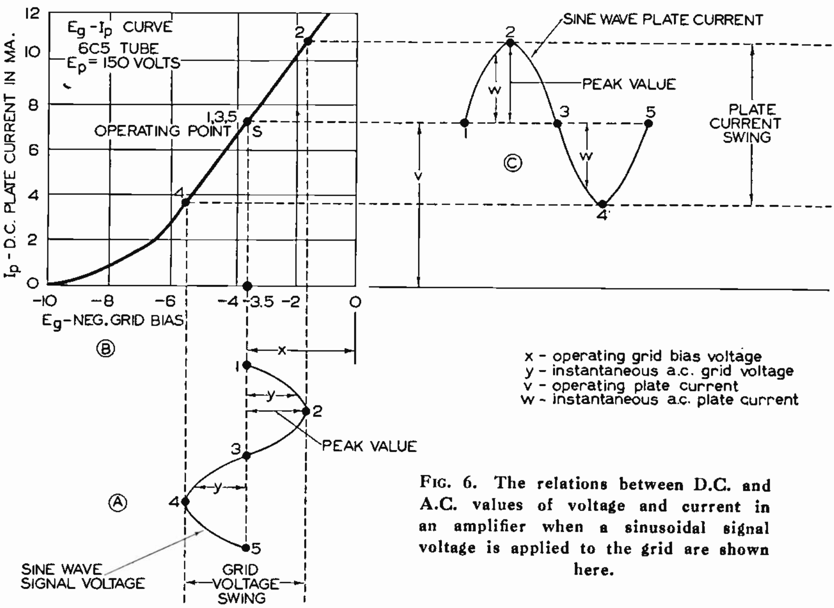


Fig. 6. The relations between D.C. and A.C. values of voltage and current in an amplifier when a sinusoidal signal voltage is applied to the grid are shown here.

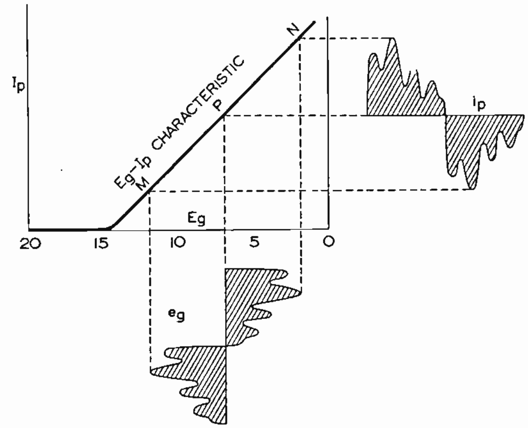
of simple sine wave components, might be that delivered by a microphone or television pick-up camera; when this signal voltage is fed into a tube having the E_g-I_p characteristic shown, the plate current i_p passed by the tube will have exactly this same wave form. This is because we are operating the tube on the straight line portion of the curve (the operating point being at P, midway between points M and N).

Meters in Tube Circuits. When we connect D.C. voltmeters and milliammeters into a tube circuit, we measure *D.C. values.* When we connect A.C. meters, using the proper precautions to keep D.C. components out of the meters (such as placing a low reactance condenser in series with the meter), we measure the *A.C. values.* Thus, when we speak of A.C. grid voltage or A.C. plate current, we really mean the *A.C.* component of the pulsating grid voltage or pulsating plate current—the component which can be measured with A.C. meters. It is perfectly correct to consider these A.C.

components independently of the D.C. components, for in an amplifier tube circuit they act on circuit parts quite independently of each other.

Swing, Peak and R.M.S. Values. The maximum or total change in a voltage or current is called its *swing;* thus the grid voltage change between points *2* and *4* in Fig. *6A* is called the *grid voltage swing,* and the plate current change between points *2* and *4* is called the *plate current swing.* The *peak value* of the A.C. component is equal to one-half the swing value in either case, as you can see. You will remember that an A.C. meter measures effective or r.m.s. values, which are peak values divided by 1.414. A D.C. voltmeter connected between grid and cathode of a tube in an amplifying circuit would thus read value *x,* while an A.C. voltmeter connected in the same way would read the r.m.s. value, equal to the peak A.C. value divided

FIG. 7. The signal currents handled by most radio and television tubes have irregular wave forms much like that shown here for e_g. It can be proven by mathematics, however, that any wave, no matter how complicated, can be broken up into a number of simple sine waves. We can simplify our work by considering only sine wave signals, for we know that the radio circuits will behave the same for one sine wave as for many.



by 1.414; a D.C. ammeter in the plate circuit would read value *v,* while an A.C. ammeter would read the r.m.s. value of current (equal to the peak A.C. value divided by 1.414).

IMPORTANT TUBE RATINGS

Although a family of curves can tell anything you may want to know about the behavior of a tube, radio men prefer a simpler way of describing tube characteristics. "Horsepower," "maximum speed" and "gasoline consumption" are three ratings which tell a great deal about the performance of an automobile; it is likewise possible to describe the behavior of a radio tube with two important ratings: *1, amplification factor; 2, A.C. plate resistance.* A third rating, *mutual conductance,* is a combination of the first two ratings.

1. **AMPLIFICATION FACTOR.** A family of E_g-I_p curves can tell you how much more effective the grid is than the plate in controlling plate current, but it is by no means convenient to puzzle over curves every time you want this information about a tube. What we want is a single rating which tells us how good a tube is as an *amplifier.*

Referring to the simple amplifier circuit (without a load) in Fig. *4,* suppose that a change in grid voltage E_g causes a certain change in plate current I_p; it is perfectly possible to return the grid voltage to its former value and adjust the plate voltage E_p until this same change in plate current is produced; the plate voltage change required will naturally be larger than the grid voltage change. Figure *8,* showing two curves taken from Fig. *5A,* will illustrate what I mean; if the 6C5 tube is operating at point *a,* a plate current increase of 4 ma. can be obtained by changing the grid voltage 2.5 volts(from *a* to *c*) or by increasing the plate voltage 50 volts (from *a* to *b;* curve *A* is for a plate voltage 50 volts higher than that for curve *B*). If we divide 50 by 2.5 we get 20; this value, showing that the grid is 20 times as effective as the plate (in this particular case) is called the *amplification factor.* In plain language, it means that a one-volt grid change will affect the plate current just as much as a 20 volt plate change.

AMPLIFICATION FACTOR does not tell directly how much the grid controls plate current, but it does express the relative effects of the grid and plate voltage on plate current.

Amplification factor is equal to the plate voltage change which will produce a certain plate current change, divided by the grid voltage change which will produce that same plate current change.

Amplification factor (also called *amplification ability, amplification number* or *amplification constant*) is generally designated by the Greek letter mu (μ), which is pronounced "mew." Amplification factor is essentially dependent upon the construction of a tube, and particularly upon the position of the grid between cathode and plate and upon the spacings between the meshes or turns of the grid wires. The closer the grid is to the cathode and the closer together the grid wires are, the larger will be the μ of a tube, because the grid will have greater control over the space charge.

Average values of μ for a particular type of tube are given on tube charts, but even tubes of the same type may vary as much as 20% from the rated value of μ. This deviation from the rated value applies to other tube ratings as well, for radio tubes are delicate devices, so compactly designed that errors of a few thousandths of an inch in the position of an electrode will greatly affect the tube ratings. These differences in tube characteristics are permitted because their elimination would greatly increase the cost of making a tube and because close similarity is generally not required.

2. **A.C. PLATE RESISTANCE.** The opposition which the plate-cathode path in a tube offers to the flow of A.C. can be obtained with Ohm's Law if the *A.C. plate voltage* and the *A.C. plate current* are known.

Equivalent A.C. Plate Voltage. Before going any further, I will explain what is meant by *A.C. plate voltage.* You know that an A.C. grid voltage acting in one circuit of a tube produces an A.C. plate current in another circuit (this fact was shown by Fig. *6*) ; thus we are dealing with two different circuits connected together only by the action of a tube. It is always simpler to study a single circuit at a time; for this reason it is common practice to transfer the effect of the A.C. grid voltage to the plate circuit. Since a plate voltage change is equal to a grid voltage change multiplied by the μ of the tube, we say that the A.C. grid voltage e_g multiplied by the μ of the tube is the *equivalent A.C. plate voltage.* Now we can consider this *equivalent A.C. plate voltage* just as if it were an actual voltage; in

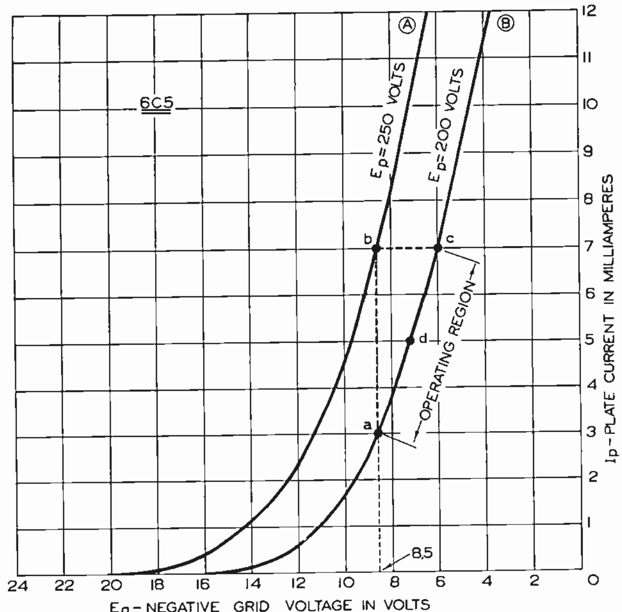


FIG. 8. The three important tube characteristic ratings for a 6C5 tube—amplification factor, A.C. plate resistance and mutual conductance, can be obtained from these two E_g-I_p characteristic curves, taken from Fig. 5A. Similar curves are available for all tubes having grids; these curves can in each case be used to secure accurate values for the three important ratings.

fact, most engineers speak of it simply as the *A.C. plate voltage.* With this in mind, and remembering how ordinary resistance is defined by Ohm's Law, we are ready for a definition of A.C. plate resistance:

> ***The A.C. plate resistance*** **of a tube is the change in plate voltage divided by the resulting change in plate current, or the A.C. plate voltage divided by the A. C. plate current.**

A.C. plate resistance is expressed in ohms, just as is any other resistance, and is commonly abbreviated as r_p. The value of r_p for a particular tube can be determined easily from the E_g-I_p characteristic. Here is an example: For operating point *d* in Fig. *8,* a grid voltage swing of 2.5 volts (from *a* to *c*) or its equivalent plate voltage change of 50 volts (*a* to *b*) produces a plate current change of 4 ma. (.004 amp.). In this case, then, r_p is equal to 50 ÷ .004 or 12,500 ohms. Tube manufacturers generally give values of r_p at one or more operating points for each type of tube, as this is a very important rating.

D.C. Plate Resistance. A radio tube is peculiar in that it offers a different plate-to-cathode resistance to a steady current than to a varying current. When only a D.C. voltage is applied to the grid, the plate voltage being fixed, a definite value of D.C. plate current will flow; by applying Ohm's Law to the plate circuit (dividing the D.C. plate voltage by the D.C. plate current), we get the *D.C. plate resistance* of the tube for that particular grid bias value. Since changing the grid bias changes the value of plate current and therefore changes the D.C. plate resistance, all operating conditions must be specified when giving a D.C. plate resistance value for a tube. With amplifiers, however, the A.C. behavior of tubes, is important.

rp gm μ

TYPE	NAME	SOCKET CONNECTIONS	CATHODE TYPE ■	FILAMENT OR HEATER VOLTS	FILAMENT OR HEATER AMPERES	PLATE MAX. VOLTS	SCREEN MAX VOLTS	USE Values to right give operating conditions and characteristics for indicated typical use	PLATE SUPPLY VOLTS	GRID VOLTS ■	SCREEN VOLTS	SCREEN MILLIAMP.	PLATE MILLIAMP.	A-C PLATE RESISTANCE OHMS	MUTUAL CONDUCTANCE MICROMHOS	VOLTAGE AMPLIFICATION FACTOR	LOAD FOR STATED POWER OUTPUT OHMS	POWER OUTPUT WATTS
40	VOLTAGE AMPLIFIER TRIODE	FIG. 1	D-C FILAMENT	5.0	0.25	180	—	CLASS A AMPLIFIER	135 ✱ 180 ✱	− 1.5 − 3.0	—	—	0.2 0.2	150000 150000	200 200	30 30	—	—
41	POWER AMPLIFIER PENTODE	FIG. 15A	HEATER	6.3	0.4	250	250	CLASS A AMPLIFIER	100 180 250	− 7.0 − 13.5 − 18.0	100 180 250	1.6 3.0 5.5	9.0 18.5 32.0	103500 81000 68000	1450 1850 2200	150 150 150	12000 9000 7600	0.33 1.50 3.40
42	POWER AMPLIFIER PENTODE	FIG 15A	HEATER	6.3	0.7	250	250	CLASS A AMPLIFIER	250	− 16.5	250	6.5	34.0	100000	2200	220	7000	3.00
43	POWER AMPLIFIER PENTODE	FIG. 15A	HEATER	25.0	0.3	135	135	CLASS A AMPLIFIER	95 135	− 15.0 − 20.0	95 135	4.0 7.0	20.0 34.0	45000 35000	2000 2300	90 80	4500 4000	0.90 2.00
45	POWER AMPLIFIER TRIODE	FIG. 1	FILAMENT	2.5	1.5	275	—	CLASS A AMPLIFIER	180 250 275	− 31.5 − 50.0 − 56.0	—	—	31.0 34.0 36.0	1650 1610 1700	2125 2175 2050	3.5 3.5 3.5	2700 3900 4600	0.82 1.60 2.00
46	DUAL-GRID POWER AMPLIFIER	FIG. 7	FILAMENT	2.5	1.75	250	—	CLASS A AMPLIFIER □	250	− 33.0	—	—	22.0	2380	2350	5.6	6400	1.25
						400	—	CLASS B AMPLIFIER ♦	300 400	0 0	—	—	Power output values are for 2 tubes at indicated plate-to-plate load.				5200 5800	16.0 20.0
47	POWER AMPLIFIER PENTODE	FIG. 6	FILAMENT	2.5	1.75	250	250	CLASS A AMPLIFIER	250	− 16.5	250	6.0	31.0	60000	2500	150	7000	2.7
48	POWER AMPLIFIER TETRODE	FIG. 15	D-C HEATER	30.0	0.4	125	100	CLASS A AMPLIFIER	96 125	− 19.0 − 20.0	96 100	9.0 9.5	52.0 56.0	—— ——	3800 3900	— —	1500 1500	2.0 2.5

Table 1. This section of the RCA Radiotron Chart is typical of the charts issued by various tube manufacturers. Socket connection numbers refer to diagrams appearing on another part of the Chart (not shown in this book).

***3.* MUTUAL CONDUCTANCE.** You are already familiar with the two important tube characteristic ratings, amplification factor and A.C. plate resistance; a third rating, which is a combination of these two, is called *mutual conductance* or *transconductance.* (Mutual conductance is actually equal to amplification factor divided by A.C. plate resistance.) *MUTUAL CONDUCTANCE is the important tube rating* which tells directly *how much the grid controls plate current,* and is defined as follows:

> ***Mutual conductance*** **of a tube is equal to the A.C. plate current divided by the A.C. grid voltage when there is *no load* in the plate circuit.**

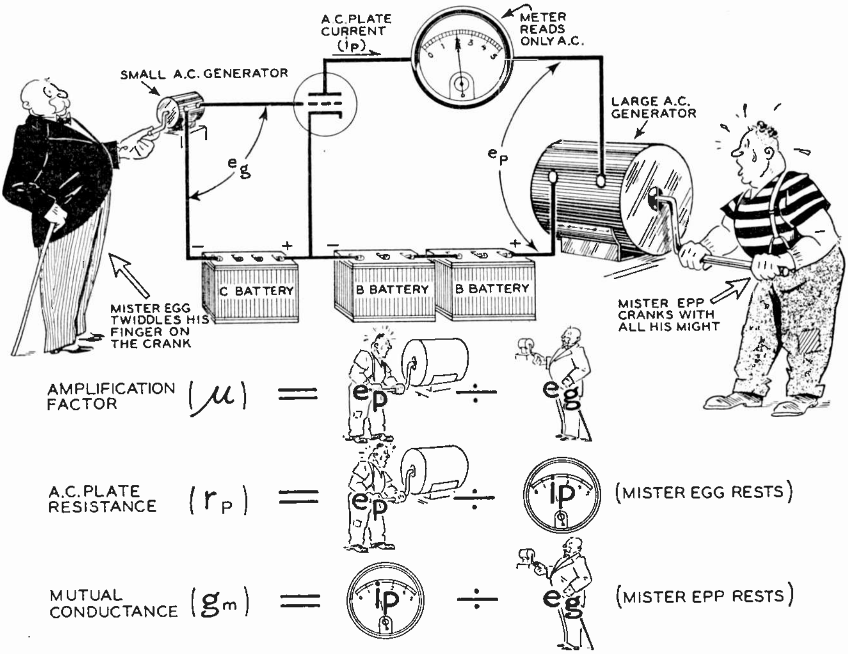
Mutual conductance, abbreviated as g_m (or s_m), is expressed in *mhos* (pronounced "mose"). The A.C. plate current *in amperes* divided by the A.C. grid voltage *in volts* gives g_m in *mhos.** A smaller unit, the *micromho,* is widely used in radio work; it is equal to one millionth of a mho (.000001 mho). Incidentally, "mho" is "ohm" spelled backwards.

Mutual conductance (sometimes known as *transconductance*) is a very important and useful tube characteristic rating, for it tells directly how much change will be produced in A.C. plate current by a 1-volt change in A.C. grid voltage. If the A.C. *grid voltage* in volts and the *mutual conductance* in mhos are known for a tube circuit (such as an amplifier circuit

*Some engineers, especially those outside of the U. S., prefer to express mutual conductance in terms of amperes per volt or microamperes per volt instead of in mhos or micromhos.

whose load has negligible resistance), the A.C. plate current in amperes is obtained simply by *multiplying* the two values together. When a tube ages, its electron emission is lowered and its g_m is reduced; this is why g_m is often measured when testing radio tubes.

Values of mutual conductance are always given on tube charts, but you may be interested in knowing how they can be obtained from E_g-I_p curves.



Here are the three tube characteristic ratings "in a nutshell," demonstrated for you by Mister Egg and Mister Epp. When both gentlemen are resting, no A.C. voltage enters the circuit and the A.C. plate current meter consequently reads zero. Mister Egg now cranks his midget generator fast enough to generate an A.C. voltage e_g of such a value that a previously selected value of A.C. plate current, i_p, flows in the plate circuit and is measured by the A.C. meter. Mister Egg rests again; Mister Epp tries his luck and finds that he has to generate a much larger A.C. voltage, e_p, to get the same A.C. plate current, i_p. The equations below the drawing now give you, in a form that is easy to remember, the three tube characteristic ratings. In these equations each man here represents the A.C. voltage which he must develop, when acting alone, to make the meter read a certain value. Fix this picture diagram in your mind and you'll have no difficulty in remembering what each of these three important ratings means.

In Fig. *8,* a grid voltage change of 2.5 volts produced a plate current change of .004 ampere; since a change corresponds to an A.C. value, the mutual conductance of the 6C5 tube (for operating point *d,* in the middle of the operating region of curve *B*) will be .004 ÷ 2.5, or .0016 mho (1,600 micromhos).

An example of a tube chart which gives the three important characteristic ratings for each tube, as well as other valuable operating information, is given in Table *1.* Note that r_p, g_m and μ vary greatly even among the eight tubes listed.

EQUIVALENT TUBE CIRCUITS

The importance of amplification factor, A.C. plate resistance and mutual conductance is more clearly realized when tube circuits are studied under practical working conditions; this is what we will do next.

A tube is really the connecting link between two important circuits, the grid circuit (in which a change is introduced) and the plate circuit (where the result of the change appears). It is not always convenient to study two separate circuits at the same time, so the practical man combines the two, for purposes of analysis, into one simple circuit called the *equivalent tube circuit.* This circuit deals *only* with the *A.C.* voltages and *A.C.* currents in the plate circuit of the tube.

Equivalent Tube Circuit without Load. First, take the case of an amplifier like that shown in Fig. *4*, which does not have a load in its plate circuit. Remember that we are dealing with *changing* values; the only resistance in the plate circuit is therefore the A.C. plate resistance r_p, and the only A.C. voltage acting on this resistance is the equivalent A.C. plate voltage (equivalent, as far as effects on the plate circuit are concerned, to the

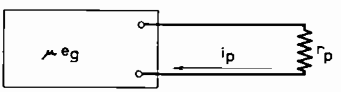


Fig. 9A. A vacuum tube operating without a load in its plate circuit can be represented by this simple A.C. circuit.

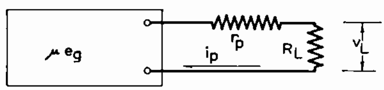


Fig. 9B. Simplified or equivalent circuit diagram of a vacuum tube operating with a load R_L in its plate circuit.

A.C. grid voltage). This simplifies Fig. *4* down to Fig. *9A*, which consists of a source (the A.C. plate voltage) represented by μe_g and a load represented by r_p. The equivalent circuit is, of course, accurate only for the set of operating conditions which correspond to the value of r_p used (since r_p varies quite widely as D.C. operating voltages are changed). This unloaded equivalent circuit is of importance only in connection with the study of the characteristic ratings of a tube.

Equivalent Tube Circuit with Load. When there is a load in the plate circuit, as is the case in Fig. *3*, this load (R_L) is simply placed in series with r_p in the equivalent circuit (Fig. *9B*). The insertion of a load in the plate circuit of an amplifier does not destroy the value of the equivalent tube circuit for analysis, provided that the D.C. operating values for the tube are kept the same. When the load absorbs some of the supply voltage, reducing the plate-to-cathode D.C. voltage, the supply voltage must be increased by the amount of the D.C. load voltage drop. If this precaution is observed, the values of μ and r_p will not be changed by the insertion of the load.

Effects of Load on Tube Output. A load resistor such as R_L in Fig. *9B* adds A.C. resistance to the plate circuit, and since A.C. current flows through it, the A.C. plate current i_p is reduced by a load. The A.C. current flowing through R_L produces across it an A.C. voltage drop v_L; in the case of a voltage amplifier we want this A.C. voltage to be as large as possible, and in case of a power amplifier we want the power absorbed by the load ($v_L \times i_p$) to be as large as possible. By applying Ohm's Law to the equivalent tube circuit in Fig. *9B*, the effects which different values of load have on an amplifier can be determined. For simplicity, we will assume that the tube has an A.C. plate resistance of 10,000 ohms, an amplification factor of 10, and an A.C. grid voltage of 1 volt.

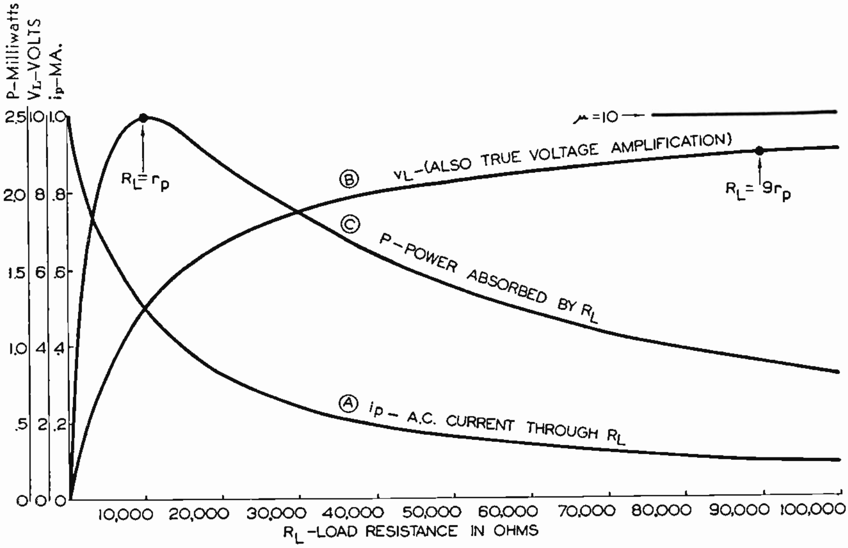


Fig. 10. These curves show the effects of various load resistance values upon the A.C. plate current, the A.C. load voltage, the true voltage amplification and the load power of a tube having a μ of 10, an A.C. plate resistance of 10,000 ohms, and an A.C. grid voltage of one volt. Curve *C* shows clearly that a tube amplifier circuit absorbs maximum power when the resistance of the load is equal to the A.C. plate resistance of the tube.

A.C. Plate Current Curve. From Ohm's Law, the A.C. plate voltage μe_g divided by the total A.C. resistance in the plate circuit ($r_p + R_L$) gives the A.C. plate current i_p. If we calculate this current for various values of load resistance R_L and plot the data on a graph, the result in curve *A* in Fig. *10*.

A.C. Output Voltage Curve. The load voltage is simply the product of i_p and R_L; by multiplying together these values for each size of load resistor considered, data for curve *B* in Fig. *10* is obtained. This curve gives the output voltage for various values of R_L; since we chose a 1 volt A.C. grid voltage, the curve also represents the true voltage amplification of the amplifier stage.

Power Output Curve.. The load power is the product of i_p and v_L, which is the A.C. plate current multiplied by the A.C. load voltage; curve *C* in Fig. *10* is obtained when load power is plotted against load resistance. Although the actual process of computing data for the curves in Fig. *10* is of no great interest to the practical radio man, the information which the curves reveal is very important. These are the facts you should remember:

1. EFFECT OF LOAD ON A.C. PLATE CURRENT:
Inserting a load in the plate circuit of an amplifier *decreases* the A.C. plate current; the greater the ohmic value of the load, the less will be the A.C. plate current.

2. A.C. PLATE CURRENT WHEN R_L IS EQUAL TO r_p:
When the plate load resistance is exactly equal to the A.C. plate resistance, the A.C. plate current will be reduced to *exactly half* its no-load value (the current when R_L is out of the circuit).

3. EFFECT OF LOAD ON AMPLIFICATION:
Increasing the plate load resistance *increases* the true amplification of an amplifier tube (true or over-all amplification is A.C. load voltage divided by A.C. grid voltage); the maximum possible amplification is μ, the amplification factor of the tube, but this limit can never be reached in actual practice. When R_L is equal to r_p, only 50% or ½ the total possible amplification is obtained, and when R_L is 9 times the value of r_p, about 90% of maximum amplification is attained.

4. WHEN MAXIMUM POWER IS ABSORBED BY THE LOAD:
The load in a tube amplifier absorbs maximum power when the resistance of the load is equal to the A.C. plate resistance of the tube; the power then decreases gradually as r_p is further increased. Maximum power output is thus obtained when the load resistor equals or *matches* the A.C. plate resistance.

5. WHEN MAXIMUM AMPLIFICATION IS OBTAINED:
Maximum true or over-all voltage amplification is obtained when R_L is many times larger than r_p.

The importance of duplicating electrical values when replacing parts in a radio receiver is quite evident from the above; when replacing that part which serves as plate load for an amplifier stage, a slightly higher resistance value is permissible when the exact replacement part cannot be obtained.

Distortion. When the wave form of the A.C. plate current is not exactly like the wave form of the A.C. grid voltage, we have signal distortion. It is not enough to get simply a maximum output voltage or maximum power from an amplifier; signal distortion must be limited to an acceptable value. With triode tubes, distortion is less when the load resistor is larger than the A.C. plate resistance, and maximum *undistorted* output power is obtained when the load resistance is about twice the A.C. plate resistance. Fortunately, tube charts give μ, r_p and recommend values of R_L for maximum undistorted power, so busy radio men need not go through tedious calculations to get these values.

TYPICAL AMPLIFIER CIRCUITS

Now that we have made a good start towards understanding the general features of tubes operating as amplifiers, let us consider tubes at work in different superheterodyne receiver circuits and in a number of other amplifier circuits which are widely used in radio and television transmitters and receivers, electronic controls, public address amplifiers and in all forms of communication (such as telephony, telegraphy and wirephoto or facsimile transmission of pictures and messages).

Resistance-Capacitance Amplifier. In Fig. *11A* is an amplifier circuit sometimes found in the audio or video frequency stages of superheterodyne receivers; it uses only resistors and condensers. The plate voltage of the tube is obtained from a D.C. supply, such as a rectifier power pack, connected between B— and B+; part of the supply voltage is dropped in load resistor R_L and a smaller part in cathode bias resistor R_g, the plate-to-cathode path in the tube getting the remainder. Electrons leaving the B—

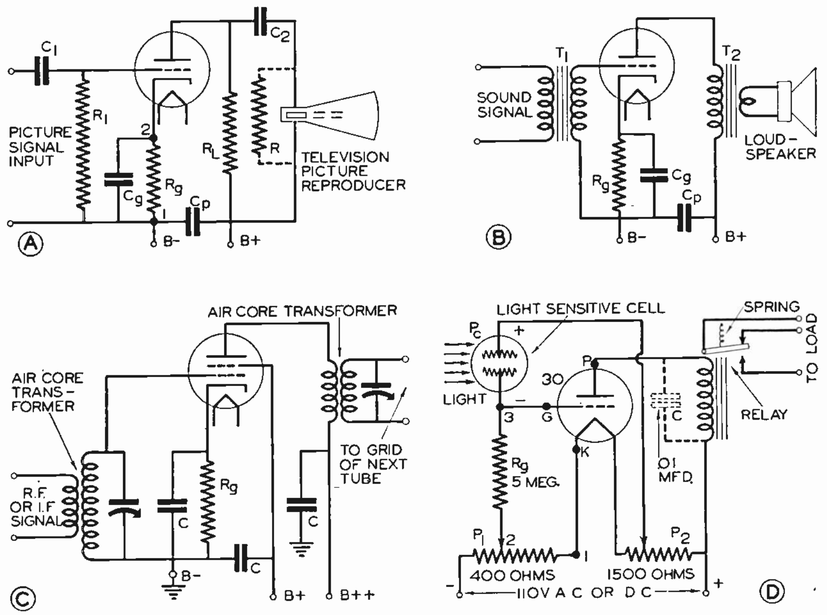


FIG. 11. Four practical amplifier circuits for radio and electronic tubes. In the photo-electric circuit (*D*), condenser *C* is used only when the source is A.C.; it prevents relay chatter.

terminal pass through R_g to point *2*, making point *1* negative with respect to the cathode of the tube. Since the grid is connected to point *1* through grid resistor R_1, the grid is automatically biased negatively with respect to the cathode without using C batteries; this is a practical and widely used way of making the power supply unit furnish *automatic C bias* for a tube. Condenser C_g serves to filter out variations in plate current flowing through R_g; you will always find a condenser like this connected across a grid-cathode bias resistor in a single-tube circuit. Condenser C_p is a low reactance path for the A.C. plate current.

Although this circuit can be used to amplify either the low frequency sound or picture signal, I have shown it connected for television use. The picture signal, fed to the input terminals, is transferred by coupling condenser C_1 to resistor R_1, and the varying voltage drop which it produces in this resistor makes the grid voltage swing above and below the value set by the automatic C bias. The plate current swings in a corresponding manner, producing across load resistor R_L a varying voltage which acts upon the cathode ray image reconstructor tube through coupling condenser C_2. Condenser C_2 also blocks the flow of D.C. plate current to the cathode ray tube. A tube having a high amplification factor gives a high over-all amplification, while a high ohmic value for R_L makes the over-all amplification of the tube approach the limit (the μ of the tube). Resistor R is sometimes placed across the input terminals of the cathode ray tube for circuit-stabilizing purposes. The cathode ray tube may be replaced by another amplifier tube; in this case C_2 would feed into the grid of this extra amplifier tube, giving repeated or what is called *cascade amplification.*

Transformer-Coupled Amplifier. Another important type of amplifier circuit, which is called a *transformer-coupled amplifier* because it uses audio transformers for coupling purposes, is shown in Fig. *11B;* this circuit, in addition to its many other applications, is very extensively used in the audio stages of superheterodyne receivers. The audio frequency input signal current flows through the primary of transformer T_1, and the signal voltage induced in the secondary winding is applied to the grid of the vacuum tube. This causes the plate current to vary, and transformer T_2 transfers the output power to the loudspeaker, which in turn converts the amplified sound signal currents into sound. The loudspeaker is the real load, and the A.C. power which it requires must be furnished by the plate circuit of the tube to the primary of coupling transformer T_2. The effect of the transformer is such that the load appears to be directly in the plate circuit, acting as a resistance which limits the flow of A.C. plate current.*

A transformer like T_2 in Fig. *11B* is preferable to a load resistor like R_L in Fig. *11A* for the plate circuit load, because the primary of a transformer has negligible D.C. resistance and therefore a very low voltage drop; practically the entire supply voltage is thus available for the plate-cathode terminals of the tube. In addition, a transformer can be made to step up the voltage which is fed to it; with voltage amplifiers this is an especially desirable feature. Transformer T_2 in Fig. *11B* must feed power into a low-resistance loudspeaker; this means that the secondary winding must deliver a high current at a low voltage. The vacuum tube, on the other hand, supplies a low current and a high voltage; to match the source with the load, a voltage step-down (current step-up) transformer is used for T_2. If T_2 were feeding into another amplifier stage, a voltage step-up transformer would, of course, be used instead.

The use of iron core transformers like those shown in Fig. *11B* is limited to audio frequency circuits, where the signals involved are below 15,000 cycles per second. Transformer-coupled amplifier circuits like this are to

*The value of this load resistance can be found by dividing the A. C. voltage across the transformer primary by the A.C. current flowing through the transformer primary.

be found in the modulation (sound signal) amplifiers of transmitters, in the audio stages of radio receivers, in the amplifier stages of electric phonographs and in audio amplifiers used in public address systems. In each case the tubes and the operating voltages are selected for the type of amplification desired (voltage or power). The final stage in an audio amplifier system is generally designed for power amplification. For voltage amplification, the effect of the load must be equivalent to that of a resistor of high ohmic value, connected in place of the primary of T_2; for power amplification, the effect of the load must be that of a resistance which matches the A.C. plate resistance of the tube or be of such a value that distortion will not be objectionable.

Tuned R.F. Amplifier Stages. In the radio frequency stages of television and sound transmitters and receivers (superheterodynes as well as T.R.F. circuits), tuned air core transformers like those shown in Fig. *11C* are generally used. Tuned transformers can be adjusted to select (or tune in) only the desired frequencies, and they therefore give desirable selectivity characteristics to the amplifiers; *tuned circuits act like resistors at resonance.* Tuned R.F. amplifier stages can be designed for use either as voltage amplifiers (by using parts which give maximum voltage across the resonant load) or as power amplifiers (by using circuit parts which give maximum transfer of power.)

Amplifiers for Photoelectric Control Systems. Amplifiers are valuable in light-sensitive control circuits, where they amplify the electrical impulses created by the light-sensitive cell when light shining on the cell is varied. A simple photoelectric amplifier circuit is given in Fig. *11D;* it is presented here simply to illustrate one of the special electronic control uses for amplifiers. P_c is a photoconductive or selenium cell, a type of light-sensitive cell whose resistance varies with variations in the light falling on it. The operation of this device is quite simple; when the light beam which is directed upon the light-sensitive cell or "electric eye" by a searchlight is interrupted by some object, the resistance of the cell increases, the vacuum tube amplifies the resulting change in current through resistor R_g by producing a plate current change, and the relay in the plate circuit of the amplifier tube opens or closes the circuit to the load which is to be controlled.

Here is how the "electric eye" amplifier circuit works. Potentiometers P_1 and P_2 are first adjusted, with light on the cell, to make the plate current high enough to cause the relay armature to "pull up" against its core. P_1 controls the negative bias on the grid of the tube, while P_2 controls the voltage applied to the light-sensitive cell. The setting of P_1 determines how much more negative point *2* is than the cathode (point *1*), while the electron flow from *2* to *3* and through P_c to P_2 determines how much more positive the grid (point *3*) is than point *2*. The net grid-cathode voltage is therefore the difference between negative bias *1-2* and positive bias *2-3*.

The resistance of the cell is lowest when light is shining on it; when the light is cut off by a passing object, the cell resistance increases from ten to twenty-five times, reducing the current flowing through P_c and R_g. As a result, the positive bias *2-3* is decreased, the bias on the grid of the tube becomes more negative, the plate current reduces, and the relay armature "drops out." Since the relay has two fixed contacts, the load being controlled can be connected to start either when the relay drops out or pulls up, as desired. Thus the interruption of a beam of light can be made to ring a bell, open a door, actuate an electromagnetic counter, start or stop a motor, or do many other tasks too numerous to mention.

The circuit given in Fig. *11D* will operate on either a 110 volt A.C. or 110 volt D.C. supply. Connect with polarity as indicated, for D.C.; with A.C. the circuit is in operation only for that half of the cycle when polarity is as shown.

ELECTRONIC TUBES AS GENERATORS

The ability of a triode electronic tube to act as an amplifier makes it possible to utilize this tube in generating an A.C. signal. You already know that in an amplifier the variations in grid voltage produce a varying current and voltage in the plate circuit of the tube. If, now, some of the varying power in the plate circuit can be fed back to the grid, the tube will repeatedly reamplify the varying power without further aid from an outside source.

A simple but effective vacuum tube oscillator, known as a *tuned grid, tickler feed-back circuit,* is shown in Fig. *12A*. Its greatest use is in superheterodyne receivers, but you will also find this circuit in transmitters, in test apparatus and in electronic control systems. When the tube is first connected to a D.C. supply voltage, the plate current rises. This increasing current flowing through coil L_T (called a *tickler* or *feed-back* coil) induces a voltage in coil L and this induced voltage charges condenser C. The resonant circuit made up of L and C goes into oscillation at a frequency which is determined by the inductance of L and the capacity of C. The oscillating or alternating current which flows through this resonant circuit produces an A.C. voltage across L and C which acts upon the grid and causes the plate current to vary; this variation in plate current is again fed back by coil L_T to coil L in the same manner as before. This feed-back action is accumulative (it builds up) provided that the current through coil L_T feeds back into L a voltage which *reenforces* the original plate current change; feed-back action is limited to a safe value by the automatic C bias voltage which is provided by a resistor and condenser in the grid circuit.

Automatic C Bias. When this circuit is oscillating, the resonant circuit made up of L and C feeds an A.C. voltage to the grid through low reactance condenser C_g. During that interval when the grid is *positive,* electrons flow from the cathode to the grid, through resistor R_g and through coil L back to the cathode; this current produces in the grid circuit a D.C. voltage drop which serves as the automatic C bias. Because of the energy-storing effect of condenser C_g, a steady current continues to flow through R_g in this same direction even after the resonant circuit voltage has reversed its polarity; condenser C_g is recharged on each positive grid swing, and as a result there is always a steady direct current flowing through R_g and placing a negative bias on the grid. This C bias automatically keeps the operating plate current at a safe low value.

Condenser C_p in the plate circuit provides a low impedance path back to the cathode for the A.C. plate current, keeping it out of the D.C. source. Condenser C_g has another important use in that it provides a low reactance A.C. path between the resonant circuit and the grid. The A.C. current flowing through L induces in coil L_s the desired A.C. output voltage, and this is in turn fed to the load. Thus every part in this circuit has a definite function.

The circuit of the famous Hartley oscillator (named after its inventor and having the same uses as the tuned grid, tickler feed-back circuit) is given in Fig. *12B*. Here a part of the oscillating *L-C* circuit voltage (the voltage between points *1* and *2*) is fed to the grid-cathode to give the necessary grid excitation for continuous oscillation.

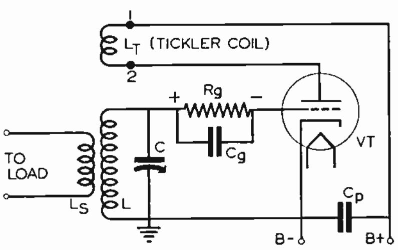


FIG. 12A. Simple tuned grid, tickler feed-back type vacuum tube oscillator circuit.

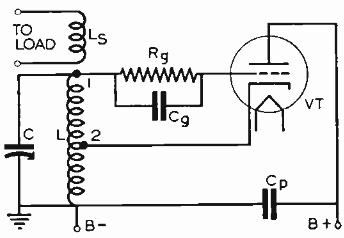


FIG. 12B. One form of the famous Hartley oscillator circuit.

In general, the frequency of an oscillator is determined by the values of inductance and capacity in the tuned circuit of the oscillator. If an iron core coil of high inductance is used with a large capacity, a low or audio frequency will be obtained; if L and C are small in electrical value, the frequency obtained will be in the I.F., R.F. or ultra high frequency regions. As a rule, the higher the mutual conductance of a vacuum tube, the better it will work in an oscillator circuit, because a large g_m allows the A.C. grid voltage to have a high degree of control over A.C. plate current.

ELECTRONIC TUBES AS MODULATED AMPLIFIERS

I now want to show you how a radio frequency signal can be modulated (made to vary) with an audio or picture signal. Although information on modulated amplifier circuits may seem out of place here, it will aid you greatly in understanding the frequency converter circuits which follow. A modulated R.F. amplifier circuit which is typical of those used in sound and visual transmitters is shown in Fig. *13A;* we will take up the function of each part in turn. Remember that the purpose of this circuit is to make an R.F. signal carry an audio or video frequency signal (a low frequency signal).

Variable condenser C tunes the input or grid *L-C* circuit to the frequency of the R.F. carrier signal which is produced by the oscillator stage of the transmitter. Condenser C_2 offers a low reactance path to this R.F. current but has no effect upon the low frequency signal being fed into the modulator stage through transformer *T*. Condenser C_3 offers a low impedance path to both the low frequency signal current and the R.F. carrier current, but has no effect upon the D.C. grid bias voltage.

Figure *13B* shows you in graphical form what goes on in the modulated amplifier circuit of Fig. *13A*.* In this modulated amplifier much depends upon the operating voltage values. The fixed or operating C bias must be *considerably more negative* than the C bias value *O* which just cuts off the plate current; point *X* on the graph in Fig. *13B* is a suitable operating point for the grid bias voltage.

When only an R.F. carrier voltage *X'* is applied to the grid-cathode terminals of tube, the plate current I_p will be as at *X"* in Fig. *13B*, which is a series of pulses all having the same amplitude. But what happens when both the R.F. carrier and the A.F. signal frequencies are applied to the grid circuit at the same time? The low A.F. frequency signal changes in amplitude much more slowly than the R.F. wave, and therefore acts as if it were shifting the grid bias slowly above and below the operating grid voltage represented by point *X*. When the bias is shifted to point *Y*,

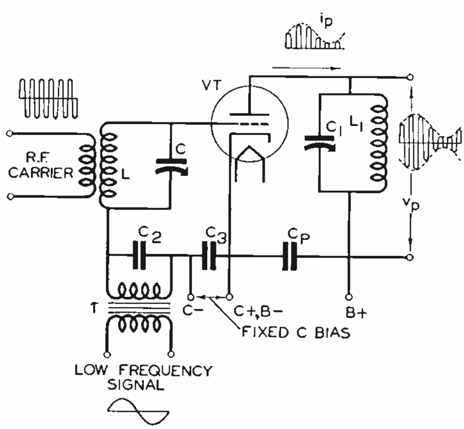


FIG. 13A. Modulated amplifier circuit; both R.F. and A.F. signals are fed to its grid circuit to produce a combination of the two signals in the plate output circuit.

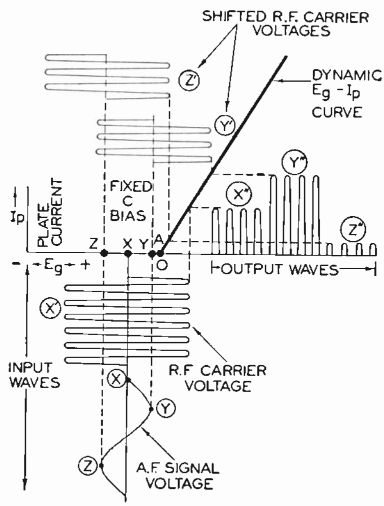


FIG. 13B. This graph explains how an R.F. signal is modulated with an A.F. signal by the modulated amplifier circuit at the left.

the R.F. signal (represented by *Y'* and shown directly above the E_g-I_p curve) has a maximum influence on plate current, and the current pulses which flow are of maximum amplitude as at *Y"*. When the bias is at point *Z*, the R.F. signal (represented by *Z'* and shown above *Y'*) has a minimum influence on plate current, and the pulses are of minimum amplitude, as at *Z"*. The resulting plate current wave form for one complete cycle is shown by the i_p curve at the top of the circuit diagram in Fig. *13A*.

When the pulsating R.F. plate current enters the tuned circuit C_1-L_1, condenser C_1 continually charges and discharges, supplying the missing half-cycles and rebuilding the wave in the manner illustrated in Fig. *13C*. This, then, is one way in which an R.F. signal can be modulated by (mixed with) an audio signal; the form of the final output wave is shown at v_p in Fig. *13A*. After additional amplification, this modulated R.F. wave can be fed to the transmitting antenna and radiated into space.

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*Since this amplifier contains a load (made up of coil L_1 and condenser C_1, which together act as a resistance at resonance), we cannot use an ordinary or static tube characteristic curve; we must use a dynamic E_g-I_p characteristic curve, which expresses how plate current will vary with grid voltage *when there is a load in the circuit*.

ELECTRONIC TUBES AS FREQUENCY CONVERTERS

The frequency converter stage, which converts currents of two different frequencies to a third frequency, is a very important section of the superheterodyne receiver which we are considering in this lesson; let us study its

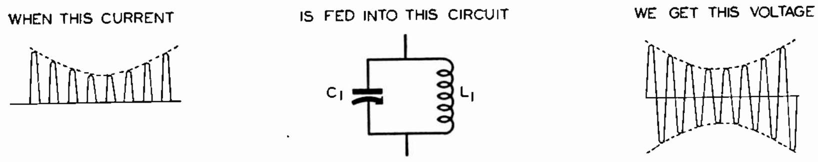

FIG. 13C. An L-C resonant circuit inserted into the plate lead of a modulating amplifier rebuilds the current pulses into a sine wave form.

action. The modulated amplifier circuit shown in Fig. *13A* can also serve as a frequency converter. One of the R.F. signals, that produced by the local oscillator in the receiver, is shown in Fig. *14A*, and the incoming radio carrier signal, of slightly lower frequency, is represented by the sine wave curve in Fig. *14B;* when these two frequencies are mixed in the grid circuit of the modulated amplifier, the resulting current will vary in amplitude at a rate corresponding to the difference between the frequencies at *A* and *B*, as shown at *C*. Since both of the input signals are R.F. values, transformer *T* in Fig. *13A* must be an R.F. (air core) transformer in this case.

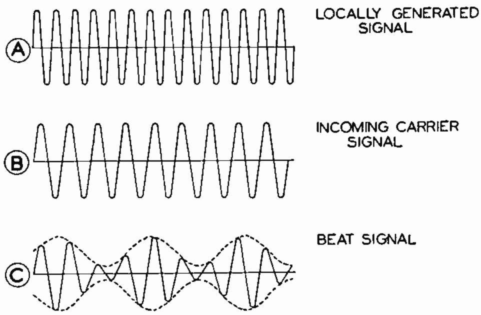

FIG. 14. How a frequency converter produces a beat frequency.

Tube *VT* in Fig. *13A* would generally be biased to cut-off (the operating point for the grid voltage would be at *A* in Fig. *13B*) for a frequency converter stage of a superheterodyne receiver. This means that the lower half of the wave pattern in Fig. *14C* will be chopped off, giving in the plate circuit a series of current pulses whose amplitudes vary at the beat frequency rate. With resonant circuit L_1-C_1 tuned to the beat frequency, only a beat frequency voltage will appear across the output terminals, to be sent on to the next stage.*

The entire frequency conversion process is illustrated in Fig. *15* for the case where two R.F. frequencies (both unmodulated) are fed into the circuit of Fig. *13A*. If the incoming signal (the R.F. carrier frequency) is modulated with an audio or picture frequency, the beat frequency (the I.F.) will also be modulated with this audio or picture signal. Thus, if the station being tuned in has a carrier frequency of 900 kc. and the local R.F. oscillator of the superheterodyne is set at 1,075 kc., the plate tuning circuit of the amplifier must be made to respond to the 175 kc. difference frequency, which is the I.F. frequency of the receiver.

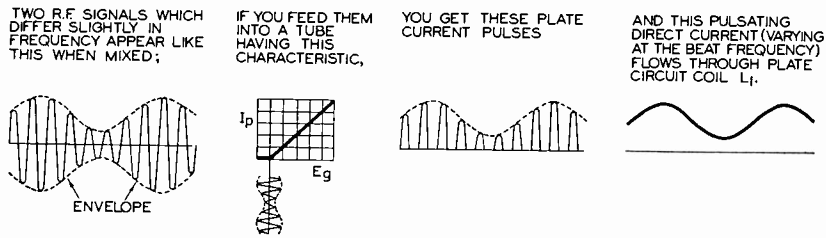

FIG. 15. A bird's-eye view of the entire process of frequency conversion. If one of the original R.F. signals is modulated, the envelope of the two mixed signals will be modulated, and the plate current pulses as well as the pulsating D.C. coil current will be modulated in the same manner.

VACUUM TUBES AS DEMODULATORS OR DETECTORS

Curiously enough, the same sort of circuit which is used for modulating an R.F. current can be used for demodulating it (removing the signal from the carrier), the chief difference being in the plate load. The schematic diagram of a typical *demodulator* or *detector* circuit is shown in Fig. *16;* the desired modulated R.F. carrier (the desired broadcast program) is selected by resonant circuit L_T-C_T and then fed to the grid of the tube. This tube being biased to the plate current cut-off point, there will be produced in the plate circuit a pulsating direct current which has three important components: *1, the direct current; 2, the carrier frequency; 3, the modulation frequencies.* Condenser C_o by-passes the carrier frequency current around load R_o, while the D.C. and the modulation frequency currents both pass through R_o, producing voltage drops. If the next stage is connected to terminals *1* and *2* through a condenser or transformer, only

*The resonant circuit can be tuned either to the sum of or difference between the local and incoming signal frequencies, depending upon which of these two beat frequencies is desired. It can be shown mathematically that when two signal frequencies are mixed together and sent through an amplifier having a sharp plate current cut-off characteristic, the resulting wave will contain the *two original frequencies*, a frequency equal to the *sum of the original frequencies, a difference frequency* and *harmonics* of each of these four fundamentals. For more information about the general nature of harmonics, review the last few pages of reference book 2X "The Language of Radio-Tricians."

the desired modulation frequencies (the audio or picture signals) will be transferred for further amplification.*

THE SUPERHETERODYNE CIRCUIT

The complete circuit diagram of a superheterodyne receiver, shown in Fig. *17*, should not offer any difficulties, since you have already studied each of its sections in detail. As a review, let us trace a radio signal through the entire receiver.

The antenna system intercepts the modulated R.F. carrier wave, causing a modulated R.F. current to flow in coil L_1. The modulated carrier voltage induced in coil L_2 is, after being stepped up by resonant circuit

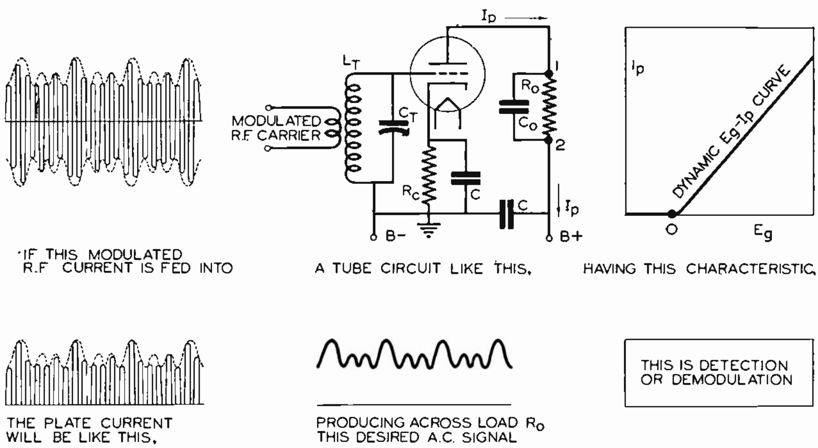

FIG. 16. When the grid bias in this detector circuit is set at cut-off (point *O* on the characteristic curve) by choosing the correct value of bias resistor R_c, and a modulated R.F. wave is fed into the grid circuit, the A.C. pulsations which flow in the plate circuit produce a pulsating voltage across the resistance load R_o; the A.C. part of this voltage is the desired A.F. signal.

L_2-C_2,† applied to the grid of vacuum tube VT_1 in the R.F. amplifier stage (a voltage amplifier), causing an amplified A.C. current of the same modulated R.F. wave form to flow through L_3 in the amplifier plate circuit. This varying current through L_3 induces in coil L_4 a voltage of similar wave form, which again is stepped up by the resonant circuit, then applied to the grid input of mixer-first detector tube VT_3.

*In a modulated amplifier, the load circuit is tuned to the *R.F. carrier;* in a frequency converter, the load circuit is tuned to the *beat frequency;* in a detector, the load circuit *by-passes R.F.* while accepting the modulation signal. The circuit of Fig. *13A* can therefore be made to serve as a modulator, as a frequency converter, or as a demodulator simply by using the proper load circuit.

†The action of a series resonant circuit in stepping up a voltage is as follows: The coil and condenser together have a resonant frequency at which their reactances cancel each other; when the voltage induced in the coil is at this resonant frequency, a large A.C. current flows in the resonant circuit. This A.C. current naturally produces an A.C. voltage drop across the coil and across the condenser (since each, acting alone, offers a high reactance to A.C.); the resulting output voltage (across either the coil or the condenser) is therefore many times greater than the original induced voltage.

Vacuum tube VT_2 is in an oscillator circuit producing a frequency which is generally higher in value than the carrier frequency; tickler coil L_T provides the necessary feed-back action. Coil L_6 takes the output power from oscillating circuit C_5-L_5, inducing in the input or grid-cathode circuit of tube VT_3 the locally generated R.F. signal voltage.

Thus there are two R.F. signals, differing in frequency by a definite amount, being fed to mixer-first detector tube VT_3; the result is a strong modulated I.F. current in the plate circuit of tube VT_3. This modulated I.F. current, through tuning, causes a much larger I.F. current to flow through coil L_7, inducing in L_8 an I.F. voltage which after resonance step-

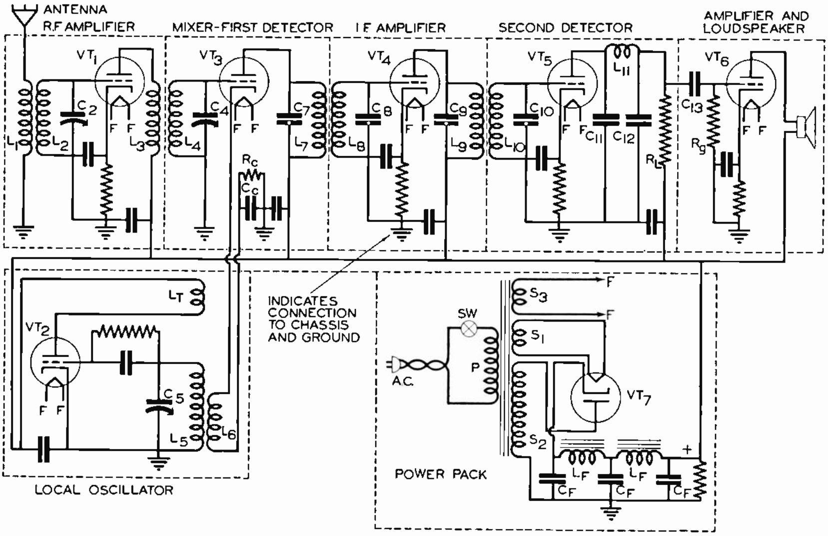

FIG. 17. A simple but complete superheterodyne circuit. The circuit is essentially the same for both picture and sound signals up to resistor R_L in the output of the detector stage; sound signals are further amplified by an A.F. amplifier before being fed to the loudspeaker, but the television image reproducer is often connected directly across R_L, no picture signal amplifier being used. Dotted lines separate the different stages.

up is applied to the grid of tube VT_4 (biased for voltage amplification). An amplified I.F. current thus flows through L_9, inducing a high value of modulated I.F. voltage in L_{10}. This voltage, after resonance step-up, is applied to the grid input of the second detector tube VT_5, which is operated at a grid bias giving plate current cut-off.

As a result, only the audio frequency current, a duplicate of the original sound signal, flows through load resistor R_L. A strong A.F. voltage is thus produced across R_L, the I.F. current being choked out by coil L_{11} and by-passed around the load by condensers C_{11} and C_{12}. Only the varying part of the voltage across R_L gets through condenser C_{13} to produce a varying voltage across R_g and at the grid input of power amplifier tube VT_6. The load on VT_6 will be a loudspeaker in the case of a sound receiver; if picture signals are being picked up, the television reconstructor device is often connected directly across R_g, the power amplifier stage being omitted. With television receivers, tubes VT_1, VT_2 and VT_3 should be of the "acorn" type, since these midget tubes are better suited for ultra high frequency circuits than ordinary radio tubes. VT_5 can also be an acorn tube, since in acting as a detector it must handle the high picture frequencies.

Only the power pack circuit remains to be reviewed. Secondary winding S_1 of power transformer P furnishes a low A.C. voltage for the filament of rectifier tube VT_7, while secondary winding S_3 furnishes power for all other tube filaments (connections to the F-F terminals of the tubes have been omitted for simplicity). Secondary S_2 furnishes a stepped-up A.C. voltage to the rectifier circuit, which in turn converts it to a pulsating D.C. current. Fluctuations in the current are filtered out by chokes L_F and condensers C_F. The filtered D.C. voltage is fed to each plate circuit; because of the resistors shunted by condensers in each cathode-to-ground connection, the rectifier also supplies an automatic C bias voltage for each tube.

Although Fig. *17* shows the essential parts of a superheterodyne circuit, many variations are possible in each stage and section. You now have the important fundamental principles of tubes at work in radio and electronic circuits; in future lessons you will learn more about how individual circuits behave under various conditions.

TEST QUESTIONS

Be sure to number your Answer Sheet 10FR-3.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Describe briefly the important function of a superheterodyne circuit.
2. What are the four important parts in a power pack?
3. What job is performed by the rectifier tube in a power pack?
4. Name the two basic types of tube amplifiers.
5. What will the E_g-I_p characteristic curve of a tube tell you directly?
6. What important tube rating tells directly how much the grid controls plate current?
7. When does the load in a tube amplifier circuit absorb *maximum power?*
8. What characteristic of a triode electronic tube makes it possible to use this tube in generating an A.C. signal?
9. When the resonant circuit of the oscillator (Fig. *12A*) goes into oscillation, what determines its frequency?
10. What are the three important components in the pulsating direct current which flows in the plate circuit of a demodulator or detector stage?

HOW IRON CORE COILS AND TRANSFORMERS OPERATE IN RADIO CIRCUITS

11FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

HOW-TO-STUDY TIPS

When You Feel Sleepy: The room may be too hot; turn off the heat, open the windows and put on a coat if necessary, for it is easier to study in a cool room. Sponge your face and neck, and particularly your eyes, with cold water. Take a brisk five- or ten-minute walk. Only when you know that the sleepy feeling is due to an extreme lack of sleep should you yield to it; in this case go to bed and get a good rest so you can start fresh the next day and make up for lost time.

When You Hate to Start Studying: Set a definite starting time for study each day and make up your mind to open a text-book and start studying at this time. Leave the sharpening of pencils, trimming of finger nails, and the other little ways of wasting time until after the study period. Remember that the longer you put off doing a task, the less you feel like starting it. Whenever possible, stop your studies at an interesting point, so you have something to which you can look forward the next day. You might even try setting your alarm clock to ring at the time when you plan to start studying.

When You Can't Concentrate: You are your own task-master and will have to discipline yourself for mental laziness. Regular exercising of the mind builds up its vigor and power, just as physical exercise builds up strength. If your mind begins to wander from study while you are alone in a quiet room, try moving to a noisy room, or try turning on the radio. Be sure, however, to select a location or tune in a program which is free from loud conversation. The human mind oftentimes accepts sound or the mere presence of people as a challenge and concentrates on study and this challenge instead of on a host of other things. Study yourself and experiment until you find a particular scheme which helps you to concentrate. Once you acquire the ability to concentrate, you will understand and remember the thoughts expressed in each sentence instead of simply reading groups of words over and over.

When You Have Difficulty in Understanding a Subject: Try outlining the text-book or parts of it. Jot down in a notebook a few words which are descriptive of each paragraph, copying all titles as well in their proper order, then study this outline for a while. Rewriting an explanation in your own words is another way of understanding and mastering it.

J. E. SMITH

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

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How Iron-Core Coils and Transformers Operate in Radio Circuits

INTRODUCTION

YOU have progressed far enough with your studies now to know that a great many radio devices depend for their operation upon the flow of magnetic flux (magnetic lines of force) through iron cores; loudspeakers, meters and transformers are just a few well-known examples. The magnetic fields produced by these iron-core radio devices serve one of the following three important uses:

1. ***Produce mechanical motion of some part,*** **as in a METER, RELAY or LOUDSPEAKER.**
2. ***Increase the inductance of a coil,*** **as in a CHOKE COIL.**
3. ***Induce a voltage in an adjacent coil,*** **as in a TRANSFORMER, in certain types of MICROPHONES and in some PHONO PICK-UPS.**

Before discussing magnetic fields at work in these three ways, I want to tell you about the various magnetic materials which are used in these devices to give most efficient production of magnetic fields.

Magnetic Materials. Good magnetic materials, which allow low magnetizing forces to produce strong magnetic fields, include iron, steel, steel mixed with cobalt or chromium, and certain alloys which do not contain iron. "Alnico," a mixture of aluminum, nickel and cobalt, is an example of the latter. Some of these materials, such as iron, steel, and steel mixed with silicon will, if properly annealed by being heated white hot and allowed to cool slowly, give up their magnetic properties as soon as the magnetizing force (the current flowing through a coil) is removed. Other materials, such as steel mixed with chromium, steel mixed with cobalt, and "Alnico" will, if properly hardened by being heated to a certain critical high temperature and then dropped into cold water or oil, retain their magnetic properties long after the magnetizing force has been removed. It is this last group of materials which makes it possible for us to build permanent magnets.

MAGNETIC FIELDS AT WORK

Using Magnetic Fields to Produce Motion. As you know, direct current flowing through a coil sets up a magnetic field which passes through the coil, and we have what is known as an *electromagnet.* If such a coil is pivoted and brought near another magnetic field, this coil will behave exactly as if it were a compass needle or permanent magnet. If we know or can find the North and South poles of this electromagnet and of the device which is producing this other magnetic field, we can apply the following general rule to find out what the direction of motion will be: *Like or similar poles repel, and unlike poles attract.* Furthermore, we can use this rule to determine how any two magnets will interact, regardless of whether they are permanent magnets or electromagnets. There is, however, another way of determining the nature of the motion in a magnetic device; this second explanation, given in the following paragraph, is often more convenient to use.

Any given permanent magnet or electromagnet has a certain magnetizing force under all conditions, but the strength of the resulting magnetic field depends entirely upon the opposition which the magnetic flux encounters in its various paths. When a movable magnetic object is placed in the magnetic field produced by some device, this object will take a position *which gives the greatest possible increase in the magnetic flux produced by the device.*

If the magnetic object is merely pivoted, it will try to rotate to a position where its longest dimension will be *parallel to the magnetic lines of force* in its vicinity, just as does the needle of a compass. If the magnetic object is a permanent magnet, it will take a position which makes its own field *aid and increase the original magnetic field.* This is why a steel rod will be "sucked into" the center of an air-core coil through which current is flowing, and this is why bits of iron and steel are attracted to the poles of both permanent magnets and electromagnets.

There are a number of well-known radio devices which use magnetic fields, produced either by permanent magnets or by electromagnets, to produce motion. Loudspeakers are an example; a sketch and simplified cross-section diagram of an electromagnetic type loudspeaker are shown in Fig. *1A*. The electromagnet is here in the form of a solid steel cylinder having a round rod or core of steel in the center, with the magnetizing coil wound over this core. The voice coil to which is attached the paper cone of the loudspeaker is free to move in and out in the air space provided between the central core and the outer cylinder. Direct current is sent through the magnetizing or field coil, producing a very strong magnetic field in the air gap through which moves the voice coil. When the voice coil is excited (fed) with audio frequency current, it sets up its own magnetic field which alternately repels and attracts the main field, with the result that the voice coil and its attached paper cone move in and out in accordance with the variations in the audio frequency signal, producing sound waves. The loudspeaker shown in Fig. *1B,* known as a *P.M.* (permanent magnet) *dynamic loudspeaker,* works in exactly the same way except that here the strong magnetic field is produced by two U-shaped permanent magnets arranged as shown in the sketches. P.M. dynamic loudspeakers are also made in the cylindrical form shown in Fig. *1A,* with a highly magnetized steel cylinder replacing the core and field coil.

Ordinary radio headphones illustrate another application of magnetic fields for producing motion. As you can see from the diagram in Fig. *1C,* a coil of wire is wound on each leg of a U-shaped core. The coils are so connected together in series that current flowing through makes them always of opposite polarity, one a north pole and the other a south pole. Directly over, but not touching these poles, is a thin steel diaphragm; the more current there is flowing through the coils, the more is this diaphragm attracted toward the ends of the U-shaped core. If the current is varying, as it is in the case of an audio frequency current, the position of the disc will vary in accordance with the current changes; thus sound waves are produced. Incidentally, the U-shaped core is

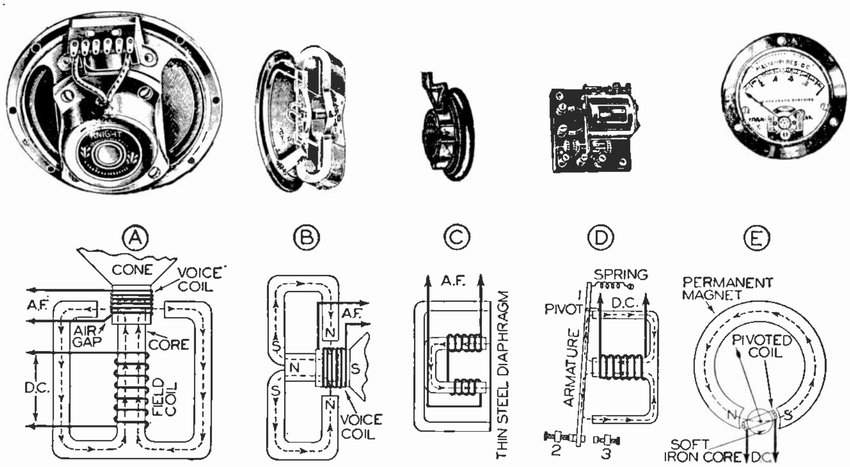


FIG. 1. Examples of radio devices which utilize strong magnetic fields to produce mechanical motion are shown here. Left to right: ordinary dynamic loudspeaker, P.M. dynamic loudspeaker, headphone, relay and D.C. meter. The simplified diagrams give the operating principles of each device. Dotted lines with arrows indicate the paths taken by magnetic flux.

usually made a permanent magnet, to give a certain amount of pull upon the diaphragm at all times and thus secure more faithful reproduction of sound.

The ability of an electromagnet to attract pieces of iron is made use of in relays like that shown in Fig. *1D.* Current flowing through the coil serves to magnetize the soft iron central core and the U-shaped soft iron frame, and the soft iron armature is attracted. One end of this armature is pivoted, but the other end can move. When there is no current through the relay, the armature (which connects to relay terminal *1*) is held against contact *2* by a small spring, and with current flowing the armature is up against contact *3*.

An example of a coil rotating in a magnetic field produced by a permanent magnet is the meter shown in Fig. *1E.* The current being measured is sent through the moving coil of the meter, producing a magnetic field which reacts with the field of the permanent magnet and causes the coil and its indicating needle to rotate against the retarding force of a small coil spring. Many direct current meters operate on this general principle.

Using Iron Cores to Secure Greater Inductance. When a current flows through an air-core coil which has a certain inductance, a definite amount of magnetic flux is produced. You can increase the amount of this flux either by increasing the inductance of the coil or by increasing the current flowing through it. Adding turns of wire to the coil or changing the coil shape can change its inductance, but a more convenient and more effective procedure is to use iron or steel instead of air for the core of the coil. Where direct currents are involved, solid iron or steel cores may be used, but with alternating current the core must be made up of steel wires or thin steel sheets assembled to produce the desired shape of core. Even with this procedure for breaking up the core into small sec-

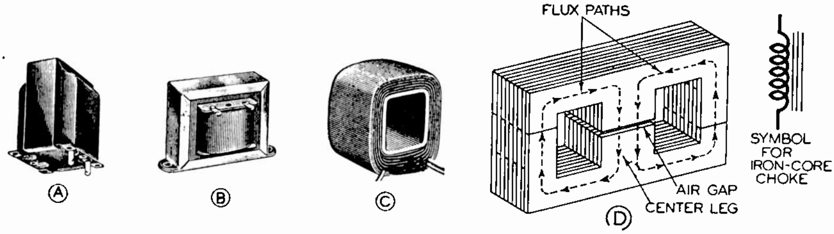


Fig. 2. Here you have a complete pictorial story of iron-core chokes—how they look, how the coil alone appears, how the core is constructed and how they are shown in symbolic form.

tions, certain undesirable effects occur which limit the use of iron-core coils to frequencies below about 10,000 cycles.

Iron-core coils are often referred to as low frequency chokes or as iron-core chokes, because they are highly effective in blocking or choking the flow of low frequency alternating currents in the power supplies of receivers and transmitters. They are also used as line filters to prevent the flow of interfering signal currents; in audio circuits they serve either to block the flow of signal currents in certain circuits or prevent the passage of low frequency power line currents which might create hum interference. Iron-core chokes used as loads for vacuum tube amplifiers in audio circuits develop a large signal voltage for transfer to another amplifier stage.

Typical iron-core chokes are pictured in Figs. *2A* and *2B*. The iron cores used are generally made of E-shaped sheets of silicon steel, each about .01 inch thick, stacked together to give a core resembling that shown in Fig. *2D*. This is known as laminated construction, and each individual sheet is called a lamination. The coil is wound in layers upon a separate cardboard coil form, so that when finished it appears as at Fig. *2C*. Varnished paper is used as insulation between each layer of wire, and the finished coil is covered with heavy varnished cloth. After baking the coil in an oven to drive off moisture, it is generally dipped in hot wax to make it moisture-proof. The laminations are then assembled around the coil, with the coil located on the center leg, and the laminations are either bolted together or squeezed together by a metal frame or case.

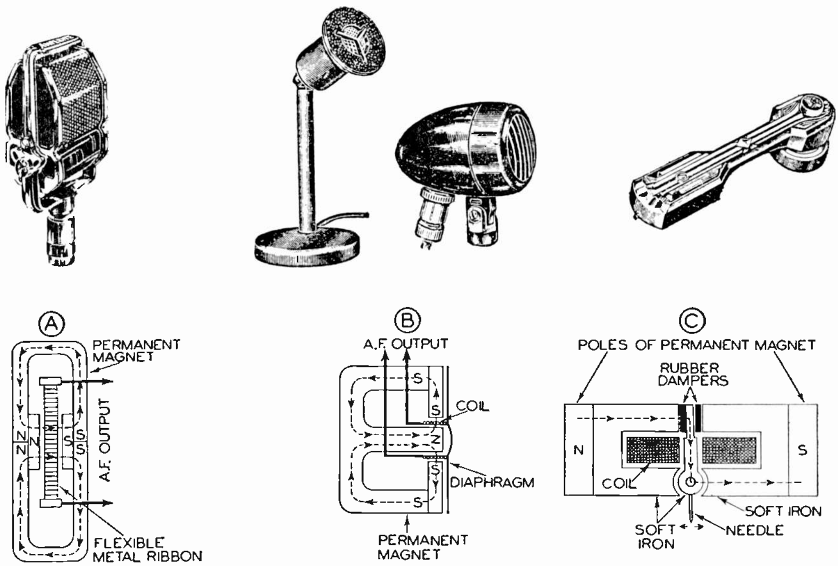


FIG. 3. In these well-known radio devices, strong magnetic fields are used to induce desired A.F. voltages in coils. At *A* is a velocity microphone of a type used in broadcast studios; at *B* is shown the Western Electric "salt-shaker" dynamic microphone and a "bullet" dynamic microphone, both having essentially the same operating principles, while at *C* is a magnetic type phonograph pick-up unit.

The paths taken by magnetic flux in the core of an iron-core choke are indicated in Fig. *2D*. Note that the paths are entirely through the iron core, and not through air in the vicinity of the core. This is highly desirable in a good choke coil, for in radio apparatus any flux which leaks away from an iron-core coil may cause severe interference in other radio circuits. Cores designed for use at audio rather than power line frequencies generally have an air gap in the middle leg of the core, as indicated in Fig. *2D;* the reason for this will be explained later.

Using Magnetic Fields to Secure Induced Voltages. As you know, a voltage is induced in any coil when the flux linkages through that coil are changed. For a given coil, the amount of flux change in a given time such as one second is a measure of the amount of voltage which will be induced. Large changes in flux produce large voltages, hence iron-core devices are desirable to produce these large fluxes. Voltages can be induced either by moving the coil through a fixed magnetic field, or by leaving the coil stationary and varying the flux, for flux linkages are changed in both cases.

The velocity microphone illustrated in Fig. *3A* is an example of the case where a coil is moved in a fixed magnetic field. Two horse-shoe shaped permanent magnets are mounted with similar poles together, soft steel bars being fastened across the junctions to hold the magnets together and increase the amount of flux flowing across the air gap. A flexible metal ribbon mounted in this gap serves as a single turn coil. This ribbon is usually crimped in accordion fashion so it can move in and out of the magnetic field under the influence of sound waves. This motion of the ribbon causes its flux linkages to change, and consequently a varying voltage is induced in the ribbon.

A dynamic microphone, two examples of which are shown in Fig. *3B*, has essentially the same electrical operating principle as a velocity microphone, but the arrangement of parts differs considerably. The permanent magnet is in the shape of a central cylinder inside a steel cup, as you can see from the cross-section diagram in Fig. *3B*. A coil of wire located in the air gap between the poles of the magnet is mounted on a flexible metal diaphragm which moves back and forth under the influence of sound waves. This motion changes the flux linkages in the coil, and as a consequence the desired varying voltage is induced in the moving coil.

A magnetic phonograph pick-up unit also depends for its action upon a change in flux linkages in a coil. Fig. *3C* shows a typical unit and a simplified diagram explaining its operation; only the poles of the U-shaped permanent magnet appear in the diagram, for you are looking at the end of the unit. This pick-up unit is designed for lateral-cut phonograph records, where the groove is always the same depth but winds or wiggles back and forth between (but never touching) the adjacent grooves, in accordance with the audio signal. Under a microscope the groove would often look like a sine wave. The needle riding in the groove naturally follows its wavy path, causing the pivoted core (in which the needle is imbedded) to rock back and forth between the two U-shaped soft iron pieces. With the core tilted in the position shown, magnetic flux passes through in the direction indicated; with the core tilted the other way, the flux, always choosing the most favorable path, will travel in the opposite direction through the pivoted core. This varying and alternating flux induces in the coil an A.F. voltage whose wave form corresponds to the variations in the record groove. Rubber dampers prevent the core from "sticking" in any one position, and also prevent it from vibrating too greatly at certain frequencies (because of mechanical resonance).

An iron-core transformer is perhaps the most common application where a magnetic field is used to produce an induced voltage of the desired magnitude. Two or more coils are magnetically coupled together by an iron core, so that a varying current in one coil produces a varying flux in the core, and this in turn induces a varying voltage in the other coils.

A number of examples of iron-core transformers are shown in Fig. *4A*. In appearance and construction they differ very little from the iron-core chokes shown in Fig. *2*, the core being almost identical in shape.

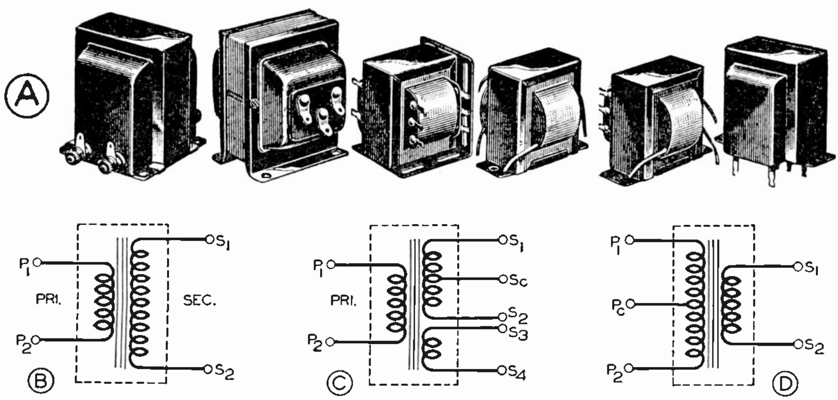


Fig. 4. Different types of low frequency transformers, all of which depend for their operation upon induced voltages produced by strong magnetic fields, are pictured here together with representative schematic diagrams for iron-core transformers. The parallel lines between the coils always indicate the presence of an iron core, while the dotted line indicates that the transformer has an iron housing which acts as a shield. The resistance as measured with an ohmmeter between the two *P* terminals or between *S* terminals for any one winding should be low, indicating continuity. The measured resistance between any *P* terminal and any *S* terminal should be infinite (very high), indicating no connection.

There are, of course, two separate windings; these are usually wound one over the other, with heavy, varnished paper or cloth separating the two coils.

You can distinguish choke coils from transformers by the fact that chokes usually have only two terminals (although occasionally there will be three if the choke coil is tapped); a transformer has a minimum of four terminals, and will have two extra terminals for each extra coil, as well as an extra terminal for each tap.

The terminals of individual coils in a transformer can be identified with the aid of an ohmmeter. Continuity (low resistance) between any two terminals indicates that they are on the same coil winding, while infinite resistance (an open circuit) between terminals indicates that they are on separate coils. A study of the schematic transformer symbols in Figs. *4B, 4C and 4D* will make these facts clearer to you.

That winding of an iron-core transformer which is intended to be connected to the power or signal source is always known as the *primary winding;* all other windings or coils are called *secondary windings.* There is no general rule for identifying the primary winding; manufacturers of transformers will usually either mark the terminals or supply a diagram indicating the purpose of each terminal.

Transformers with iron cores give almost perfect transfer of power from one winding to another. This means that for a definite primary voltage and primary current, you can secure either high voltage and low current at a secondary winding by using more turns on it than on the primary, or can secure low voltage and high current by using fewer turns on the secondary but using heavier wire.

Transformers designed primarily to transfer power are called *power supply transformers* or simply *power transformers.* Those used in radio receivers are built for operation at power line frequencies, of which 60 cycles is the most common; frequencies ranging from 25 cycles to 135 cycles are encountered in certain localities, however.

In vacuum tube amplifier circuits, iron-core transformers are used to couple circuits as well as to step up or amplify voltages (transfer of power is of minor importance in this case); transformers designed specifically for this purpose are known as *audio transformers, audio coupling transformers* or *audio amplifier transformers.*

Transformers which are designed primarily to deliver maximum power to a load at a certain voltage while offering a definite impedance to the source are known as *matching transformers.*

MAGNETIC CIRCUITS

The amount of magnetic flux and the path which it takes play such important parts in the operation of iron-core chokes and transformers that I want you to know a little more about the exact nature of magnetic circuits as used in these devices. A general idea of the problems involved will be sufficient, for the actual design of iron-core devices is not a job required of radio men.

Magnetic circuits can be compared with electric circuits, for they have certain things in common. A simple electric circuit like that in Fig. *5A* consists of a source of electromotive force E, and a resistance R which opposes the flow of current through the electric circuit. Voltage E and resistance R together determine the amount of current I which will flow. A magnetic circuit likewise has a source, which produces magnetic flux, and an opposition to the flow of this flux in the circuit. The source of flux is called the *magnetomotive force* (abbreviated m.m.f.), while the *opposition effect* of the magnetic circuit is called its *reluctance.*

One example of a magnetic circuit is shown in Fig. *5B*. Here the electric current *I* flowing through a coil having *N* turns is a measure of the magnetomotive force which produces the magnetic flux, and the iron core in series with the air gap forms the magnetic circuit which offers a certain opposition or reluctance to the flow of this magnetic flux. Actually the greatest part of the reluctance occurs in the air gap, for iron offers but little opposition to the flow of magnetic flux.

Another example of a magnetic circuit is given in Fig. *5C*. The magnetomotive force is here produced by a permanent magnet, and the controlling reluctance in the magnetic circuit is that offered by the two air gaps associated with the soft steel cylindrical core. Incidentally, this magnetic circuit is typical of those found in direct current meters.

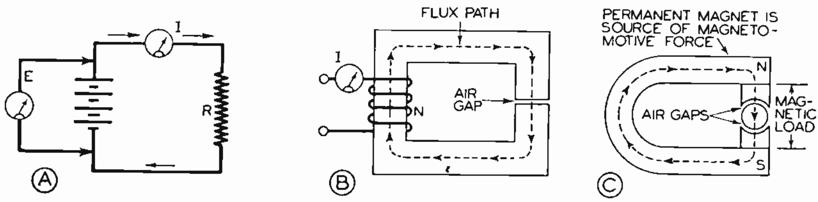


Fig. 5. These diagrams show the similarity between electric and magnetic circuits.

Thus you can see that electromotive force in an electric circuit is comparable with magnetomotive force in a magnetic circuit, resistance is comparable to reluctance, and current is comparable to magnetic flux.

How is magnetic flux measured? Although the exact amount of magnetic flux in a magnetic circuit cannot be measured directly and conveniently with ordinary measuring instruments, there are several laboratory methods for doing this. Since these methods are rather interesting and at the same time show more clearly the characteristics of a magnetic circuit, I will tell you about two of them.

One method for measuring magnetic flux depends upon the fact that pure bismuth (a metal) changes in electrical resistance when placed in a magnetic field. A piece of bismuth wire, wound in spiral form, is placed at various points in a magnetic field and its resistance measured at each point. The ohmmeter used to measure its electrical resistance is calibrated to read in *"magnetic lines per unit area."* The initial calibration of this meter (called a fluxmeter) must, of course, be made with magnetic fields of known value.

The second laboratory method for measuring magnetic flux is based upon the fact that a coil of wire moved through a magnetic field will absorb a certain amount of energy. The instrument used here is a *ballistic galvanometer,* which essentially is a D'Arsonval type microammeter having a heavy movement and no retarding spring. Under this condition the movement rotates through an angle which is dependent upon the quantity of electricity fed to its coil. An exploring coil made up of a definite number of turns of wire wound on a coil form of definite size is connected across the terminals of this ballistic galvanometer. The exploring coil is placed in the magnetic field being measured, the galvanometer switch is closed and the exploring coil is suddenly removed from the field. The movement of the ballistic galvanometer is then dependent upon the total amount of flux which was cut by the coil. Mathematical calculations then give the exact number of magnetic lines in the field. This is the fundamental method used in laboratories for measuring magnetic flux.

There are a number of practical ways for measuring magnetic flux in terms of the effects produced. The pull or repelling force which the magnetic field exerts on an iron object or another magnetic field can be measured, the amount by which the magnetic field increases the inductance of a coil can be measured, or the amount of induced voltage can be measured. These are all problems for the scientist, however; all I want you to remember is that increasing the magnetomotive force increases the magnetic flux, decreasing the magnetomotive force decreases the flux, and changing the reluctance of the magnetic circuit by changing some part of its path also changes the magnetic flux.

Units of Magnetomotive Force. You know that increasing either the number of turns in a coil or increasing the current through the coil will increase the flux-producing ability or magnetomotive force of the coil. This magnetomotive force can therefore be expressed in terms of *ampere-turns.*

The *ampere-turn* is the practical unit of magnetomotive force for coils, but of course does not apply directly to permanent magnets. A more basic unit of measurement for magnetomotive force, which applies directly to permanent magnets as well as coils, is the *gilbert,* a unit which corresponds to volts in electric circuits. To change ampere-turns to gilberts, simply multiply the number of ampere-turns by the number 1.26; to change gilberts to ampere-turns, multiply the m.m.f. in gilberts by the number .80.

Units of Flux. The magnetic line of force is a unit originally conceived by the great scientist Faraday, and retained to this day because of its convenience. The technical name for a magnetic line of force is the *maxwell.* A larger unit, the *kilomaxwell,* is equal to 1,000 lines of force or to one *kiloline.*

Flux density indicates how many lines of flux pass through a given unit of area. Flux density can therefore be expressed in terms of lines per square inch, maxwells per square inch, kilolines per square inch, or kilomaxwells per square inch. If the unit of area is one square centimeter (metric units) another unit is used; a flux density of one line per square centimeter is known as a *gauss*. A kilogauss would then be equal to 1,000 gausses or 1,000 lines of flux per square centimeter.

Units of Reluctance. Now we can define the magnetic opposition to the existence of flux in a magnetic circuit. If a circuit has a magnetomotive force of one gilbert and this sets up a flux of one maxwell (one line of force), then scientists say that the magnetic circuit has a reluctance of one *oersted* (sometimes called one *rel*).

Now let us see what controls the reluctance of a magnetic path. Turning back once more to electric circuits for comparison, you will remember that the resistance of the circuit can be increased either by increasing the length of the wire path, by decreasing the cross-sectional area of the wire path, or by making the current flow through wire which has a high resistance, such as nichrome wire; all these things increase the circuit resistance. Likewise, in a magnetic circuit the reluctance of the path for flux is increased *by increasing the length of the path, by decreasing the cross-sectional area of the path* and *by using materials for the path which have higher reluctivity* (higher reluctance per unit volume to magnetic flux). Under normal operating conditions, air has a great deal more reluctivity than an iron or steel core; furthermore, different types of iron cores vary greatly in reluctivity, cast iron being quite high in reluctivity and wrought iron being low.

Laws of Magnetic Circuits. Kirchhoff's laws for magnetic circuits are much like those for electrical circuits. These laws are:

1. **All of the flux flowing to a point in a magnetic circuit equals all of the flux flowing away from that point.**
2. **The sum of the reluctance drops in a magnetic circuit must equal the sum of the magnetomotive forces acting in that circuit.**

Permeance of Magnetic Circuits. In electrical circuits we express the ability of the circuit to conduct current as its conductance; this rating is expressed in mhos, and is obtained by dividing the number *one* by the circuit resistance in ohms. In a similar manner, the ability of a magnetic circuit to allow magnetic lines to exist is called its *permeance*. The number *one* divided by the reluctance in oersteds gives the permeance, expressed as so many "perms."

SATURATION IN MAGNETIC CIRCUITS

We know that doubling the source voltage in an electrical circuit will double the current, but even though a magnetic circuit behaves much like electrical circuits in some ways, it is not safe to say that doubling the magnetomotive force will double the magnetic flux. Except for air and certain non-magnetic metals, the reluctance of a magnetic path varies with the magnetomotive force acting upon it. Let me describe to you an interesting experiment which will prove this fact.

We will use for this experiment a direct current generator like that shown in Fig. *6A,* which has two magnetic circuits in parallel, each consisting of a part of the soft iron frame, the two field poles, the armature and the air gaps. The field poles are excited (magnetized) by a direct current flowing through coils which are wound around the poles; the resulting flux flows through the two magnetic paths and in particular across the air gap. The armature winding, which is embedded in the armature, moves through these air gaps when the generator is driven by an engine or motor. The voltage induced in the armature wires reverses in polarity continually and is therefore A.C. in character, but is rectified by the commutator and brushes so that a D.C. voltage is delivered.

When the armature of this D.C. generator is driven at a constant speed, the value of generated voltage depends upon the total flux produced by the field coil (although current for the field coil is generally supplied by the generator itself, the coils being connected in parallel with the brushes, we are using an independent field current supply in this experiment for a particular purpose). If we start with zero field current and gradually increase the field current, measuring the generated voltage E for each increase in current, we will secure the heavy line curve in Fig. *6B* when we plot the results on a graph. The field current I_f is here a measure of the magnetomotive force, for I_f multiplied by the number of turns in the field coils gives ampere-turns. The generated voltage is likewise a measure of the amount of magnetic flux, for the generator is being rotated at constant speed. The curve in Fig. *6B* thus gives us the relation between the magnetomotive force and the flux in this magnetic circuit. You can see that for low values of magnetomotive force the flux increases uniformly with magnetomotive force, but at high values of magnetomotive force additional increases produce little or no increase in flux.

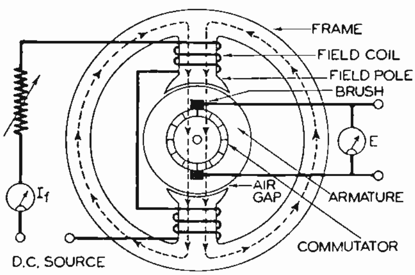


FIG. 6A. Cross-section diagram of a simple two-pole direct current generator, with which the effects of magnetic saturation and residual magnetism (hysteresis) can be shown.

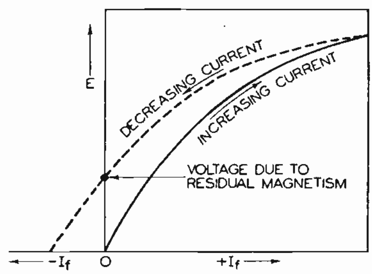


FIG. 6B. Magnetization curves for the generator in Fig. *6A*. Field current I_f corresponds to magnetomotive force, while output voltage E corresponds to magnetic flux.

Technicians say that the condition of *saturation* exists in an iron core when increases in magnetomotive force produce little or no increase in magnetic flux. They explain their statement by saying that under this condition all of the tiny magnetic particles in the iron or steel which make up the magnetic path have been lined up in the direction of the magnetic lines of force as far as they can go.

HYSTERESIS AND EDDY CURRENT LOSSES

When we reduce the field current in our direct current generator, we find that for any given lower value of field current the generated voltage is considerably higher than it was when we previously increased the field current up to this value. In fact, we obtain results corresponding to the dotted line curve in Fig. *6B* when reducing the field current to zero. Technicians explain this mysterious characteristic of magnetic circuits by saying that the tiny magnetic particles in the iron or steel

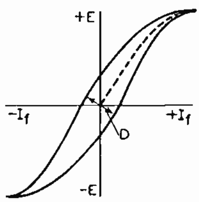


FIG. 7A. Example of a hysteresis loop for iron; this is really the magnetization curve in Fig. *6B* completed for one complete cycle of change in field current. Hysteresis losses are proportional to distance *D*.

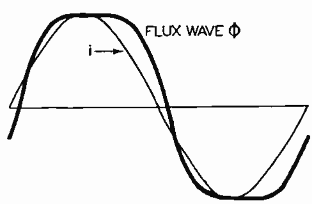


FIG. 7B. When a sine wave magnetizing current *i* is used for an iron-core coil which has hysteresis losses corresponding to the hysteresis loop in Fig. *7A*, the distorted flux wave shown here is produced.

tend to stay lined up with the magnetic lines of force. Now when the field current is reduced to zero, we will still obtain some generated voltage, because the iron retains some of its magnetic properties.

To get rid of this so-called *residual magnetism* in a magnetic circuit, we must reverse the magnetomotive force by sending current through the coil in the opposite direction. If we continue increasing the field current in the opposite direction, we will again reach the condition of saturation; flux now flows through the armature in the opposite direction, and the induced voltage is of opposite polarity. Decreasing this current to zero again and then reversing its direction and increasing its value to get maximum positive saturation will give us a complete cycle of changes in magnetizing current. If the data for this complete cycle is charted on a graph, we will secure a curve like that shown in Fig. *7A*, which is called a *hysteresis loop*. The wider this loop is at *D*, the more reverse current or energy is required to remove the residual magnetism.

To be sure, it is not customary to vary the field current of a generator in this fashion, but the magnetizing current in a transformer does go through exactly this same cycle of events when the primary current is of sine wave form. Clearly, then, we should expect iron cores in choke coils or transformers like those shown in Fig. *4* to become saturated for a part of each cycle when primary current is excessive. Under this condition the resulting flux wave produced by a sine wave primary current i will be considerably distorted, as indicated in Fig. *7B*, and the secondary voltage induced by this flux will be correspondingly distorted.

The radio engineer tries to use iron cores which have the narrowest possible hysteresis loop and endeavors to keep the primary current below the point at which distortion due to saturation will occur. In this way he can keep distortion and losses due to hysteresis at a minimum.

Eddy Current Losses. There is one other important loss which occurs when alternating current is sent through an iron-core coil. The iron in the core is a fairly good conductor of electricity, and acts like a great number of rings, each of which behaves like a short-circuited secondary turn. The varying flux in the core induces a voltage in each ring, this voltage sends through the ring a current which is known as an *eddy current*, and the eddy current in turn sets up a flux which tends to reduce the original magnetic flux. As a result, the inductance of the iron-core coil is lowered, causing excessive primary current to flow, and considerable power is wasted in these eddy currents.

Eddy current losses can be reduced considerably in low-frequency iron-core devices by constructing the core from thin sheets of steel called *laminations*. These sheets are annealed (softened) in such a way that their surfaces are coated with an iron oxide which is a fairly good insulator; oftentimes the surfaces of the laminations are varnished in addition, to give even better insulation. Thus the eddy current rings are made negligibly small in size. Both eddy current and hysteresis losses increase greatly with frequency; this is the reason why even laminated iron cores are of no value for radio frequency purposes. (By using cores made of finely powdered steel mixed with bakelite, engineers have reduced these losses enough to permit use of these cores at radio frequencies, with resulting increases in inductance for a given coil.)

B-H CHARACTERISTICS OF MAGNETIC MATERIALS

Manufacturers of laminated sheet steel for iron-core coils and transformers generally specify the characteristics of their materials by means of curves like those in Fig. *8*, which give the relation between magneto-motive force per unit volume of the material (a block or cube of the material) and flux density. The magneto-motive force is expressed either in gilberts per centimeter or ampere-turns per inch, and is usually assigned the symbol H. Flux density is expressed either in kilolines (kilogausses) per square centimeter or per square inch, and is usually assigned the symbol B. For convenience these curves expressing the characteristics of magnetic materials are commonly called *B-H curves.*

Note that for air the abscissa (horizontal scale) readings must be multiplied by 200; this is because air is so much poorer a magnetic conducting material than iron or steel. The curve for air applies also to non-magnetic materials like brass, copper, wood, bakelite and fiber. Furthermore, this graph shows clearly that flux density increases uniformly with magnetomotive force only for air and non-magnetic materials; all magnetic materials become saturated when subjected to large magnetomotive forces.

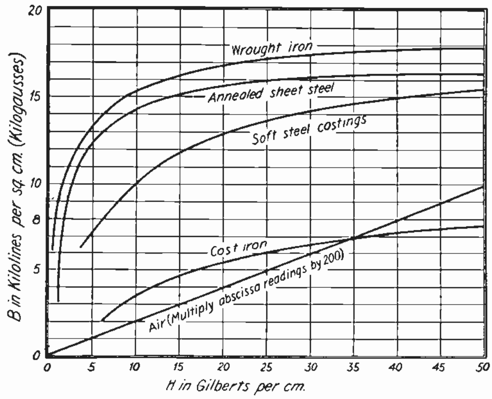


FIG. 8. Curves like these, known as B-H curves, tell radio designers how various magnetic materials will behave when used as cores for coils. The horizontal scale (abscissa) corresponds to magnetomotive force, while the vertical scale corresponds to flux; with these relations in mind, you can see that for iron and steel, increasing the m.m.f. (H) beyond a certain point results in saturation and little or no increase in flux (B).

In your work you will seldom if ever have occasion to use B-H curves. They are intended primarily for the designer of iron-core devices, and tell him how much magnetomotive force he will require to send the desired amount of flux through a particular magnetic circuit. B-H curves have been taken up here only to show that good iron-core chokes and transformers cannot be designed merely by guesswork. It takes engineering skill and a knowledge of the characteristics of magnetic materials to build good iron-core devices, and there are definite limits to the uses for each device.

AIR GAPS AND LEAKAGE FLUX

I have just shown you how saturation and its resulting distortion of the flux wave can be eliminated by using air for the magnetic path. An air-core coil has little inductance, however, so the designer combines the two magnetic materials, using an iron core to get the desired amount of flux with a reasonable number of ampere-turns, and inserting in the magnetic path an air gap whose reluctance is so high in comparison with that of the iron path that it predominates and results in negligible saturation.

The use of iron for magnetic paths has another important advantage in that it keeps magnetic flux in a definite path where it will not too greatly affect nearby apparatus. There is, however, always a certain amount of flux which prefers a path through the air surrounding an iron core, as indicated in Fig. *9A*. This condition corresponds to the electrical circuit shown in Fig. *9B*, where the leakage resistance of the condenser acts as a leakage path for alternating current around the condenser load. In magnetic circuits more flux takes these leakage paths as the iron core becomes saturated, for the reluctance of a saturated core goes up very rapidly.

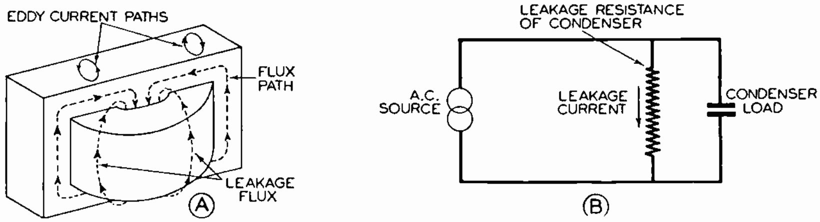


FIG. 9. These diagrams show the similarity between leakage flux in a magnetic circuit and leakage current in an electric circuit.

In iron-core coils and transformers the leakage flux is relatively unimportant as far as operation of the device itself is concerned, but this leakage flux can create interference by inducing voltages in nearby circuits. Designing the iron core to operate below saturation keeps leakage flux at a minimum; furthermore, the coil and core together are often covered with a soft steel casing like that shown in Fig. *2A* and in some of the transformers in Fig. *4A*, so leakage flux will flow through this casing and back to the iron core instead of wandering off through air.

Obviously, energy utilized in producing leakage flux is wasted, for in a transformer this leakage flux does not link the secondary coil. Leakage flux therefore *does not induce any voltage in the secondary winding* of the transformer in which it is produced. Leakage flux gives to the primary winding an inductive reactance (usually called a leakage reactance) which acts in series with whatever impedance the secondary load reflects into the primary, thereby limiting the primary current.

POWER TRANSFORMERS

Homes in this country are commonly wired for 110 to 115 volts A.C. power, with a few having 220 volt A.C. lines. It is highly desirable to obtain all voltages required for a radio receiver from this power line; this means that we must have low A.C. voltages for the filaments and heaters of the tubes, and high A.C. voltages which can be converted into D.C. for the various tube electrodes. Line voltage must be stepped up (increased) in one case and stepped down (decreased) in the other case. A power transformer is used for this purpose.

Air gaps are rarely used in the iron cores of power supply transformers, for any slight distortion of the line voltage wave form is quite permissible and saturation effects are relatively unimportant. The primary winding of the power transformer, which is connected directly across the power line, is so designed that when the secondary windings are open only enough primary current will flow to keep the iron core at the desired flux density. The number of turns required for this condition divided by the applied line voltage gives what is called the turns-per-volt ratio of the primary.

Turns-Per-Volt Ratio. The number of turns required on a secondary winding in order to secure a certain voltage can be determined simply by multiplying this desired voltage by the turns-per-volt ratio of the primary. For example, if the primary has a ten-turns-per-volt ratio and 500 volts is desired at the secondary winding, this winding will require 500 times 10, or 5,000 turns. The turns-per-volt ratio of a power transformer varies considerably with the design of the transformer.

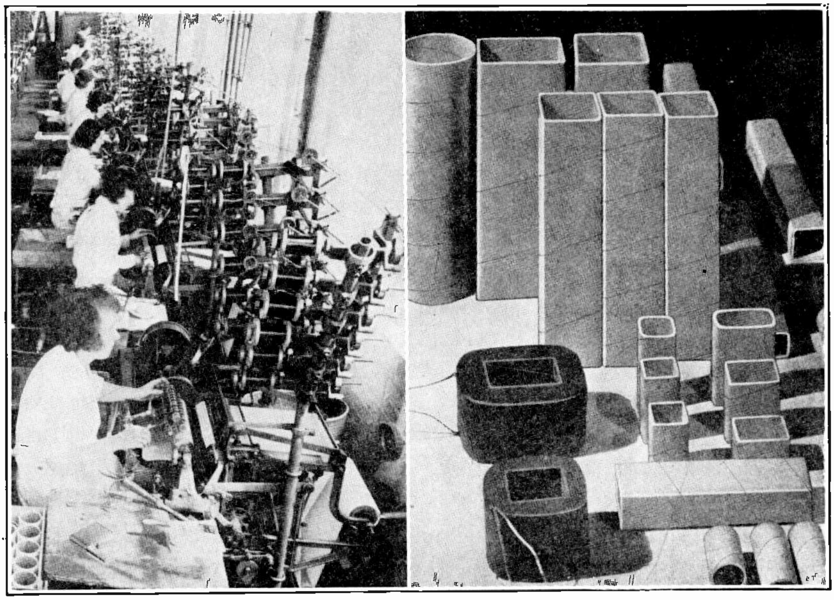
Turns Ratio. Although designers of power transformers think in terms of turns-per-volt, users of these transformers prefer to think in terms of how many times more turns there are on one winding than on another; they call this value the *turns ratio*. For example, if one winding has twenty times as many turns as the other, then one voltage will be twenty times as high and the turns ratio will be 20. The turns ratio and primary voltage alone are not sufficient to determine the secondary voltage; you must also know whether you have a step-up or step-down transformer.

You can always measure the turns ratio of a power transformer by connecting it to an A.C. source of known value and measuring the voltage across each winding. The larger voltage divided by the smaller voltage gives you the turns ratio. The winding giving the highest voltage will have the most turns of wire.

A word of caution—before you connect a power transformer into a voltage source, be sure that the winding will handle that voltage safely; otherwise the current flow will be excessive, and the transformer may heat up to the point where it will be seriously damaged. For this reason you should always observe voltage ratings. You can connect a winding to a voltage lower than its rated value, but never to a voltage which is considerably higher than rated value.

When a power transformer has several secondary windings, the primary winding must supply the power required for each secondary winding, together with the power wasted in the eddy current, hysteresis and copper losses of the transformer itself (copper losses are those due to the production of heat in the electrical resistance of the copper windings).

A power transformer which had no losses could transfer unlimited



Courtesy Universal Winding Co.

Scene in an American factory which manufactures iron-core transformers for radio purposes, showing the machines used for winding the coils. Six or more coils are wound on a single spiral-wrapped paper form like one of those shown at the right; when winding is completed and the operator has anchored the lead wires, the machine automatically separates the coils with sharp cutting knives. Operators perform only the starting and finishing operations; the machines do the rest, placing layers of insulating paper between each layer of a winding and stopping automatically when the correct number of turns has been wound. Samples of finished coils produced by machines like these can be seen in the foreground in the righthand photo.

amounts of power, but all actual transformers have losses and these increase so greatly as load is applied that a practical limit is reached above which the transformer becomes overheated and subject to breakdown. Power transformers are therefore rated according to power handling ability as well as voltage. The larger the wire used for the windings (to reduce resistance) and the larger the iron core (to reduce hysteresis and eddy current losses), the more power will a transformer be able to handle. This is why power transformers having high power ratings are so large and heavy. The weight of a power transformer is a good indication of its power handling ability.

IRON-CORE CHOKES

Up to this point in the Course I have considered the inductance of a coil as being determined by the flux linkages produced when one ampere of current flows. This is a perfectly satisfactory definition for air-core coils and any other coils where flux increases uniformly with current, but when we come to iron-core coils we must take the effects of saturation and hysteresis into account by considering the *changes* produced in flux linkages by *changes* in coil current.

We can simplify our study of the inductance of iron-core coils by considering a typical coil having a definite number of turns and a certain iron core, and determining how flux varies with current either by actual measurements or by computations based upon the B-H curve for the core material. Let us assume that the curve in Fig. *10* is secured with our typical coil.

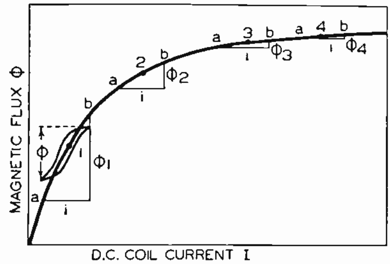


FIG. 10. Magnetization curve for an iron-core choke, showing how the value of D.C. coil current *I* affects the opposition which the coil offers to alternating current.

At point *1* on the curve in Fig. *10*, a current change i produces the flux change Φ_1, but at points *2*, *3* and *4* the same current change produces less and less change in flux. Consequently, according to the definition for inductance, our coil will have the highest inductance when the direct current through it is low (below point *1*) and will have the lowest inductance when the direct current is beyond point *4*.

If we consider these current changes to be produced by alternating current flowing through the coil along with direct current, then we have the condition existing in power pack filter chokes and in plate load inductances of vacuum tube circuits. The direct current makes the iron core operate at a definite flux density (at a definite point on the curve in Fig. *10*), while the alternating current makes the flux vary above and below this operating value.

Now you can realize that an iron-core coil operated near saturation (as at point *4* in Fig. *10*) will offer very much less inductance to A.C.

than will a coil operated lower down on the flux-current curve or B-H curve. The amount of direct current actually determines what the inductance of the coil will be; increasing the direct current brings the iron core closer to saturation and thus reduces the inductance.

If this direct current (often called a *polarizing current*) is made large enough, by accident or otherwise, to produce saturation, then the coil will have *little or no inductance* and will offer very little opposition to the flow of alternating current. For example, if the power pack in a radio receiver is overloaded, excessive direct current will be drawn through the filter choke, saturating its core and removing its inductance. As a result the rectified A.C. voltage will not be properly filtered, and a loud 60 or 120-cycle hum will be heard from the loudspeaker.

The insertion of an air gap in the magnetic circuit of an iron-core coil tends to prevent saturation, making the inductance more uniform. For this reason a great many chokes are made with an air gap in the middle leg; being inside the coil, however, it cannot be seen unless the coil is cut away.

Hysteresis is another important factor affecting the performance of an iron-core choke coil. You are already familiar with the hysteresis loop obtained by varying coil current from maximum positive to maximum negative values and plotting measured values of flux; in our iron-core coil, which is carrying both A.C. and D.C., the coil current is likewise passing through maximum positive and negative values, and consequently the flux will actually be following little hysteresis loops at each operating value (the hysteresis loop around point *1* in Fig. *10* is an example), instead of following the main curve. If the width of this hysteresis loop is too great, the alternating current will be greatly distorted in passing through the choke coil. The greater the hysteresis effect, the greater will be the distortion; furthermore, hysteresis effects also tend to lower the inductance of a coil. (You can verify this statement by referring to Fig. *10;* for a given change i in coil current, flux change Φ_1 occurs when there is no hysteresis, while the considerably smaller flux change Φ is obtained with the hysteresis loop shown. This smaller flux change means hysteresis has lowered the inductance of the coil.) The designer minimizes these by choosing for the core a laminated sheet steel which has negligible hysteresis losses.

Let me summarize for you the important facts about iron core coils which carry both alternating current and direct current:

1. When iron-core chokes are used in radio circuits, the maximum value of direct current specified by the manufacturer must not be exceeded if rated inductance is to be secured.

2. Increasing the direct current through an iron-core coil *reduces* its inductance.

3. Transformers used in amplifier circuits must be operated at or below a specific polarizing current if distortion of the output is to be avoided.

For this reason audio transformers are specified for operation with definite tubes; since different tubes draw different D.C. plate currents, this is merely a convenient way of specifying the polarizing current for which the transformer was designed.

Swinging Chokes. In the filter sections of power packs using mercury vapor rectifier tubes, the choke nearest the tube will function more efficiently if its inductance decreases considerably when rectified current goes up. This choke is therefore designed to have a less effective air gap; since its inductance swings up and down with current, it is known as a *swinging choke.*

AUDIO FREQUENCY TRANSFORMERS

Transformers are widely used for coupling purposes in the low frequency amplifier sections of sound receivers, as well as in public address and intercommunication systems. There are four outstanding properties of transformers which make them preferable to other coupling systems:

1. **A coupling transformer can give a highly desirable step-up in signal voltage.**
2. **A coupling transformer can be made to match two different impedances, thereby giving maximum transfer of power.**
3. **A coupling transformer transfers only alternating current, keeping direct currents in their proper circuits.**
4. **The response characteristic of a coupling transformer can be made uniform over a wide range of audio frequencies.**

Audio frequency transformers are essentially iron-core chokes with an extra winding placed on the core to serve as the secondary. Just as with chokes, the iron core has an air gap in order to prevent magnetic saturation of the core. Only the best grades of sheet steel laminations made for radio purposes can be used, for eddy current losses, hysteresis losses and distortion must be kept low over a wide range of audio frequencies.

A high turns-per-volt ratio is very desirable in audio frequency transformers, for it gives a more uniform response over the frequency range. There is very little loss in a good A.F. transformer, and the loss which does exist merely has the effect of a high resistance shunting the primary winding.

Leakage inductance can be kept at a minimum in A.F. transformers by using tight coupling between primary and secondary windings. At high frequencies, however, this leakage inductance acts with the distributed capacity of the turns in the coils and the capacity between primary and secondary coils to form a resonant circuit which boosts the primary A.F. current at high frequencies; this is why some transformers give higher output voltages at the higher frequencies.

TYPICAL USES FOR A.F. TRANSFORMERS

A few examples of how A.F. transformers are actually used in radio circuits will help to clarify the things I have just told you. In Fig. *11A* is the schematic circuit diagram of an audio amplifier used in many radio receivers today. Tube VT_1 in the voltage amplifier stage feeds through audio coupling transformer T_1 into the grid of tube VT_2 in the output or power amplifier stage. The A.F. signal current i_{P1} flowing through the primary of T_1 induces voltage e_{S1} in the secondary. Furthermore, the primary current flowing through the primary reactance causes a voltage e_{P1} to be developed across the primary; e_{P1} multiplied by the turns ratio of the transformer gives the value of e_{S1}, for T_1 is a voltage step-up transformer. Since the grid of tube VT_2 is negatively biased, there is no load across the secondary winding, and no secondary current.

Secondary voltage e_{S1} acting on the tube VT_2 causes an A.F. plate current to flow through the primary of audio transformer T_2, inducing in the secondary of this transformer a voltage e_S. The loudspeaker acts as a load across the secondary, and current i_S flows. Since an output transformer, if properly designed, has negligible power loss, the power supplied to the loudspeaker (i_S multiplied by e_S) will be equal to the power supplied to the primary.

Maximum power is transferred from tube VT_2 to the loudspeaker when the A.C. plate resistance of the tube equals the impedance or resistance of the load circuit (which here is the loudspeaker and transformer T_2). The loudspeaker has a definite impedance, so that a definite current i_S will flow for a definite secondary voltage e_S. But only for the case where T_2 is a 1-to-1 ratio transformer (same number of turns on primary as on secondary) does the tube "feel" this value of load impedance; for all other turns ratios, the impedance across terminals *1* and *2* (which are the load terminals as far as the tube is concerned), is equal to e_P divided by i_P (Ohm's Law for A.C. circuits). If the primary has more turns than the secondary, e_P will be greater than e_S by the turns ratio, and i_P will be smaller than i_S by the turns ratio, so the primary impedance will be very much greater than the load impedance.

By changing the turns ratio we can get exactly the values of i_P and e_P which will make the primary impedance equal to the A.C. plate resistance of the tube and at the same time supply the required voltage and current to the load. T_2 here serves as a *matching transformer,* for in one direction it offers a correct impedance match to the source, and in the other direction delivers the correct voltage and current to the load. A radio man seldom finds it necessary to make calculations of impedance, for he can secure transformers which are designed to match definite values of impedance or to couple definite types of loudspeakers with definite tubes and give maximum transfer of power.

Notice that the primaries of transformers T_1 and T_2 also carry the D.C. plate currents of the tubes to which they are connected. This polarizing current must therefore be taken into account when selecting or designing the transformer. An A.F. transformer designed for a tube circuit which has low direct current should not be used in a circuit which is supplying a high D.C. plate current, for distortion would result. It is usually permissible, however, to use transformers designed for high polarizing currents in circuits which have low direct current.

Audio transformers which have a center-tapped primary winding or center-tapped secondary are for use in so-called push-pull and push-push circuits, which will be studied later in the Course. A typical

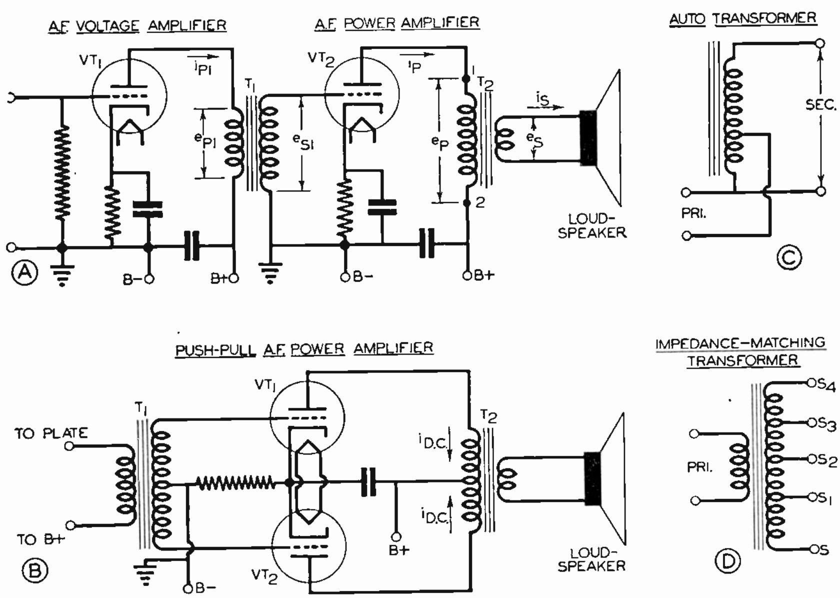


Fig. 11. Several types of A.F. transformers are shown in these typical radio circuits. Schematic diagrams for an auto transformer *C* and an impedance-matching transformer which has several extra taps for universal use *D* are also given.

push-pull circuit is shown in Fig. *11B* merely to indicate the transformer connections. Here T_1 is a voltage step-up transformer, while T_2 is an impedance-matching transformer. Observe that D.C. plate current flows in opposite directions through the primary of T_2; the magnetic fluxes produced by these currents therefore cancel, and there is no possibility of saturation in this particular transformer.

A special type of audio transformer known as an *auto transformer* is shown in Fig. *11C*. It consists simply of a single winding which is tapped at one point. Voltage is applied between this tap and one end of the winding, and voltage is taken off between the two ends of the winding, as indicated. The number of turns in the entire winding divided by the number of turns connected across the input terminals gives the voltage step-up ratio of this auto transformer.

An audio transformer having many taps on the secondary winding is called an impedance-matching transformer. An example of one is shown in Fig. *11D;* by connecting the load between terminal S and one of terminals S_1, S_2, S_3 and S_4, the correct turns ratio for a satisfactory match can be secured. Transformers like these are widely used in public address systems for matching amplifiers with different types of loudspeakers and for connecting more than one loudspeaker to an amplifier.

PUTTING SATURATION TO USE

Although saturation is a highly undesirable condition in iron-core chokes and A.F. transformers used in conventional radio circuits, saturation does have a number of interesting and useful applications. Of particular interest to radio men is the electric lamp (colorama) tuning indicator used in some of the radio receivers manufactured by the General Electric Company. The station tuning dial in these receivers is illuminated by the light from a group of red bulbs when a station is not properly tuned, but is illuminated by green lamps when the receiver is correctly tuned to a station. A study of the circuit diagram in Fig. *12* will show you just how saturation is utilized to secure this novel indication of correct tuning.

Power transformer T_2 in Fig. *12* furnishes A.C. power to the tuning lamp circuit; its voltage is high enough for either the series-parallel group of red bulbs alone or for the series group of green bulbs, but not for both groups at once. Transformer T_1 has an iron core which saturates readily. The primary of this transformer is connected into the plate circuit of an R.F. amplifier tube whose D.C. plate current is high when the receiver is not tuned to a broadcast station or is incorrectly tuned, but is low when a station is properly tuned in. The high plate current naturally saturates the core of T_1, reducing the inductance across the secondary (across terminals *1* and *2*) to a very low value so that the secondary acts as a short circuit, preventing any current from flowing through the green bulbs. Thus the full secondary voltage of T_2 is applied to the red bulbs and they glow for the condition when the receiver is not tuned to a station.

Now let us see what happens when the receiver is tuned correctly to a station. The D.C. plate current drops, the core of T_1 is no longer saturated, the inductance of the secondary of T_1 becomes high, and we have the effect of an open circuit between terminals *1* and *2*. Now the current flowing through the two groups of bulbs is sufficient to light the green bulbs, but not enough for the series-parallel group of red bulbs. The 15-ohm resistors serve to keep the currents at the proper values for each condition.

IDENTIFYING IRON-CORE CHOKES AND TRANSFORMERS IN RADIO RECEIVERS

Power Transformers. You can generally assume that the largest iron-core device in a radio receiver is the power transformer, for it must handle all of the filament power and electrode power required by the tubes in the receiver. There are, however, a number of other clues which will assist you in identifying the power transformer.

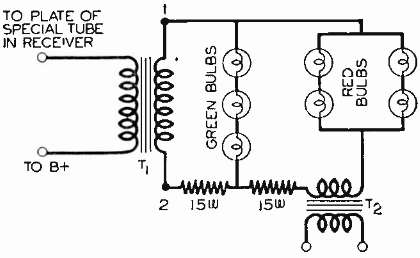
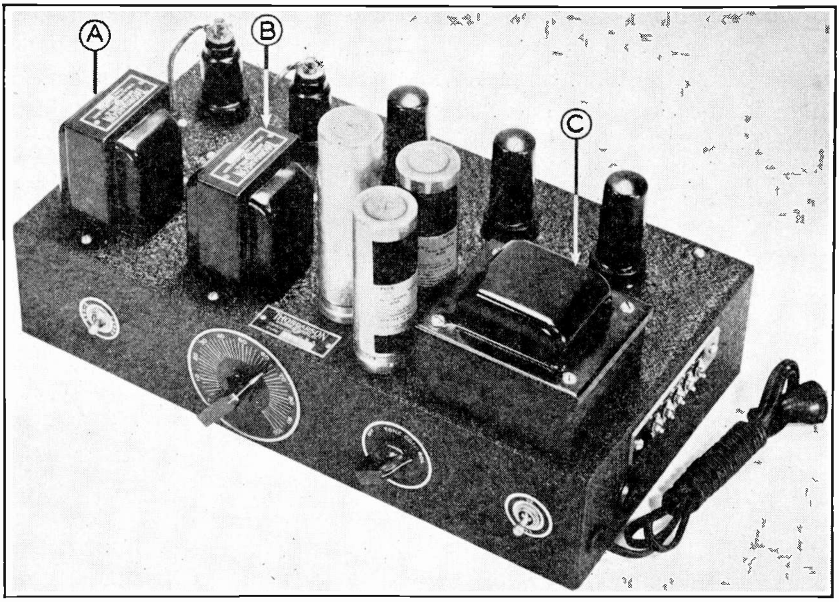


FIG. 12. Simplified diagram of the General Electric Colorama tuning system, an excellent practical example of saturation being put to a useful purpose.

Power transformers have a great many terminals or leads. You will find heavy insulated wires (usually twisted) running from it to the filament terminals of each tube socket, with two or more sets of these twisted wires in some receivers. You will find two wires running from the power transformer to the plates of the rectifier tube (assuming it is a full-wave rectifier tube). Two more wires will run directly to the line cord through the on-off power switch of the receiver.

The high-voltage secondary winding of a radio receiver power transformer can always be identified with an ohmmeter, for it will have *the highest resistance* of all windings on the core. This winding will usually have a center-tap terminal located between the two outer terminals of the winding; naturally the resistance between this mid-tap and an outer terminal will be *about* half of that between the two outer terminals. (Since the tap is so located that the number of turns on each section of the winding are equal, that half of the winding which is closer to the iron core will use the least wire and will have a lower resistance than the outer half of the winding, assuming conventional layer-wound coils.)

Iron-Core Chokes. You can distinguish iron-core chokes from iron-core transformers in radio receivers by counting the terminals (or leads). Iron-core chokes will have two or three terminals (or leads), while transformers have at least four leads. (Auto transformers have three or more leads, but are seldom found in radio receivers.)



Courtesy Thordarson Electric Mfg. Co.

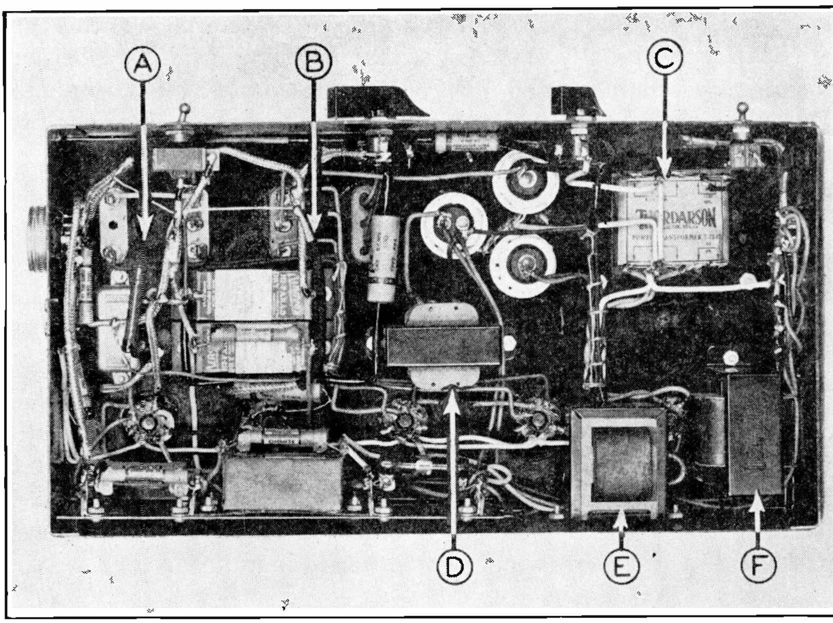
Positive identification of the iron-core transformers mounted on the chassis of this Thordarson 6-watt audio amplifier cannot be made without looking underneath the chassis and counting the lead wires for each unit. A bottom view of this chassis appears on the opposite page.

Iron-core chokes used in radio receivers are of two types, those designed to handle A.F. signal currents and those designed to filter the rectified current in the power pack.

Signal current chokes are so rare in the average radio receiver that it is safe to assume any iron-core choke to be a filter choke, unless you can trace a connection from this choke directly to the grid or plate of a signal circuit tube. Signal current chokes are small in size, and have many turns of fine wire.

Filter chokes, as used in power supply systems, must handle rather large direct currents; their D.C. resistance will range from 100 to 1,000 ohms. Incidentally, the field coil of a dynamic loudspeaker is very often used as a filter choke as well as for producing magnetic flux for the loudspeaker.

Audio Transformers. Immediate identification is perhaps most difficult in the case of audio transformers. For one thing, it is safe to assume that a receiver which uses a dynamic loudspeaker always has an output transformer or impedance-matching transformer between the loud-



Courtesy Thordarson Electric Mfg. Co.

The transformers used in this audio amplifier are identified as follows by counting leads: *A*, auto transformer—5 leads (this can be identified positively only by referring to the circuit diagram, for an output transformer, a coupling transformer or a filament transformer could also have 5 leads); *B*, output transformer—8 leads (could also be a power transformer, but only one is needed here and that is positively identified as *C* because of its larger size); *C*, power transformer—10 leads; *D*, filter choke—2 leads; *E*, filter choke—2 leads; *F*, filter choke—2 leads.

speaker and the output stage. Generally this transformer will be mounted on the frame of the loudspeaker, but if not, there will be two wires running from the loudspeaker to the transformer.

In the case of a two-tube output stage, the plates of the output tubes will connect to the outer terminals of the primary winding on the output transformer, and there will be a center tap on this winding. In the case of a single-tube output stage, one end of the primary will go to the plate of the output tube and the other end will go to the highest output voltage terminal in the power supply.

Since the impedance of the average loudspeaker is much lower than the A.C. plate resistance of an output tube, a step-down ratio is required in the output transformer. The primary winding will therefore have a much higher resistance than the secondary winding (which connects to the loudspeaker).

Most of the other A.F. transformers which you will encounter in receivers have voltage step-up ratios, and can be identified through their connections to the grids and plates of amplifier tubes. The primary winding, which connects to the plate of a tube, will therefore have a lower resistance than the secondary winding. Transformers of this type are heavier and usually much larger than output transformers, because the primary windings on an A.F. coupling transformer must handle the D.C. plate currents and therefore must have a large enough core to prevent saturation.

The above suggestions are merely of a general nature; for further information on a particular receiver, it is recommended that you refer to the schematic circuit diagram and service instructions for that receiver, particularly if you encounter exceptions to the above general statements.

Looking Ahead. Having now mastered the important fundamental features of most of the parts used in radio equipment, and having acquired a good idea of how these parts perform in vacuum tube circuits, you are ready to study in detail the use for these vacuum tube circuits in radio apparatus. In the next two lessons you will find a wealth of interesting and highly practical information on A.C. to D.C. power packs and special power supply systems used in radio.

TEST QUESTIONS

Be sure to number your Answer Sheet 11FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Name three important uses for magnetic fields in iron-core radio devices.

2. When a movable magnetic object is placed in the magnetic field produced by some device, what position will this object take?

3. What is the opposition effect in a magnetic circuit called?

4. What is the *practical unit* of magnetomotive force for coils?

5. What condition is said to exist in an iron core when increases in magnetomotive force produce little or no increase in magnetic flux?

6. How can eddy current losses be reduced considerably in low frequency iron-core devices?

7. Does leakage flux induce any voltage in the secondary winding of a transformer?

8. If the polarizing current in an iron-core choke coil is made large enough to produce saturation of the core, what inductance will the coil have?

9. When checking the various windings of a radio receiver power transformer with an ohmmeter, how could you identify the high-voltage secondary winding?

10. How can you distinguish iron-core chokes from iron-core transformers in radio receivers, assuming that the terminals or leads can be counted?

HOW THE A.C. RECEIVER GETS ITS POWER

12FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

CASHING IN ON DISCONTENT

Discontent — dissatisfaction — these are not pleasant words. Yet it is to discontent that the world owes practically all advancement. If Columbus had not been discontented with the accepted ideas of geography in his day, he would not have started out to prove that the earth was round — and the whole course of history would have been changed.

If the early Americans had been content to dwell at their ease in the eastern part of America, the far west with all its rich natural resources might never have been discovered.

If you had not been discontented with your lot, you would never have enrolled for the N. R. I. Course — and you would never have had similar opportunities for Success.

So — discontent is a good thing — if it makes you want to do something worth while.

Practically everyone is discontented — we are all the same in this — and we all have the same starting point. But some of us are "floored" by discontent, we develop into complainers, we find fault with anything and everything. We end up as sour and dismal failures.

Those of us who are wise use our discontent as fuel for endeavor. We keep striving toward a goal we have set for ourselves. We are happy in our work. We face defeat, and we come out the victors.

At this minute you may be discontented with many things — your progress with your Course, your earning ability, yourself.

Make that discontent pay you dividends. Don't let it throw you down. If you do, you may never be able to get up again. Keep striving to remove the cause of your discontent. Remember that it's always darkest before the dawn. And a real N. R. I. man works hardest and accomplishes most when he is face to face with the greatest discouragements.

J. E. SMITH

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
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How the A.C. Receiver Gets Its Power

SIGNAL AND POWER CIRCUITS

So far I have explained to you how the essential parts that go to make radio equipment (coils, condensers, resistors, transformers, vacuum tubes) work. In later lessons you will learn how vacuum tubes work—as radio frequency amplifiers, as generators (oscillators) of A.C. currents, as audio frequency amplifiers, as modulators that mix radio and audio frequency signals, as demodulators or detectors that separate two signals, as automatic volume controls, as a device that squelches or stops reception when the signal is too weak (quiet automatic volume controls or noise suppressors), and so forth. But before a tube can perform the function it is designed for, it must be supplied with local power. The filament or cathode must be heated to drive off or emit the electrons, the electrodes (grids, screens and plates) must be supplied with a positive or negative charge to assist or control the electrons in the tube while in motion. The filament source may be A.C. or D.C., depending on the tubes used; but the voltages applied to the electrodes must be *continuous,* which is a D.C. voltage without a fluctuation. Let me repeat, the power supply system of a vacuum tube radio device must furnish the following electrical power: A.C. or D.C. for the tube filaments and continuous current (D.C.) for the tube electrodes.

My present discussion will be limited entirely to the local power supply system. You might well ask: can we discuss the supply circuit without the other radio circuits? Indeed we can. When you come to trace radio circuits as an expert, you will automatically divide a radio sound or television receiver, or an amplifier, or a radio transmitter, or a radio testing device, into two parts, namely: *a,* the signal circuits; *b,* the power supply circuits. In fact, the separation is so important that special parts called filters, blocking condensers, bypass condensers, and chokes are used to keep these two circuits from acting on each other. Let me also stress that if you master the important functions of the power supply system, learn to trace them in radio equipment, you will be able to handle many of the common service complaints. I am taking this opportunity to caution you to read this book slowly, as it is full of important radio information.

FILAMENT POWER

Let us study, more closely, what voltages are required to make a triode, a tetrode, and a pentode operate properly. I am omitting, for the moment, the diode and twin diode as they require special consideration.* Referring to Figs. *1A* to *1D* you will observe what voltage supplies are needed, presented in the usual schematic or circuit symbol method. Figure *1A* represents the simplest triode, a tube extensively used as a power amplifier. The filament, when heated by a D.C. current, will emit electrons. A continuous D.C. voltage connected between *K*, the filament, and *P*, the plate, will draw the electrons from the filament to the plate; and a continuous D.C. voltage connected between the cathode (in this case the filament) and *G*, the grid, will electrically set the tube at the best operating condition. Observe that the grid is connected to the negative terminal of the C supply and this voltage is referred to as the "C bias" because it places a potential difference between the grid and the filament.

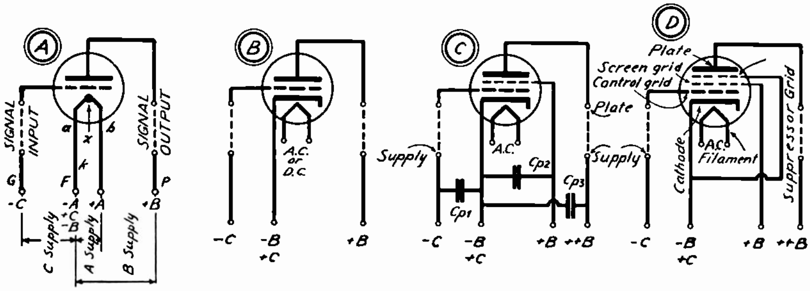

FIG. 1

The supplies required for a triode, tetrode and pentode

Heating with an A.C. Source. If A.C. current is fed to the filament the current rises to a peak twice for each cycle, once on the positive and once on the negative alternation. There is no difference which alternation does the heating. Thus the filament will come to peak heat 120 times a second, if standard 60 c.p.s. (cycles per second) current is used. If the filament is very thin, it will heat and cool rapidly and the electrons going from the filament to the plate will be varied by something else besides the input radio A.C. signal; and the loudspeaker will emit a power supply hum.

To remove the varying heat (twice the frequency of the source) the filament is made large so it will not cool off or heat up rapidly. And this is exactly how so-called A.C. filament tubes are made.

This is not all that is required to operate a tube satisfactorily; it is important that the "C" bias and plate supply voltages remain constant at all times, for the A.C. radio signal at the input (grid circuit) is the only varying quantity that should produce a varying (plate circuit)

* When diodes are used in the signal circuit they usually require only filament power. In this lesson the diode is important as it is used to convert A.C. power to D.C. power. I will come to this shortly.

output. When the filament is fed with a D.C. current, the $+C$ and $-B$ connections of the electrode voltages may be connected to either $-A$ or $+A$ filament terminals.* But suppose an A.C. source is connected to the filament; terminal *a*, Figure *1A*, will at one moment be negative with respect to terminal *b;* and the next alternation of the A.C. supply *a* will be positive with respect to *b*. The electron path from the filament to the plate will have to encounter this voltage drop between *a* and *x* and *x* and *b*, and thus vary the steady "C" bias and plate voltage supply. Now should the $+C$ and $-B$ connections be made at point *x*, which is midway between *a* and *b*, this drop is avoided and the "C" bias and plate voltage remain fixed regardless of the use of an A.C. filament supply.

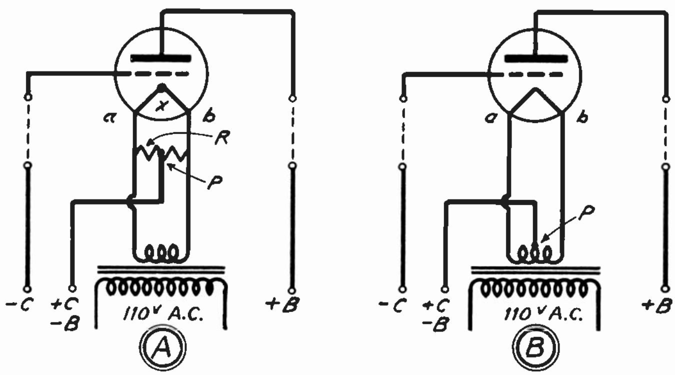

FIG. 2

The connection to *x* is inside of the tube, but it is not necessary to bring this connection out to a special prong on a tube base. There is another way of getting a mid-potential. If you shunt terminals *a* and *b* with a potentiometer *R* as shown in Figure *2A*, you have duplicated a condition which is similar to the internal (point *x*) filament connection. If the control *P* is set to the center of resistor *R*, it will always be at the same potential as point *x*. Now there is a general circuit law that says that terminals of equal potential may be connected without a change in the circuit currents. Therefore, points *x* and *P* may be considered as being the same. Figure *2A* is the accepted connection for a filament type tube, such as the 45, when the filament is heated by an A.C. current.

Figure *2B* shows a less expensive connection for A.C. filament type tubes. In this case the filament is again connected to the low voltage secondary of a 110 volt A.C. step-down transformer. The secondary

* Although either may be used, the —A terminal connection has become standard.

is provided with a center tap P, so located that when the A.C. voltages between P and a, and P and b are measured, they are equal. For this reason point P is called the electrical center. It is the $+C$ and $-B$ terminal as far as the supply circuit is concerned.

A step-down transformer is generally needed with A.C. receiver tubes,* as the filament voltage is rarely above 30 volts, the most common voltages being 1.5, 2.5, 6.3, 12 and 25 volts. The center tapped secondary is not required for heater type tubes, but when supplied is usually connected directly to the cathode of the tube.

Multiple Filament Connection. Now I am going to explain how more than one tube may be supplied with filament power. Where several tubes of the same filament voltage rating are used in radio equipment, the filaments may be connected in parallel as shown in Fig. *3A*, and to the low voltage secondary of a power transformer. Where heater and filament type tubes or tubes of different filament voltage ratings are used in the same receiver, generally separate filament secondary windings are used for each group, as shown in Fig. *3B*. For example, a 2.5 volt tube cannot be connected in parallel with a 6.3 volt tube for the filament of the 2.5 volt tube will draw too much current and burn out. Quite often an inexperienced serviceman by mistake, puts a 2.5 volt tube in a socket where a 6.3 volt tube is intended, and "puff", out goes the tube; or to be exact the filament of the tube will burn out. Not always will you find similar tubes connected to the same filament supply secondary, for special circuits may require separate secondary windings. You will encounter such conditions as you learn more about radio, but now it is the usual conditions that I want you to master.

Figures *3C* and *3D* illustrate two simple multiple tube connections. Here the filaments are connected in series, and the voltage required at xy is the sum of all the individual tube voltages. In this case each tube should have the same current rating. If the source has too large a voltage, then a series resistor R_1 is used.† Very often tubes in the same voltage group are to be connected in series but not all the tubes in a group draw the same current, for example, you will find that some 6.3 volt tubes draw 0.3 ampere, while another draws 0.8 ampere. A simple series connection cannot be used, because the high current tube will probably draw too little, while the low current tube will draw too much current. Where such tubes must be connected in series this difficulty is avoided by shunting (connecting across) the low current filament with a resistor so the resistor will conduct the extra current, R_2 in Fig. *3C* shows such a shunt resistor.‡ Tubes of different voltage ratings may be connected

* In universal receivers where 110 volt A.C. or D.C. is used, in transformerless A.C. receivers the series filament connection, to be described shortly, is used. The voltage is reduced by a series resistance.

† The ohmic value of this resistor is the *extra voltage divided by the series current* (volts $\div$ amperes).

‡ Its ohmic value is the *filament voltage* of the shunted tube *divided by the extra current.*

in series, if their currents are the same. For example, a 6.3 volt, 0.3 ampere filament may be connected in series with a 12.6 volt, 0.3 ampere tube.

Most A.C. socket and battery operated receivers have their tube filaments connected in parallel; while most universal (meaning sets operated from either an A.C. or D.C. supply) and most D.C. socket powered receivers have their tube filaments in series. Whenever a filament is intended for an A.C. source, the connecting leads are twisted as shown in Figs. *3A*, *3B*, and *3D*, to eliminate stray A.C. magnetic fields which may create an A.C. hum output. Also set designers prefer heater type tubes, for in this way the filament circuit is separated from the signal circuits.

Observe that no variable filament current controls are shown in Figs. *3A to 3D*. In the light of modern radio experience it has been found that varying the filament current to change tube characteristics or volume is a very poor method. Too much filament current weakens the filament and burns it out; too little current in addition to making the electron

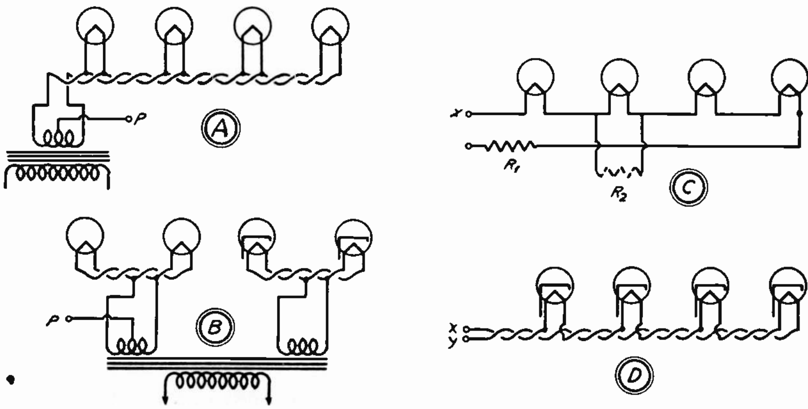

Fig. 3

emission extremely low, causes the filament to become brittle and break. You will rarely find filament current controls in modern, well-designed receivers, although you may find them in some battery receivers, particularly the very old ones. In the latter case you will find one or more tubes connected in parallel and a variable resistor (a filament rheostat) connected between one common filament terminal (usually negative for amplifier tubes) and the battery binding post.

PLATE, SCREEN AND GRID VOLTAGE SUPPLY

For the average three, four, five, and multi-element tubes in a radio receiver the plate, screen and grid supply must be a continuous; that is an unvarying, direct current. No better source than the dry or storage battery can be found; in fact, most laboratory vacuum tube equipment employ battery supplies. A complete *A* (filament), *B* (plate), and *C* (grid) battery supply is shown in Fig. *4*. A storage battery filament supply source is shown, although dry cells in parallel, series, or series-parallel, or an air cell battery may be and often is used. The connection is so obvious that little further explanation is necessary. Any of the tube circuits shown in Figs. *1A* to *1D* may be connected to these battery supplies. Where several tubes are used in the radio device the filaments are connected in parallel and to the A battery. The grids, screens and plates are connected together at the *supply* terminals (see Fig. *1C*) and to the $+B$ and $-C$ supply terminals. Where different values of +B and —C voltages are needed, separate connections as indicated in Fig. *4* are provided. To prevent the A.C. radio signals from passing through the power supply, condensers, shown as C_{p1}, C_{p2}, C_{p3} in Fig. *1C*, are used. Of course, the capacity of the condensers should be large so the signal which is high frequency alternating current, will go through the condensers and not through the power supply. Here is another example of how the A.C. signal and the D.C. power supply circuits are isolated.

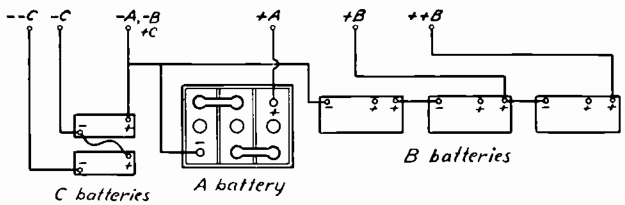

FIG. 4

Every radio expert will agree that no better high voltage D.C. supply than batteries can be obtained. Batteries would be used more often if it were not for: *a*, the expense; and *b*, the bother of changing them when their voltages drop below the useful limit. To give you some idea of cost, let me consider the A battery as a typical case. You can buy a dry cell for about 25 cents. It is rated to give 40 watt-hours. You can buy electric socket power for about 10 cents per 1000 watt-hours. Both values are top figures. Clearly you buy 1.6 watt-hours of battery energy for one cent; but a power company will furnish you 100 watt-hours for a cent, and probably less. It is no wonder that when radio first became popular, many experts worked on the problem of converting cheap A.C. to continuous current power. At first they tried to get pure D.C. current to heat the filaments, but they gave the plan up as too costly and developed A.C. tubes to be used in the manner I have described. High D.C. voltages are more economically produced and it is a simple matter to divide it so the grids, screens and plates are properly supplied. I will come back to this after I explain to you how A.C. socket power is converted (changed) to high D.C. voltage power.

For the average radio receiver and amplifier, 110 volt, 60 c.p.s. power must be converted to about 400 volts D.C. without an appreciable ripple.* In a general way this is how it is done. The low voltage A.C. socket power is first raised to a high A.C. voltage by using a step-up power transformer, because it is not simple to step-up a voltage after it has been converted to D.C. Next the A.C. is passed through a device which we call a rectifier, which allows current to flow only in one direction. A radio rectifier tube is invariably used. This output voltage from a rectifier tube is pulsating direct current varying from a peak (the largest) value, to zero. To remove the variation, the power is passed through an electrical filter consisting of condensers and choke coils, which smooths or wipes out the variation or ripple, leaving a pure D.C. source. Finally the

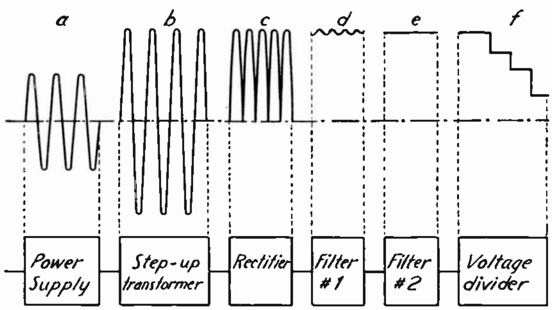

Fig. 5
Sketch showing changes that take place in the D.C. supply section of a power pack

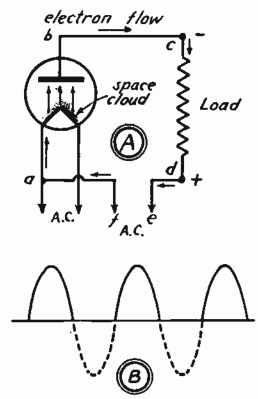

Fig. 6

high D.C. supply voltage is divided as required. The changes from A.C. to divided D.C. are portrayed in Fig. 5. The entire device is often called a "power pack."

THE HALF-WAVE RECTIFIER

Before we consider a practical A.C. to D.C. converting system let me first present the diode tube (two element tube). The simplest diode has a filament which emits electrons when heated. The electrons "hang around" the filament. Technicians call it the electron cloud or space charge. Now when an appreciable positive charge is applied to the plate the electrons in this electron cloud are attracted to the plate, leave the tube at the plate and go through the external load in the plate circuit, and return to the filament to be used over again, as shown in Fig. *6A*. When the plate is negatively charged the electrons in the space near the fila-

* Theoretically you cannot take out all of the variation; practically you can reduce it to an insignificant value. The final test is how much hum you get from the loudspeaker.

ment are forced by the plate's negative charge nearer to the filament Electrons, therefore, cannot flow the other way unless the negative charge on the plate is sufficiently strong to force the electron cloud back into the filament and through the circuit. As a rule electrons only flow in the plate load when the plate is positively charged.

The D.C. output of the rectifier, of course, is used to supply the various electrode voltages. From a practical point of view they are best represented by a resistance whose value is the required D.C. voltage divided by the current drawn. This is what I mean by the "load." Therefore, to change A.C. to pulsating D.C. we connect the A.C. source in series with the load and in series with the "one way" current device (the rectifier), as shown in Fig. *6A*.

I want you to remember which is the (+) positive and which is the (—) negative terminal of the load in a rectifier circuit. If you master the following rules you will never go wrong. Electrons flow from a negative to a positive terminal, which is another way of saying that a terminal with the most electrons will feed the electrons into the terminal with no or less electrons. Current flow, and by this we mean the old conception of current, is just the reverse; current flows from the (+) positive to the (—) negative terminal. Most radio men, however, like to remember the electron flow rule, as they have no difficulty in following the electron flow from the filament of a tube to its plate. I feel that you should learn both rules. Electron flow is shown in Fig. *6A*. Terminal *d* of the load is + (positive) while terminal *c* is — (negative). The dotted and solid line in Fig. *6B* represents the A.C. voltage supplied at terminals *f* and *e*; but only one-half, the part represented by the solid line, is the actual voltage variation across load terminals *c* and *d* of Fig. *6A*. This output voltage is a half-wave (half a cycle), and must be smoothed out before it can be used.

HALF-WAVE RECTIFICATION

I have just described the simplest of all rectifiers; the single diode, or half-wave rectifier. This tube has a filament electron emitter, although heater type electron emitters are also used. As a rule, high voltage rectifiers are of the filament type; low voltage rectifiers are of the heater type and are generally used in universal receivers and amplifiers. By high or low voltage rectifiers I mean that a high or low A.C. voltage source is to be rectified.

Figures *7A* and *7B* show circuit diagrams of two practical half-wave rectifiers just as you will find in some radio receivers and amplifiers. In both cases, a power transformer *T* is used which has at least three secondaries: *1*, a low voltage secondary *S*, to supply filament power to all signal circuit tubes; *2*, a high voltage secondary S_H, to produce the high A.C. voltage which is to be rectified; and *3*, a third low voltage secondary S_L, to heat the filament of the rectifier tube. In these circuits the voltage across terminals *xy* is the A.C. voltage to be rectified. Only that part of the A.C. voltage which makes the plate positive and permits the electrons to flow from the cathode (electron emitter) to the plate, causes electrons to pass through the entire circuit. In Fig. 7A this electron path is $a \rightarrow b \rightarrow c \rightarrow d \rightarrow e \rightarrow f_1 \rightarrow f_2$ and a. Notice that the path through the filament secondary S_L is from the center tap to both filament leads through the tube to the plate. In Fig. 7B the path is much simpler, being from $a \rightarrow b \rightarrow c \rightarrow d \rightarrow a$. In both circuits c is the negative load terminal and d is the positive load terminal—following the rule that electrons flow from — to + terminals. I want you to remember that the cathode or filament is always the positive or high voltage D.C. supply terminal.*

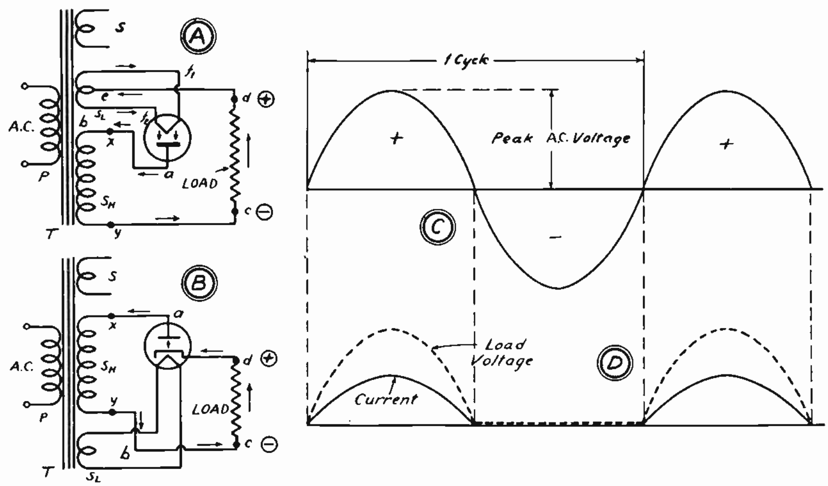

FIG. 7

Now let me give you a little more information of what takes place in these circuits. If we call that alternation of the A.C. voltage which makes the plate (+) positive the (+) alternation, then the voltage across xy can be represented by Fig. 7C. Electrons will only flow through the circuit a b c, etc., when the A.C. cycle is +; hence when the A.C. cycle becomes negative (plate negative) electrons flow in the circuit stops. This is portrayed by the solid line curve in Fig. 7D. The current at any instant of time depends on the voltage as portrayed by Fig. 7D, divided by the resistance of the circuit, and when the plate is negatively charged with respect to its filament the circuit resistance is very, very large and current ceases to flow. At the same time the voltage drop across the load depends on the value of the current at that instant times the load resistance. For that reason the load voltage variation (or curve) follows the current variation and is shown by the dash-dash (-----) curve in Fig. 7D.

* Although the plate is positive with respect to the filament (for electron attraction), in the supply circuit the filament or cathode is the positive terminal of the load.

The rectified voltage is a pulsating voltage, consisting of a D.C. component and several A.C. components, called ripple components. The important A.C. component is the original frequency of the source usually 60, 40 or 25 cycles per second, and the other A.C. components are 2, 4, 6, etc., times the original source frequency. For example, if a 60 c.p.s. source is used the A.C. components will have 60, 120, 240, 360 c.p.s. frequencies.* The important frequency is the lowest value, because an electrical filter called a low pass filter must follow this rectifier, which removes all variations above and including this minimum. Remember that for a half-wave rectifier the lowest ripple frequency equals the frequency of the A.C. supply. You will see the importance of this when I take up filters.

THE FULL-WAVE RECTIFIER

You should have no difficulty in realizing that with a single diode tube only one-half of the supply wave is being used. This does not mean that we are wasting power, because when the tube passes no current, the source supplies none. Nevertheless if both halves of the original wave can be put to work, a higher rectified voltage is obtained, and then, too, it is easier to smooth out the ripple components from the rectified output.

Full-Wave Bridge Rectifier. Without making any change in the power transformer, but using four half-wave rectifiers (single diodes) a system as shown in Fig. *8A* could be used. Observe that four indirect heated cathode tubes (*1, 2, 3* and *4*) are used, and each filament is connected to the low voltage secondary S_L.† The tubes are connected in what is referred to as a bridge arrangement, merely because it resembles a bridge or balancing circuit extensively used in radio laboratory equipment. You will find it easy to remember this circuit by following the electron flow. Let us assume for example that electrons flow from the supply terminal x of S_H to the rectifier terminal a, and seek a path through the bridge circuit to terminal y of the secondary S_H, which will be positive with respect to terminal x, as the latter is assumed as negative. From a two paths are possible, through tube #*1* or tube #*4*. Of course, you know that the only electron path through a normal acting tube is from the cathode to the plate, hence the electrons pass through tube #*1* to point b. The electron path so far considered is represented by the solid arrows. Leaving point b the only electron path is through the load resistor R to point d, because the path through tube #*2* is blocked because electrons cannot pass from a plate to a cathode. From point d, the electrons travel through tube #*3* to point c and back to the supply terminal y of S_H, the positive

* This may be proved by higher mathematics, or by an intricate laboratory test.

† If filament type diodes were used, tubes *1* and *2* would require separate secondaries, but tubes *3* and *4* could be operated in parallel; three secondaries in all. Thus short circuits are prevented.

secondary terminal for this instant, and to the starting point x. On the other hand electrons will leave the supply terminal y when it becomes negative every half cycle and they must take the $y \rightarrow c \rightarrow b \rightarrow d \rightarrow a \rightarrow x \rightarrow y$ path, indicated by the dash-dash arrows.

Now the most important fact about this circuit is that the electrons flow from point b to point d no matter which terminal of the supply they leave. Therefore, point b is the negative (—) and point d is the positive (+) load terminal. Although the A.C. supply voltage is as represented by curve V_{xy} in Fig. *8B*, the load voltage is as represented by V_{bd}, which is the full-wave rectified voltage.

The full-wave rectified voltage has twice as many peaks as the half-wave rectified voltage portrayed by Fig. *7D*. Naturally the lowest ripple frequency in this pulsating voltage has a value of twice the supply frequency, although ripple frequencies of 4, 6, etc., times the supply frequency exist. Such a pulsating voltage is easier to smooth out than a half-wave source.

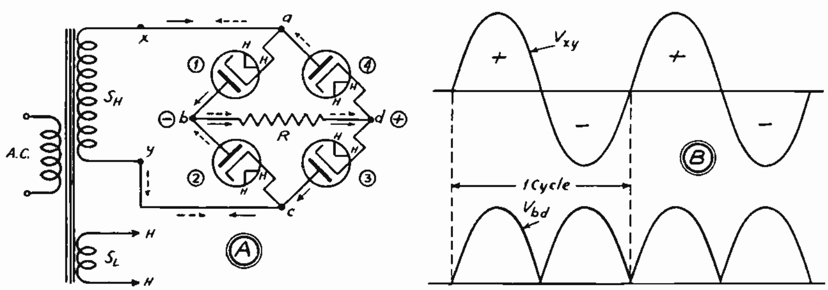

FIG. 8

Full-Wave Twin Diode Rectifier. Cost of equipment and parts, and permissible space is limited in the case of radio receivers and power amplifiers. The less equipment used, the less the chance of a breakdown. Good radio design indicated a need for a simpler full-wave rectifier. By using a supply source of twice the A.C. voltage required for a bridge rectifier and center tapping this source, two half-wave rectifiers may be used in a full-wave rectifier as shown in Fig. *9A*.

You will learn more about this circuit if we trace the electron flow. Starting with tube #*1* trace the electron flow from the filament to the plate, from terminal x to c, the center tap of the high voltage secondary. The electrons cannot go from c to y as at y they could not go from a plate to a cathode. Therefore, the path taken is from $x \rightarrow c \rightarrow a \rightarrow b$ back to the filament. The path for tube #*2* is $y \rightarrow c \rightarrow a \rightarrow b$ to filament. But the plates of the tubes are connected to the end terminals (x and y) of the secondary of the transformer and when one end is negative the other is positive with respect to the center terminal c. Hence the tubes, due to

A.C. voltages, alternate in conducting electrons from *a* to *b*, of the load *R*. The actual voltage rectified is half the value across *x* and *y*. Another way of putting it is: if the system in Fig. *9A* is used the A.C. voltage must be twice as much as in Fig. *8A* to realize about the same rectified voltage, which means a more costly transformer. For ordinary purposes it is cheaper to use a special transformer than to use four rectifier tubes.

The scheme shown in Fig. *9A* is so practical that it is now the custom to use a twin diode tube, that is two diodes in a single glass or metal shell. Figure *9B* shows such a tube connection, and in this case the filaments are internally connected in series. Twin indirect heated cathode rectifiers are also used as shown in Fig. *9C*, where the filaments are internally connected in parallel. Internal tube filament connections are made when the tube is manufactured.

In a twin diode full-wave rectifier it is desirable to use balanced tubes, that is, tubes of the same emission characteristics. Furthermore each tube should be supplied with the same amount of A.C. voltage. Both conditions

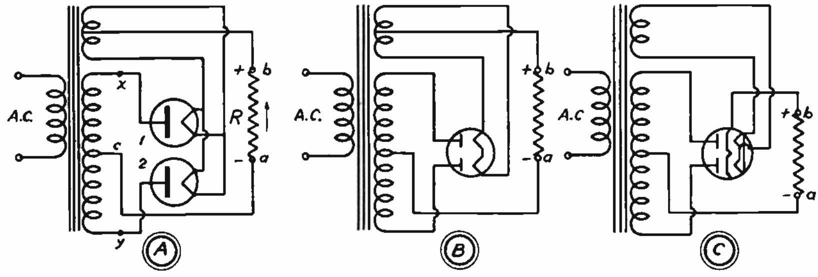

FIG. 9

make the filtering job easier. A serviceman checks the emission of each tube in a tube tester, and the A.C. voltage supplied by measuring the A.C. voltage from the terminals *c* to *x* and *c* to *y* indicated in Fig. *9A*. As in the usual receiver terminal *c* is connected to the chassis, you may test by connecting one terminal of the A.C. voltmeter to the chassis and the other terminal first to one then to the other tube plate. To maintain a condition of equal A.C. supply voltages terminal *b* of the load should connect to the center of the filament secondary supply, although this is not always done where extra filtering is provided. Where a rectifier is designed for balanced conditions, and through use or abuse the balance is destroyed, hum will be heard. Twin tubes insure, at least at the start, tubes of the same characteristics. A twin diode tube is cheaper to make and occupies less space and is, therefore, widely used in radio receivers and low powered P.A. amplifiers.

FILTERS

Let me stress once more that the output of a vacuum tube rectifier is a pulsating D.C. current, having in the case of a half-wave rectifying system a prominent ripple equal to the source frequency and in the case of the full-wave rectifier a ripple frequency equal to twice the supply frequency. Before the rectified supply can be fed to the load, which we said was the plates, screens and grids of the vacuum tubes in the set, it is important that all ripples be reduced to the lowest practical amount. A filter which will allow only a steady direct current to pass must be inserted between the rectifier output and the inputs to the tubes.

Perhaps you know that these filters are nothing more than iron core inductances and paper or electrolytic type condensers. To begin with, you know from previous study that an inductance will offer increasing reactance (opposition) to the flow of A.C. current as the frequency of the current flowing through it is increased. Naturally this suggests to us that a series inductance L as shown in Fig. *10A* may be used. Direct current suffers no opposition in flowing through the inductance if the coil resistance is low, but the various ripple frequencies are choked or reacted upon, or suppressed (different ways of saying the same thing) and the higher ripple frequencies more than the lower ones.

Of course, a choke coil with a very large inductance could be used, but a coil to do the entire filtering job would be bulky and costly. The filter job can be divided with a condenser C, as shown in Fig. *10B*. Naturally the output, as shown in Fig. *10B*, is fed to both the resistance load R and its shunt capacity C. Again going back to fundamental ideas, recall that a D.C. current cannot flow through a condenser so it has no alternative but to feed directly into the load. But a condenser will pass an A.C. current (due to its charging and discharging action), and as a matter of fact the higher the frequency, the easier it is for the current to pass. We technicians say that its "admittance" is high. So in this case, the ripple which was not suppressed by the inductance passes through the condenser more readily than through the load R, provided the reactance of the condenser for the frequency you wish to pass is much lower than the resistance of the load. If you make this ratio low for the lowest ripple frequency the passing action will be better for the higher frequency components.

Both the inductance and the condenser suppress the higher ripple frequencies more than the lowest frequency. That is why the filter is always designed for the lowest frequency, and the lower the frequency the larger should the inductance and capacitance of the filter be to do a definite amount of filtering. A half-wave rectifier has a lower ripple frequency than a full-wave rectifier; hence a better filter must be used. Here is one good reason why 60 c.p.s. receivers produce hum when used on a 25 c.p.s. source.

Multi-Section Filters. Even though the filter shown in Fig. *10B* is superior to the one shown in Fig. *10A*, the inductance and capacity must be unusually high to reduce the ripple to a satisfactory amount. Is it not natural to say that if one filter will reduce the ripple, two will be better? This sort of reasoning is correct, and cascade (one after the other) filters, as shown in Fig. *10C*, are universally used. If filter *#1* will reduce the lowest frequency 100 times, and filter *#2* will also reduce what is supplied to it 100 times, then the total reduction is 100 times 100, or a reduction of 10,000. Quite often three sections in cascade are used, but generally only in high fidelity and all-wave receivers. Here is a little technical fact; the ripple reduction * of each filter section roughly equals the reactance of the coil divided by the reactance of the condenser. The reactance is determined for the ripple frequency to be suppressed.

Filters with Input Capacity. Experts in the design of rectifiers will tell you that the average D.C. voltage from a rectifier system is a certain amount of the applied peak voltage. For a half-wave rectifier it is about 32 percent; for a full-wave rectifier it is about 64 percent.† And thus all you can get from a filter of the type shown in Fig. *10C* are these amounts. The reason for this is that filters suppress all the components in the ripple frequencies. But the question arises, can we boost the output voltage? Yes we can, and by the simple means of connecting a condenser C_1 to the rectifier output, or what is the same thing the filter input, as shown in Fig. *10D*.

Here is what happens. The voltage produced by the rectifier, charges the input condenser and continues to charge it until the rectified voltage reaches its peak value. As soon as the input voltage reduces the charge starts to feed into the load. If the load resistance is low this discharge takes place rapidly, if it has a large value (in ohms) the discharge takes place slowly. In other words, the input condenser is supplying energy to the load long after the rectified source has stopped to supply energy. This information is graphically presented in Fig. *10E*. I have taken a half-wave rectified voltage as our example, which is represented by curve *#1*. The average output voltage, the D.C. voltage when the input condenser C_1 is omitted in the circuit (shown in Fig. *10C*) is given by curve *#2* (a straight line) of Fig. *10E*, and as you see is quite low. When the input condenser C_1 is inserted, as in Fig. 10D, the voltage across the input condenser follows dotted curve *#3*. Its average *value is quite high,* and the ripple, that is its variation from the average, is small.

Many Radio-Tricians often measure the A.C. voltage of the power transformer and then the D.C. voltage of the output. Where a condenser

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* Ripple input divided by the ripple output.

† The peak value is 1.41 times the effective value (which you measure with a commercial voltmeter).

input is used, the D.C. voltage may be greater than the A.C. voltage. With a condenser input filter you may, with a small load (low current drain) obtain a D.C. voltage nearly equal to the peak input, which is 1.41 times the A.C. value that is measured.* Another reason why a condenser input is desirable may be gained by the following reasoning. If the input condenser reduces the ripple, then the following filter has less work to do and its components need not be as large as when the input condenser is omitted.

The system has disadvantages. One I pointed out, namely that as the load increases the D.C. voltage drops. That is exactly what happens in an audio amplifier when it is first amplifying weak and then loud sounds. A condenser input filter might cause distortion if the output voltage drops too much.

Another difficulty is the sudden rush of current at the beginning of each cycle (point x in Fig. *10E*), when the condenser is being charged.

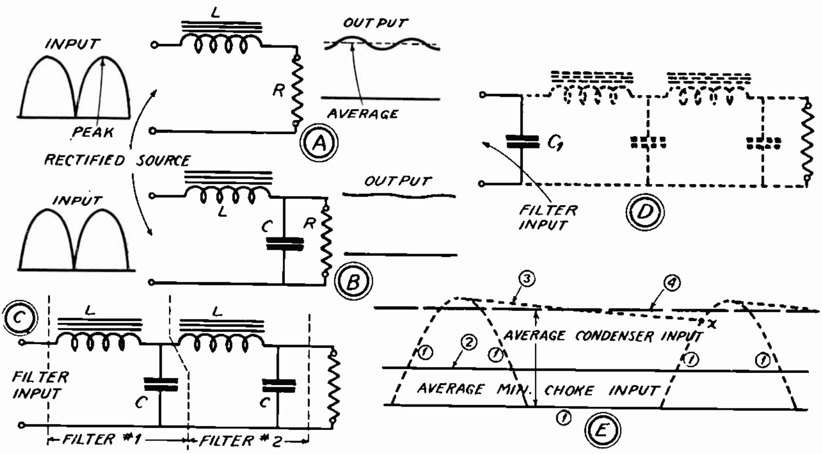


Fig. 10

This sudden rush of current may ruin the rectifier tube. Fortunately this current rush is of little importance in ordinary vacuum tube rectifiers used in radio receivers and amplifiers. Where this effect is important coil input filters are used. In considering the input condenser, it is important to realize that should it (and as a matter of fact any of the other filter condensers) become shorted or leaky (have low resistance) the entire D.C. voltage will be thrown across the rectifier tube and the tube will be destroyed. If you encounter a *vacuum* rectifier tube that glows blue (indicating that the tube is passing too high a D.C. current) be sure to test the input and other filter condensers, replacing if necessary before you put in a new rectifier tube. A grounded choke may be the cause, so test them too.

* A larger input condenser, a lower current drain, a higher ripple frequency will tend to give a D.C. output voltage nearer the peak A.C. input.

Tuned Filters. Early in the development of radio, engineers naturally asked themselves why they could not tune out the ripple which created the most trouble. Indeed this is often done. As the most prominent frequency is the lowest, circuits resonating to this frequency were developed. Figure *11A* shows the parallel resonant circuit through which the D.C. and all A.C. components must pass. Now circuit L_1 and C_1, when tuned to a definite frequency will offer a very large impedance to the current of that frequency. This is the nature of parallel resonant circuits and this opposition, queerly enough, increases as the series resistance of the coil and condenser is decreased. The capacity of C_1 should be small so the passing action shall be low for higher ripple frequencies.

Another possible filter circuit is shown in Fig. *11B*. Here we find a series resonant circuit bridged across the filter. When L_2 and C_2 are in resonance with the lowest ripple frequency, it offers very little opposition to that component. Naturally that component passes through this "leg", as it is called, instead of going to the load. Although this circuit is effective

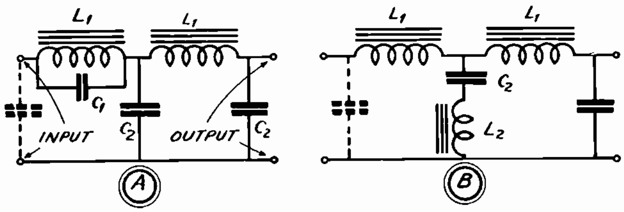


Fig. 11

at the frequency for which it is designed, the lowest ripple frequency, it actually destroys filtering at higher frequencies. At frequencies above the resonant value, the leg is principally inductive and the shunting effect of C_2 is totally destroyed. Thus you really have only one filter section with two chokes working.

Either resonant filter circuit may be used with a condenser input, the condenser shown in Figs. *11A* and *11B* by dotted lines and symbols. For 60 cycle, half-wave rectifiers, the circuit L_1-C_1 or L_2-C_2 would be made to resonate to 60 c.p.s.; for a 60 cycle per second full-wave rectifier these circuits should resonate to 120 c.p.s. Quite often you will find radio receivers and amplifiers with such a filter incorporated in the power supply that seems to defy hum correction. This is often due to the change in the inductance value of the iron core choke (shift in the laminations due to rough handling), or more often due to the fact that the frequency of the supply main does not agree with the designed resonant frequency. You should try various small condensers in shunt with condenser C_1 or C_2 or open the air gap in the iron core choke, although the latter procedure should be done only after a little radio experience.

WHAT TO EXPECT FROM A RECTIFIER TUBE

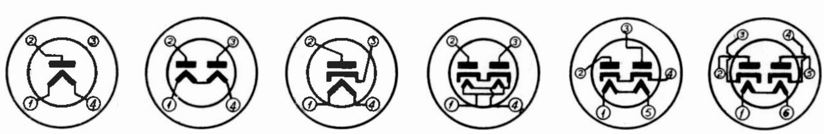
Not every radio receiver or amplifier uses the same type of rectifier tube. Different types are used for a particular set of reasons. The features that make different types necessary are: *1*, filament voltage; *2*, cathode-heater insulation; *3*, voltage output; *4*, current output; *5*, full or half-wave; and *6*, regulation. Items *1* and *2* are dictated by the type of power supply that is to be used; items *3*, *4* and *5* by the D. C. supply re-

TABLE NO. 1

AVERAGE CHARACTERISTICS OF SMALL RECTIFIER TUBES

Type Number	H. W. or F. W.	V or M	Base Number	F or H	Filament		Max. A. C. Voltage Per Plate	Max. D. C. Output Current	Max. Output Voltage		Inverse Peak Voltage	Peak Current
					V	I			Choke Input	Condenser Input		
5Z3	F. W.	V	4–2	F	5	3	500	250	360	475	1400	....
12Z3	H. W.	V	4–3	H	12.6	.3	250	60	N. U.	250	700	....
25Z5	F. W.	V	6–1	H	25	.3	125	100	N. U.	108	350	....
1V	H. W.	V	4–3	H	6.3	.3	350	50	N. U.	400	1000	....
80	F. W.	V	4–2	F	5	2	400	125	290	390	1100	....
81	H. W.	V	4–1	F	7.5	1.25	700	85	530	780*	1960	....
83V	F. W.	V	4–4	H	5	2	500	250	425	600	1400	....
84	F. W.	V	5–1	H	6.3	.5	350	50	300	430	1000	....
82	F. W.	M	4–2	F	2.5	3	500	125	500	N. R.	1400	400
83	F. W.	M	4–2	F	5	3	500	250	500	N. R.	1400	800

Explanation of table: F. W.—full wave; H. W.—half wave; F—filament tube; H—heater tube; N. R.—not recommended; N. U.—generally not used; V—vacuum tube; M—mercury vapor tube; *—in full wave connection; filament voltage in volts; filament current in amperes; plate voltage in volts; plate current in milliamperes; inverse peak voltage based on F. W. connection.



4-1 4-2 4-3 4-4 5-1 6-1

Pin Arrangement—Base Numbers; Bottom view of tube connections

quired; and item *6* by the maximum signal changes you expect to incorporate in a radio device. Regulation in a power supply is a new term which I will shortly clear up. Improved regulation is obtained by using a gaseous (mercury vapor) rectifier which will be considered after we take up the vacuum type rectifier. Table No. 1 lists the characteristics of vacuum and gaseous rectifier tubes in general use, and is included in this lesson so you may refer to it as needed.

Vacuum Rectifiers. The performance of any radio device is best shown by curves, and vacuum tube rectifiers are no exception. Fig. *12A* shows a number of curves for a half-wave rectifier, and for a condenser input filter. Each curve is for a definite A.C. voltage supply and in the diagram is the voltage $V_{A.C.}$ which you would measure with an A.C. voltmeter connected across the high voltage secondary. The D.C. current would be measured with a D.C. milliammeter connected in series with the load as indicated, but the D.C. voltage would be measured across the filter input, because the resistance of the iron core choke is a part of the load. Observe that for a filter with a condenser input the output voltage is quite high even for large currents, but the D.C. voltage drops rapidly as the load is increased from a small to rated value. This is primarily due to the inability of the input condenser to maintain its charge after the rectified voltage starts to drop from its peak.

Figure *12B* is the same type of information for a typical full-wave, vacuum tube rectifier, and in this case I am showing the difference between choke and condenser input. Observe that when the input condenser is omitted, that is we have a choke input, the D.C. output voltage is initially low for low load currents, but as the load is increased the variation is not as marked. This change is primarily due to the D.C. resistance within the rectifier tube which in turn is the result of the electronic space charge. If it were not for the tube resistance, the decrease in voltage would be much less. This variation in D.C. output voltage with load current is *regulation,* and is considered good when the least change is obtained.

Table No. 1 presents the general characteristics of the important tubes and the maximum A.C. voltage and D.C. load current. What D.C. output voltage to expect for a *condenser* input and for *choke* input is then given for these maximum conditions. For any other condition you must refer to operating curves similar to those given in Figs. *12A* and *12B* for the particular tube to be used. The latter are supplied by the tube manufacturer. Of course, when you service radio equipment you are guided by the voltage and current charts supplied by the maker of the receiver, amplifier or transmitter.

Mercury Vapor Rectifiers. If you trace the circuit shown with Fig. *12A*, you will see that D.C. current flows through the tube, the iron core choke, the load and the high voltage secondary. To get improved regulation, or what is more obvious, to keep the voltage across the load *R* as nearly constant as possible with changes in current, the remainder of the circuit should have low resistance. It is easy enough to make the secondary and the iron core choke with low ohmic resistance, but it is not so easy to obtain a vacuum tube rectifier with low ohmic resistance. However, a mercury vapor diode does exhibit a desirable quality and that is its voltage drop (current through it times its resistance) is constant and very nearly equal to 15 volts. Clearly, if a mercury vapor rectifier is used with low resistance chokes and a low resistance secondary exceptionally good regulation will be realized. How do these tubes, extensively used in radio transmitters, high powered audio amplifiers and many radio receivers, work?

In the first place, this tube is a vacuum tube rectifier with a small amount of mercury included, and for this reason is called a mercury vapor tube. Usually a little ball of mercury is enclosed which creates mercury vapor at ordinary room temperature, and when the tube heats up more vapor is automatically produced. Usually oxide coated filaments are used to produce the electrons that are drawn to the plate. When the tube

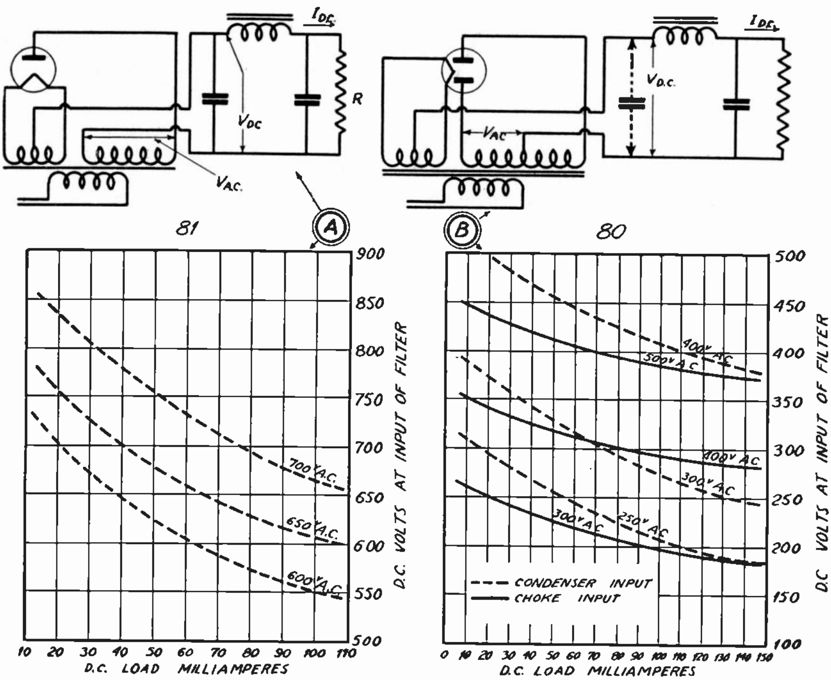


FIG. 12

The above curves show the D.C. voltage and D.C. load current at input of filter when certain fixed values of A.C. voltage are applied to plate or plates of 81 and 80 rectifier tubes

is placed in operation, the high speed electrons leaving the filament bombard (strike) the mercury atoms and deprive the latter of their free electrons. This leaves a positive gas ion (mercury atom without its free electrons) and an extra electron which moves toward the plate. The positive ion moves slowly (about 1/600th as fast as the electron) to the filament and in doing so gets into the electron cloud (space charge) surrounding the filament. In fact it partly neutralizes (destroys) the electron cloud and nearly all of the electrons leaving the filament have an open path to the plate. The higher the potential difference between plate and filament the greater the space current, but this voltage drop must not be too large (22 volts in a mercury vapor tube) otherwise the heavy gas ions will bombard the filament and destroy it.* The maximum or peak current of a vapor tube is important and should never be exceeded.

A typical full-wave mercury vapor rectifier circuit is shown in Fig. *13*. The rectifier tube when in operation emits a blue glow, which quickly distinguishes it from the vacuum type rectifier tube, which emits no glow. The filter circuit always has a choke coil input, for a condenser input would cause sharp peak current rushes which would ruin the tube. Of course, the input condenser would produce poor regulation, which is the primary reason for using mercury vapor tubes.

The maximum voltage drop exists across the load, the voltage drop across the tube is constant, and if the other parts have low resistance the regulation will be excellent, in fact, the D.C. voltage output is practically independent of the current (load) drawn, within the useful limits of the tube.

Sudden current changes in the rectifier circuit may set up radio frequency (high A.C.) currents which would interfere with the signals in the signal circuit. For this reason small *R.F.C.* chokes are often connected in each plate circuit, as shown. A two millihenry, low resistance choke is generally used. The tube should be shielded to prevent stray fields getting into the signal circuit. The need for shielding and chokes is determined by the designer. Shielding should not be used unless necessary, as it prevents the heat generated by the tube from escaping and eventually causes tube destruction. As a short or sudden overload would cause excessive tube current, a line fuse is recommended (50 percent greater than rated load) so the fuse will burn out rather than the tube.

Now allow me to consider two more advanced ideas, facts that you will want to know when you become a Radio-Trician. In a choke coil input filter, the input choke L_1 in Fig. *13* has a definite effect on the rectified output. From long experience experts have found that the inductance of the first choke in henries should be equal to the load resistance, R, divided by 500. This is called the optimum (best) inductance. When this is done, four desirable effects are produced: *1*, the peak current through the tube is limited to the peak D.C. value, hence there is less tendency to ruin the rectifier tube and less chance for interfering current; *2*, the filtering action is improved; *3*, the regulation of the supply is better; and *4*, there is less tendency to overheat the supply transformer, which means a reduction in the cost of power equipment. The inductance of the input choke L_1 is quite critical, that is it must be quite close to the estimated value.

As the radio device (the signal circuit) swings from low to high signal levels, first low and then high current demands are made on the supply.

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* When large mercury vapor rectifier tubes are used in transmitters and high powered public address systems a special relay is used to delay the high voltage connection until the cathode heats up and produces the necessary electron cloud.

In other words the load resistor R is increasing and decreasing. As the load resistor R * decreases the input filter choke inductance should decrease if optimum condition is desired. Now the inductance of an iron core choke coil normally will decrease when the current through it increases but by proper design (adjusting the air gap), it can be made to decrease so optimum inductance is always obtained. Such a choke is called a "swinging choke" and is an essential part in a well designed rectifier system using mercury vapor tubes. Now for another important advanced fact.

Peak Inverse Voltage. A rectifier tube should pass electrons from the cathode to the plate, when the plate is charged positively. But what will happen if the filament is positively charged, a condition which exists once every cycle of the A.C. supply? If the voltage is too high, a current will arc (spark) across the space and destroy the cathode emitting characteristic. The maximum A.C. voltage that you can connect to a rectifier tube with the negative terminal to the plate, the positive terminal to the

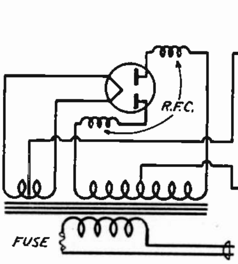

Fig. 13

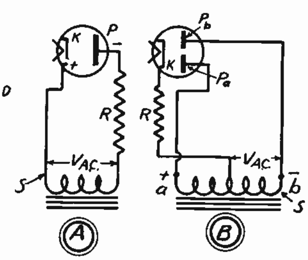

Fig. 14

filament, without arcing is called the *peak inverse voltage* rating of the tube. This factor is extremely important with mercury vapor tubes as arcing takes place at a lower voltage when this gas is present.

Figure *14A* shows a single diode connected through the load R to the high voltage secondary. Once each half cycle the plate (P) is positive (+), while the cathode (K) is negative (—), and once each half cycle the plate is negative (—) and the filament is positive (+). When the diode passes electrons the voltage across the tube is lower than $V_{A.C.}$ because of the voltage drop in the load R; but when the "inverse" condition exists no current flows, no voltage drop takes place at R and the diode receives the full $V_{A.C.}$. Its peak value is 1.41 times the value measured by an A.C. voltmeter.

Referring to Fig. *14B,* a full-wave connection, observe that when plate P_a is receiving electrons, plate P_b is negative, therefore not working. However, as the path between K and P_a is conducting (current flowing), terminal K is approximately at the same potential as P_a. Hence the inverse

* The lowest load current should be 10 percent of the normal value. This minimum current is essentially determined by the bleeder resistance, which I will shortly explain.

voltage between K and P_b is the same as that between a and b. The peak inverse voltage is twice the peak voltage of $V_{A.C.}$ or 2.82 times $V_{A.C.}$. Strictly speaking you should subtract the tube drop, about 15 volts for a mercury vapor tube, from this computed value which is lost in the path from K to P_a. You will find that the largest $V_{A.C.}$ (root mean square) that you can apply to a full-wave diode, as given by most tube tables, is the inverse peak voltage divided by 2.8. Check this in Table No. 1. The peak inverse voltage rating of a tube determines the greatest A.C. voltage you can rectify.

DIVIDING THE VOLTAGE

Now that I have shown you how A.C. is converted to D.C., I am going to consider an important phase of power supplies, namely how the D.C. power is distributed. This will be important to you as a Radio-Trician.

It makes little difference to the rectifier how this power is distributed to the vacuum tubes in a radio device, for it is merely called on to deliver a definite D.C. voltage output and a definite load current. To be sure, the radio designer works "in reverse." He determines what is the maximum D.C. voltage and current, and depending on whether he uses one type of rectifier or another, refers to a set of curves, as shown in Figs. *12A* and *12B* and determines from these two values (current and voltage) how much A.C. voltage should be supplied by the power transformer. If one type of rectifier is unable to supply the demand, a larger tube is used.

Usually the D.C. voltage is equal to the largest plate voltage (probably the plate voltage for the power audio tubes) plus the largest C bias. To this must be added the voltage drops in the iron core chokes in the filter, as they are really a part of the load. The current demanded from the power supply is the sum of all the electrodes (plates, screens, grids, etc.) currents of the tubes in the device except the diode power rectifiers. The computed voltage divided by the computed current is the load resistance R that I have constantly referred to.

How is this total load divided or distributed to the various tubes? Basically there are two methods: *1*, the parallel voltage divider as shown in Fig. *15A;* and *2*, the series voltage divider as presented in Fig. *15B*. There are a number of variations which combine the two basic methods.

Circuit Laws to Remember. In order to fully understand how the divider circuits work I want you to recall a number of important circuit laws. They are:

1. The currents to a terminal must equal the currents away from the terminal.

2. In *any complete* circuit the generated (supply) voltage must equal all the voltage drops.

3. The voltage drop across any device is the current times the resistance (Ohm's Law).

4. Current flows from the positive (+) to the negative (—) terminal.

This is just the opposite for electron flow. (In the following discussion I am going to switch to current flow, not electron flow, as this is the way radio men analyze circuits. I want you to be able to do things the way experts do them.)

5. If terminal *A* is positive with respect to terminal *B*, terminal *B* will be negative with respect to terminal *A*.

Parallel Voltage Dividers. Referring to Fig. *15A*, observe that the total voltage and current demanded from the rectifier is indicated by V and I respectively. The voltage divides itself between resistors R_5, R_4, R_3, R_2, R_1, R_{c1} and R_{c2} because of the currents flowing through them. The total current flows through R_5 and R_4. At point *1* the current through R_3 is I less I_1. I_1 is the current that passes through the triode tube indicated, returning to the main circuit at point *4*. The current at point *2* divides, part going through R_2 and part going through another tube, and in this case indicated by I_2. Again the current through R_2 divides into two paths, the one indicated by I_3 and the other through R_1 Although

A calibrated adjustable resistor tester which enables a service-man to determine proper replacement values of defective resistors, measure unknown resistors by the substitution method, can be used as a calibrated variable resistor for adjusting voltage, as a potentiometer or voltage divider

the current indicated by I_2 and I_3 may go through a tube, it may also be the supply to a screen grid or tube electrode whose plate is supplied through the I_1 path. These facts do not concern us in a general study of supplies but you must recognize that regardless of the path they all come back to terminal *4*. This common terminal is the filament or cathode tube terminal and is the —B supply connection. Incidentally, it is connected to the chassis frame which in turn is grounded. As terminal —B is common to all tubes it is the reference or ground terminal; as all currents flow to it from the chokes, terminals *1, 2* and *3* will be positive with respect to terminal *4*. That is why these points are marked +B, ++B and +++B, the number of "+" marks to indicate which is the higher positive terminal.

From terminal *4*, the current from all the tubes (marked $I_1 + I_2 + I_3$) joins the current from R_1 and flows through R_{c1} and R_{c2} back to the supply. There are two important facts at this point that I want to clear up. What is the potential of points *5* and *6* with respect to —B or point *4*? Point *4* is, of course, positive with respect to point *5*, but what is the potential of point *5* with respect to point *4*? Point *5* is negative with respect to point *4* and you can prove this with a D.C. voltmeter marked — and +. If you connect its + terminal to *4* and its — terminal to *5* the meter will read up scale; if you reverse the meter connection the meter will read down off scale, indicating a wrong connection. Thus point *6* is negative with respect to *5* and more negative with respect to *4* and, if we wish, more negative with respect to *3*, *2* and *1*. We stop at point *4* as this is the common reference terminal. Now if you want to make a grid negative with respect to its filament or cathode, connect it to point *5* or *6* as shown for the triode.

The other fact that I want to bring out is the bleeder current from *3* to *4* through R_1. This current would flow from the supply through chokes and the resistors even if all the tubes except the rectifier were removed from the receiver or amplifier. It is called a "bleeder" current, because it is not used in operating the tubes in the receiver. It should be as large as possible, but never so large that the rectifier will have to supply more than it can handle. The purpose of the bleeder current is to improve regulation, which is another way of saying that as more current is demanded from the power pack the voltage supplied changes only a small amount.†

How are resistors R_3, R_2, etc., determined? I am only going to hint at the method, as this is a problem for the designer. He must know the voltage drops through each resistor, an easy matter if voltages of each point with respect to ground or —B are known. Then he determines the current through each resistor; simple if he knows what should enter and what should leave each terminal. The resistor is then determined by Ohm's Law.

But you are going to say: "Do I have to do this if a resistor in a receiver, for example that I have in for repairs, burns out?" Not at all. Suppose resistor R_3 burns out. The most sensible thing to do is to insert a variable resistor, such as are now available for service work; connect a voltmeter between the chassis and point # *2* and vary this test resistor until the correct voltage * (given by the maker of the receiver) is obtained. If the test resistor is not calibrated (reads the resistance) remove the test resistor and measure its existing value with a serviceman's ohmmeter. The voltage drop across R_3 times the current through R_3 gives the power in watts dissipated by the resistor. To be on the safe side get a replacement resistor having a wattage rating 4 or 5 times this value. As this procedure is generally used by servicemen, whenever a burned

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† It is interesting to know that in receivers which do not rely on the bleeder current from a voltage divider for better voltage regulation, it is becoming good design practice to use a wet electrolytic input filter condenser which will leak above a definite voltage; below this voltage the condenser acts normally. When the receiver is first thrown on, or when the supply voltage rises this condenser acts as a load, reducing the voltage supplied to the tube circuits.

* A service diagram will tell you which is the + connection of the burned out resistor. If you do not know the correct voltage, adjust the test resistor for best results. Quite often the circuit diagram for the defective receiver gives the value of the resistor that has burned out, which eliminates this service procedure.

out resistor which carries current must be replaced, it should be remembered.

Series Voltage Dividers. Another method of dividing power from the power pack (the power transformer, the rectifier and the filter) is shown in Fig. *15B*. Each tube is fed directly from the supply. In this case a heater type triode is shown, the current tracing from point a to b through the current limiting resistor R_1, through the tube (plate to

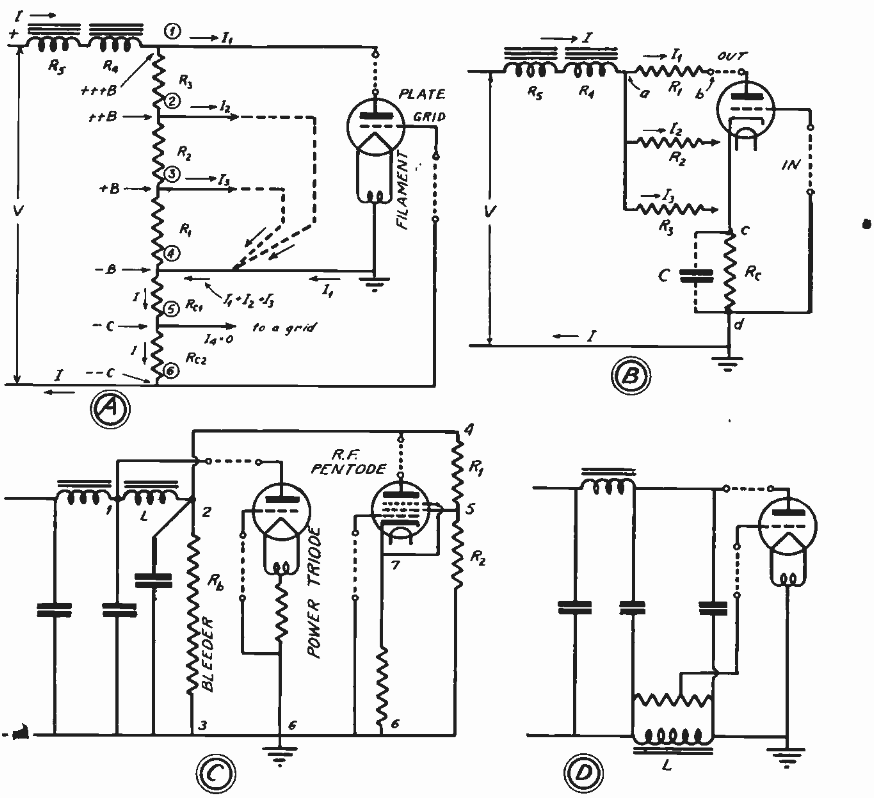

FIG. 15

cathode)* to point c and then through resistor R_c to the other supply terminal d. As current flows from $a \rightarrow b \rightarrow c \rightarrow d$, point a is positive with respect to b, b positive with respect to c, and c positive with respect to d. The voltage drop from b to c is the tube's plate voltage, the drop across R_c is the C bias grid voltage, and the drop across R_1 is included so the total of the voltage drops will equal the supply voltage. If the tube shown required the full voltage developed by the power supply re-

* Remember I am discussing current, which is the flow opposite to electrons.

sistor R_1 should be omitted, but for tubes requiring less than the maximum available, the limiting resistors R_2, R_3 are quite essential. As point *d* is negative with respect to point *c* (the cathode) the grid is connected to *d*, thus supplying the negative C bias voltage. As the signal is fed to the grid through this connecting wire it would have to pass through the C bias resistor R_c, unless condenser *C* is inserted. Condenser *C* is a bypass condenser and offers practically no reactance to the A.C. signal. There is another important reason for using condenser *C*. When the grid is actuated by an A.C. signal the current from *a* to *d* will vary. Therefore the voltage across R_c will vary, and the applied steady direct C bias voltage will be made to vary. Recall that I said that when a condenser is placed across a resistor, across which a pulsating voltage is applied, the energy in the peaks will be stored in the condenser and discharge into the resistor when the voltage is a minimum, thus greatly reducing the voltage variation. This is the second reason why *C* is used across R_c.

All tube circuits return to point *d*, and this becomes the common terminal of the receiver or amplifier. Hence it is connected to the chassis and grounded. Point *d* is not the —B connection; each tube has its own —B. The important facts to remember about series voltage dividers are that every tube is connected to the main supply terminals and the voltage drops in that tube circuit equals the total voltage available.

Modified Voltage Dividers. A combined parallel and series voltage divider is shown in Fig. *15C*. In this case, the choke coil *L* and the bleeder resistor R_b form a potential divider. The R.F. pentode tube is fed from points *2* and *3*. The total voltage equals the sum of the plate voltage *4* to *7* and the C bias voltage *7* to *6*. But to get an intermediate voltage for the screen grid another voltage divider consisting of R_1 and R_2 is used. To be sure, it is possible to tap bleeder resistor R_b, but as the latter is usually some distance (in the chassis) away from the tube, a separate divider near the tube is used. The triode tube is connected between the input of choke coil *L* and point *3*, the return terminal. In this way an unusually large voltage may be obtained. This is permissible only when the power for the tube does not have to be well filtered. Quite often *L* is the field coil of a dynamic loudspeaker,* a subject you will study later. Thus the field coil serves several purposes; a choke, a voltage reducer, and an electromagnet for a loudspeaker.

Another use for a choke is shown in Fig. *15D*. Here *L*, which may be the field of an electromagnetic loudspeaker, is not only used as a filter choke but as a voltage divider in order to supply the tube with a C bias voltage. A resistance voltage divider resistor is often used across the coil as shown, or the resistor may be omitted and the connection made to a tap on coil *L*. Both methods are practical and in commercial use.

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* D.C. current for the loudspeaker field of a dynamic unit is an important supply. The scheme shown in Fig. 15 C, is the usual one for A.C. Receivers.

CONTROLLING THE LINE VOLTAGE

The voltage fed to filaments of the tubes in the radio device and the high A.C. rectifier voltage must be substantially constant if the radio receiver or amplifier is to work efficiently. Should the voltage be too low, the filament or cathode will emit insufficient electrons, and furthermore the filament will in time become brittle and break with a severe jar; if the filament voltage is too high the emission characteristic of the filament or cathode may be quickly exhausted and perhaps the filament will eventually burn out. The D.C. voltage output of the power pack will rise or drop as the A.C. voltage delivered from the high voltage secondary of the power transformer increases and drops. All this is dependent on the voltage of the A.C. supply mains. No designer expects

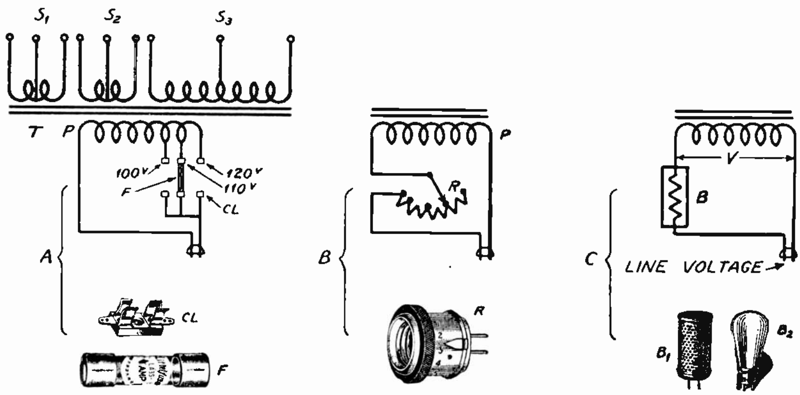

FIG. 16

the A.C. line voltage to remain constant, but he does assume that it will not vary more than 5 percent,† that is if the line voltage is rated at **110** volts A.C., the designer assumes it will not vary more than 5.5 volts or from 104.5 to 115.5 volts. When you go on a job, a difference of about 5 volts should be considered as normal.

To take care of different line voltages, and the line voltage in one town may be 110 volts, 115 or 105 in another, it is customary to incorporate in a well designed radio device some provision to adjust the receiver or amplifier to the voltage available. The most universal practice is shown in Fig. *16A*. As you observe, the primary *P*, of the power transformer *T* has three primary taps allowing a change in the primary to secondary turn ratio. The more turns on the primary the lower the secondary voltage will be. Two and sometimes three adjustments are

† Percentage will be extensively used in the course. To find the exact value indicated: multiply by the percentage and divide by 100. In this case you should multiply 110 by 5 and get 550. Then you would divide by 100 and get 5.5 volts. the answer.

provided, namely: for 120, 110; or 120, 110 and 100 volt inputs. As a further protection the ratio is changed by resetting the fuse *F* in the clips *CL*. When you run across such a receiver in an installation or service job, measure the line voltage with an 0-150 volt A.C. voltmeter and set the fuse in the clips marked with the nearest voltage. For example, if you measure 116 volts place the fuse in the 120 volt clips, if you measure 112 volts place the fuse in the 110 volt position. Some servicemen place the fuse in the next highest voltage position and try the receiver on actual reception. If reception is normal they leave it there, if not they set the tap to the nearest voltage. They do this to take care of high voltages which may appear on the line. The fuse usually has a 3 ampere rating.

What should be done if no adjustments are provided and you measure the line voltage and find it higher than what the device is designed for? Rated line voltage is given on the name plate of the receiver or amplifier; if none is to be found assume it to be 110 volts. You should insert a line regulator or variable resister *R* as shown in Fig. *16B*. Then you connect a 0-15 A.C. voltmeter across some tube filament and regulate *R* until the meter reads slightly below the filament voltage rating of the tube you test.

Suppose you know that line voltage varies from hour to hour, or for example the customer tells you that the tubes burn out too often, which is generally an indication of line voltage variation. Fortunately we can get a resistance device which will automatically increase its resistance if the line voltage increases, decreasing in resistance if the line voltage drops. Such a device is called a "ballast" and two types are shown in Fig. *16C*. A ballast is nothing more than a resistor employing nickel or iron wire. As the line voltage increases, the primary current goes up. This sends more current through the ballast. It gets hot and naturally its resistance increases. But iron and nickel have the property of increasing its resistance to a greater extent than copper or other resistance wire. As the resistance goes up the voltage drop through the resistor increases and the voltage *V* reduces. Of course, the line current goes down and so does the ballast resistance, but a balancing action takes place in favor of reduced primary voltage.

To use a ballast, select if possible a 100 volt primary tap and procure a ballast for the receiver. These ballasts are made for 5, 6, 7, 8, 9, 10, etc., tube receivers. It is a compromise, but a fairly reliable one. The glass type ballast appears from experience to give the best ballast action. In some receivers the ballast is designed into the receiver and the voltage *V* is maintained fairly constant, usually about 85 volts, even if the line voltage varies from 90 to 130 volts. In the latter case the power transformer is designed to work from an 85 volt source.

TEST QUESTIONS

Be sure to number your Answer Sheet 12FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What electrical power must the power supply system of a vacuum tube radio device furnish to the filament and the tube electrodes?
2. In what two parts may a radio receiver be automatically divided?
3. What would you expect to happen to a 2.5 volt filament tube, if it was placed in a 6.3 volt tube socket?
4. What type of current exists at the output of the rectifier tube?
5. What would happen to the rectifier tube if the input condenser was shorted?
6. In the case of a full-wave rectifier designed for a 60 c.p.s. source, should the tuned filter resonate to 60 or 120 c.p.s.?
7. How can you distinguish a mercury vapor rectifier tube when in operation?
8. What are the two basic methods of dividing the D.C. voltage?
9. What is the purpose of the bleeder current in the voltage divider system?
10. What percentage of line voltage variation does the receiver designer assume?

SPECIAL POWER SUPPLIES FOR RADIO EQUIPMENT

13FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

GETTING PRACTICAL EXPERIENCE

After you finish this lesson, you will have mastered enough of the fundamentals of radio to think about getting actual servicing experience. Your first attempts to repair defective radio receivers will undoubtedly lead you into difficulties. This will be a healthy and normal state of affairs, and will serve to familiarize you with actual radio sets.

As you progress with your Course, you will find one after another of these initial servicing problems clearing up; the mere fact that you yourself were confronted with a particular problem will serve to make the explanation of that problem more interesting and easier to master.

In one of your later Extra Money Job Sheets will be a detailed procedure for getting practical servicing experience in a minimum of time by working on only one or two receivers. For this you will need a broadcast band superheterodyne receiver having from five to eight tubes, so watch for an opportunity to borrow or purchase a used set of this type which is in good operating condition.

When you begin to service radio receivers, you will find that defective parts in power supply systems and defective tubes cause more than half of the troubles encountered. The importance of mastering the information given in this lesson is thus quite obvious. Make it a point to examine carefully the power supply system of each receiver to which you have access, for actual contact with various types of power supply parts will help you to master the important facts about these parts.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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Printed in U.S.A.

Special Power Supplies for Radio Equipment

A VARIETY OF SUPPLY CONDITIONS WILL BE ENCOUNTERED

What will supply power to the radio receiver in the farm home where often no local electric power is available; and when electric power does exist, it is usually 32 volts D.C. current? What should supply the power in an automobile or truck where a radio receiver or a public address amplifier is to be installed? What changes are necessary, or what special receivers are required when you are called on to install a radio set or amplifier in localities where: 110 volts D. C.; or 110 volts, 40 or 25 c.p.s. (cycles per second); or where 220 volts, 60 c.p.s. power is delivered at the wall or floor outlet socket? What should you do if radio equipment is to be installed in a place where no electric power of any kind is at hand? Are you to say that no radio equipment can be installed, because you and others might be inclined to think that 60 c.p.s., 110 volt equipment is the only type available? Not at all. It is the ability to handle these special conditions that will make you a better radio technician, increasing at the same time your earning capacity.

Vacuum tube equipment must have D.C. or A.C. power to heat the filament, and continuous current to apply to the tube electrodes. The signal circuit, that is the circuit that actually handles the incoming signals, may not be different for different power supply conditions; nor need the tubes in a D.C. powered receiver be different than the tubes for an A.C. powered receiver. To be sure, one group or series of tubes may be better adapted for battery operation, another set for A.C. operation and another series for D.C. sources. Yet if you study these series or groups usually referred to as the 2 volt (battery), the 2.5 volt (A.C.), and the 6.3 volt (A.C.-D.C.) series of tubes, you will find that there are diodes, triodes, tetrodes, pentrodes and multi-grid tubes which are apparently physical duplications but designed to meet a special supply condition. Receivers and amplifiers are on the market to handle any power condition, and you or any buyer can get these special instruments merely by asking for them. But don't you want to know why they are different? That is the purpose of this lesson.

What are you to do when no power at all is available? As you will shortly learn, two procedures are possible. You may use equipment designed for battery operation or you can install a gasoline engine driving an A.C. generator. If the latter is advisable, then it is a matter of common sense to use a 110 volt, 60 c.p.s. A.C. generator so that standard equipment may be used.

With this short introduction, I hope I have convinced you that there is a definite need for radio apparatus other than that intended for 110 volt, 60 c.p.s. So let us investigate the different ways of supplying the filament and electrode voltages.

THE MODERN BATTERY RECEIVER

When radio equipment has to rely on batteries as the source of power, it is important that the most economical use be made of the batteries. Any tube made, even an A.C. tube will operate from batteries, but the power required may be excessive. For example, the filament of a typical 2.5 volt A.C. triode tube will draw 1 ampere, a total of 2.5 watts for filament power; the same tube will require 250 volts on the plate and draw .005 ampere (5 milliamperes) or a total of 1.25 watts for plate power. Compare these figures with a 2 volt triode tube designed for batteries. The filament of this tube draws .060 ampere when connected to a 2 volt source, a total of .12 watt; the plate draws .003 ampere when connected to a 135 volt source, a total of .405 watt for its plate supply. To be sure the A.C. tube is more powerful, but the battery tube will do almost as well under all conditions except power output. You can make battery receivers and amplifiers with as much amplification (signal build up), but you cannot get a large power output without resorting to many large batteries. This is the sacrifice you have to make to use batteries economically.

So in the modern battery receiver you will find special battery tubes employed. The filament voltage is usually 2 volts and the plate and other electrode voltages are supplied from batteries, and are rarely over 180 volts. I shall limit my discussion to 2 volt tubes.*

Air Cell Filament Battery. The 2 volt series of tubes became popular because of the development of the so-called "air cell battery." A cross sectional illustration is shown in Fig. *1*. This cell, like the dry cell, has a zinc and carbon electrode. However, the cell is so designed that the hydrogen, which forms in both the *dry* and *air* cells, when deposited on the carbon electrode, combines with oxygen which is "breathed" through porous carbon to form water. In the hermetically sealed dry cell, a special chemical is required to free the hydrogen bubbles from the carbon plate which, as you know, reduces both the voltage and current. This chemical is referred to as a "depolarizer," and produces the necessary oxygen to free the hydrogen bubbles. None is used in the air cell, as oxygen is drawn directly from the surrounding air for this purpose, and

* The 30 triode, 31 power triode, 32 screen grid, 33 power pentode, 34 super R.F. pentode, 19 class B twin triodes and the 1A6 and 1C6 pentagrid converters are in this group. Formerly the 99 and 120 type, 3 volt tubes were used in battery sets but are rarely used in recently designed equipment. The first receiver, even before the advent of A.C. receivers, used the 01A, 71A and 12A battery tubes (triodes), but these are now discarded because they take too much power to operate.

therefore the hydrogen bubbles cannot affect the generating ability of the cell.

The air cell battery has two cells built into a one-piece, molded, hard rubber case, the two cells permanently connected in series, giving about 2.5 volts. Only two terminals, a "+" and a "—" binding post exist. The battery is shipped dry to the radio dealers with the chemical inside each cell. The vent plug is unscrewed, the thin rubber membrane cut away, the cells filled with ordinary drinking water. About six quarts are required. The cellophane covering the breathing carbon electrodes is removed, and the battery is ready to use.

At the start the battery will deliver 2.53 volts to an average battery receiver, and for a period of 1,000 hours the voltage will gradually reduce to 2.2 volts. Then the voltage drops quickly to a value that renders the

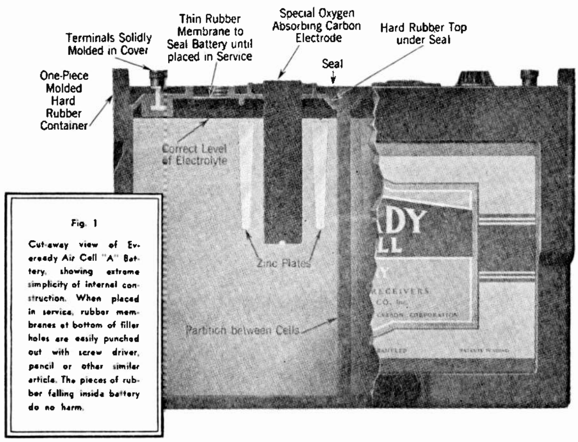

Fig. 1.—Air Cell "A" Battery

battery useless. After this the battery is "dead" and a new one must be used. But 1,000 hours is a reasonably long time. For example: if the receiver is used 3 hours a day, the battery will serve for 1,000 divided by 3 or 333 days, nearly one year. As the total energy available from this source is limited to 600 ampere-hours the battery will even last longer on sets with few tubes. The average sensitive receiver requires about .55 ampere and the battery will last over 1,000 hours. You should never draw more than .75 ampere from an air cell battery as its life will be considerably shortened.

Fortunately the air cell or 2 volt series of tubes will operate satisfactorily if the voltage is maintained below 2.2 volts and above 1.9 volts. Therefore the filaments of all the tubes are connected in parallel and a resistor placed in series with the main supply so the tube filament voltage will never exceed 2.2 volts. The whole story is graphically shown in Fig. 2. The tubes may draw different values of current, and the exact value required by each type may be determined by referring to a tube table. A total of .62 ampere is required for this 6 tube receiver. Each tube filament must have 2.2 volts applied and as a value of 2.53 volts is supplied by the air cell battery, a resistor R must supply a voltage drop of .33 volts. This resistor may be determined by Ohm's Law and is equal to .33 divided by .62, which equals .53 ohms. A resistor having a value of ½ ohm will do; there is no need of "hitting the nail too close on the head." A difference of 5% is quite all right. Of course, if the resistor happened to figure out .59 ohms, you would probably have difficulty in getting that exact size. This is what I would do. I would procure a 1 ohm (2 watt or more) resistor of the sliding clamp type, connect one lead to a and the sliding clamp to b. Before I would connect the air cell battery I would make sure that the entire resistor was in the circuit. Then I would connect a reliable 0-10 volt D.C. meter across one of the tube filaments and reduce the resistor value until the meter read 2.2 volts. To be sure, I would use a brand new air cell battery.

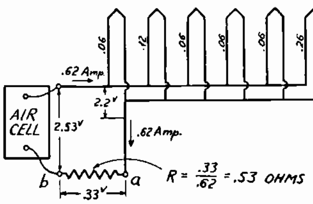

FIG. 2

Why have I gone into all this detail? Simply because there are many "old time" battery receivers that work well enough except, the batteries have to be replaced too often. These older sets use 01A, 71A and 12A type tubes.* Usually you do not have to make very many alterations to change over to tubes which draw less power. Place a 30 tube wherever there is an 01A, a 31 tube wherever there is a 12A or 71A tube. Figure up the total filament current (a 30 tube draws .06 ampere, a 31 tube draws .13 ampere) and divide .33 by this total. Insert the new resistances in any lead from the air cell battery. Short all the filament resistors or rheostats in the old receiver, as they should not be used. Now for the volume control; later on you will be able to recognize the R.F. stages. Locate the second R.F. stage and connect a 5,000 ohm variable resistor between the plate and the plate supply. If the set happens to be a neutrodyne you will have to rebalance the set so it will not squeal. You will probably have to reduce the C bias and plate voltages. A tube table will tell you the correct values. All this will be familiar as you progress with the course.

* Some of the receivers use 99 and 120 tubes. Replace a 99 with a 30, and a 120 with a 31.

Storage and Dry Battery Filament Supplies. Although the air cell battery was developed to overcome the difficulties experienced with storage and dry cells, the latter are nevertheless used quite regularly in receivers employing the 2 volt tubes, mainly because the air cell battery is not readily obtained.†

An ordinary automobile battery and the older radio storage battery will deliver about 6 volts, that is because three 2 volt cells are used connected in series. One cell can be used on a 2 volt tube receiver. A 100 ampere-hour fully charged cell will supply filament power to an ordinary battery receiver for about two months, without charging. If the three cells are connected in parallel, the battery will last six months. Of course, the customer will not be able to charge the battery, for if he had this facility he would be better off with some other type of receiver. If you furnish or service the modern battery receiver and use a 2 volt storage battery, you should supply it on a rental basis or at least on some plan

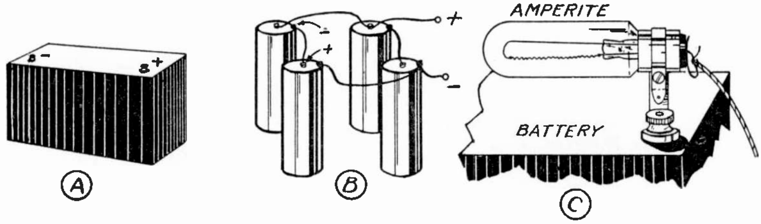

Fig. 3

where a freshly charged battery is installed regularly. The average life of a storage battery if kept in good condition is about two years. In using a storage battery the series resistor (*R* in Fig. *2*) is omitted.

Until recently it was not considered wise to connect dry cells to a 2 volt battery receiver. Dry cells lose their voltage too quickly under constant use of 2 to 3 hours. However, there is now available a ballast resistor designed especially for dry cells used with 2 volt tubes, which will compensate for this voltage drop. Either a 3 volt *A pack* as shown in Fig. *3A*, or 4 dry cells connected in series-parallel, as shown in Fig. *3B* may be used. The ballast* shown in Fig. *3C* is connected in series with the filament battery and has the job of keeping the voltage within the range of 1.9 to 2.2 volts for battery voltage changes of 3.4 to 2.2, the usual variation of two dry cells in series during their useful life.

B and C Batteries. In checking tube tables and the circuit diagrams of several modern battery receivers I found that the usual B (electrode)

† You can procure an air cell battery from most wholesale radio supply houses doing business by the mails.

* If you plan to use this ballast, write to the Amperite Corporation, 561 Broadway, New York City, for technical information and the correct sizes to use.

voltages are 180, 135, 90 and 67.5 volts. The required C bias voltages varied considerably, the usual values being —3 —4.5, —9, —13.5, —18, —22.5 and —30 volts. Nevertheless, all these values are quite easy to obtain from regular B and C batteries, because these batteries are made up of a number of 1.5 volt cells connected in series. Figure *4A* illustrates a typical B block having +45, +22½ and —B volt terminals; Fig. *4B* shows a 4.5 volt C battery; Fig. *4C* a 4.5 volt C battery with —1½ and —3 volt terminals; Fig. *4D* a 7½ volt C battery with —1½, —3, —4.5, —6 and —7½ volt terminals; Fig. *4E* a 22½ volt C battery with —3, —4½, —16½ and —22½ volt terminals.

You will rarely encounter a receiver that employs a plate voltage of less than 90 volts. Remember that for every 45 volts required, a standard

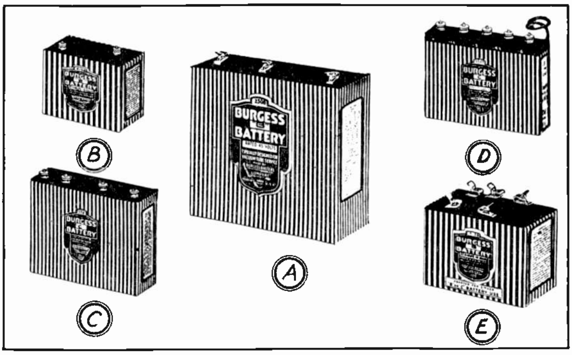

Fig. 4

45 B block should be used, and be sure to get the type with a 22½ volt tap. Where 90 volts are required use 2 blocks, where 135 volts are needed use 3 blocks and where 180 volts are specified connect 4 B blocks as shown in Fig. *5A*. The usual 67½, 90, 135 and 180 volt taps are clearly indicated.

As I previously mentioned, the C bias voltages required for a modern battery receiver will be quite varied. Personally I have found that if you buy two 4½ volt types with the —1½ and —3 volt taps, and one of the 22½ volt type with the —3, —4½, —16½ and —22½ volt taps, you will be able to meet all cases. Figure *5B* shows how a receiver requiring —3, —4½ and —22½ volts is supplied with one large (with only a + and a —22½ terminal) and one small C battery; while Fig. *5C* shows how all these voltages are supplied with a single large C battery with several intermediate taps. You will generally find that where the largest C bias is —22½ volts the largest B voltage is 135 volts; but where 180 volts B are required, the C bias voltage will be about —30 volts.* Figure

* Except in class B push-push output amplifiers, where no C battery is required.

5D shows how the latter condition may be fulfilled. With these examples I feel sure you can figure out other conditions as they arise.

A Typical A, B, C Supply. To illustrate a typical supply system for a modern battery receiver I have drawn Fig. *6*, the supply circuits of a 5 tube receiver.† I purposely left out the coils, resistors, condensers, transformers and other signal circuit parts, so you may concentrate on the supply system. The filament circuit is drawn with heavy lines. Observe that the —A battery terminal connects directly to one terminal of all the tubes, the +A battery terminal traces through the ballast resistors, two being used. One ballast feeds 3 tubes, while the other controls 2 tubes. Both ballasts are built into a glass envelope and the entire

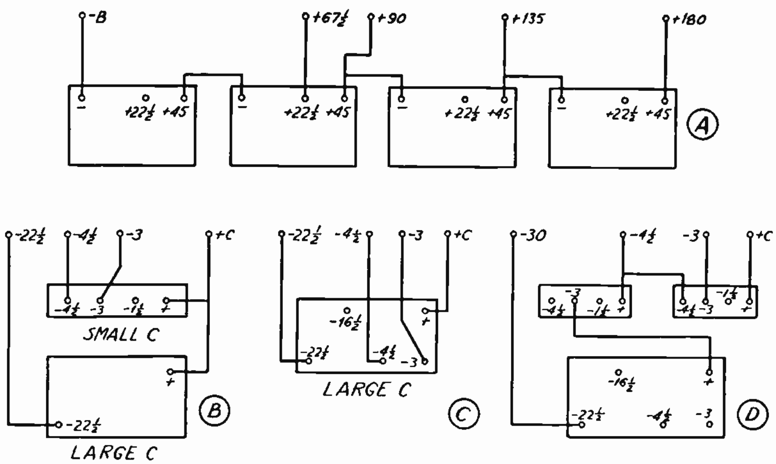

Fig. 5

device looks like a tube. In this receiver a 135 volt B supply is required, the lower screen grid voltage is obtained within the receiver by a resistance drop. Reading from left to right, the second tube requires no C bias (a special oscillator connection which you will eventually learn about). The purpose of resistor *R* is to supply the C bias voltage to the last tube; the voltage drop in *R* is produced by the plate and screen grid currents which flow through it. The first and fourth tubes require a —4½ volt C bias voltage; the third tube is supplied with a —3 volt C bias. A small 4½ volt C battery will suffice.

Connecting a battery receiver to a set of batteries is a very simple task. The receiver is usually supplied with a cable having different colored wires, or wires with two colors as indicated in Fig. *6*. Either the end of each wire in the cable has a small metal tag indicating the voltage

† Battery receivers employ loudspeakers which require no special field power supply before they will operate. They are called magnetic loudspeakers.

and whether it is an A, B or C connection; or the set is supplied with connecting information. With this information, the batteries required and the connections to be made are simple.

THE MODERN 110 VOLT D.C. RECEIVER

Now I shall consider the receiver or amplifier that is designed to operate from a 110 volt D.C. socket outlet, a type of supply that you will encounter in the business sections of some large cities or in a small community where a small power house has been locally erected. In this case we have direct current to operate tube filaments and to supply the electrode voltages. More than enough voltage is available for heating filaments, but not enough voltage is provided for the plates of the output tubes which should be as near 250 volts as possible. Even in the battery receiver, at least a 135 volt supply is generally used. As it may be inad-

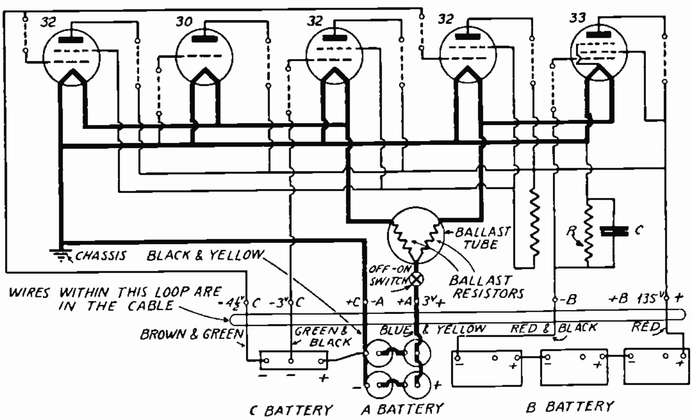

FIG. 6

visable to raise D.C. from a low to high value by using some complicated system, the designer of 110 volt D.C. receivers must be satisfied with what he can get with the available tubes. Tube manufacturers have tried to meet this condition with special power tubes; for example the 43 power pentode will deliver 0.9 watt of audio power when the plate voltage is 95 volts and the C bias voltage is —15 volts (a total of 110 volts). Some of the designers of radio equipment prefer to use standard tubes, even at the sacrifice of power output, so replacement tubes will be easier to get.

The tube filaments of a 110 volt D.C. set are always connected in series, for in this way the applied voltage can be used in the filaments rather than wasted in a resistor. As a rule the 6.3 volt series of tubes are employed, and if possible a high filament voltage power tube (the 43 power pentode requires 25 volts). The tubes in a modern 110 volt D.C. receiver are of the heater type, which simplifies the design of the supply system. The filaments may therefore be connected in series without regard to the other circuits. For example, Fig. *7A* shows 5 tubes, four 6.3 volts and one 25 volt (power) type tubes in series. Their net voltage drop is 50.2 volts and as the line is 110 volts, the resistor R must be inserted to take up the difference of 59.8 volts. As these tubes draw .3 ampere resistor R will be equal (by Ohm's Law) to 59.8 volts divided by .3 ampere, or very nearly 200 ohms. The power wasted is 59.8 volts multiplied by .3 ampere, which equals 18 watts. A 25 watt resistor exposed to the air is used.

Now let us turn to the electrodes' voltage supply. If they were connected directly to the 110 volt D.C. source, a "whine" would be emitted from the receiver. This is the A.C. ripple introduced by the commutator of the generator at the power house. To eliminate this whine, a simple filter shown in Fig. *7B* is used. Above everything else, it is important that the iron core choke has a low resistance, otherwise there would be too much reduction in the voltage fed to the electrodes.

A typical D.C. socket power receiver is shown in Fig. *8*, and in this case too, only the supply circuits are shown. (You should master the details of this circuit, as well as the other typical circuits given in this

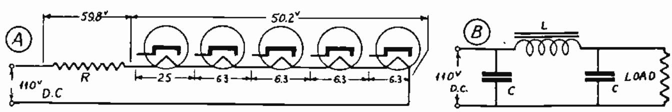

FIG. 7

lesson, for they show how the various power supplies used in receivers and amplifiers differ.) Again the solid black lines indicate the filament supply circuit, and resistor R_1 is used to limit the current flowing to a normal value. Observe that all plates connect to the + supply terminal. From each plate you can trace the circuit through the tube, through the cathode or C bias resistors (R_2, R_3, R_4 and R_5). Resistor R_2 is variable and as you will eventually learn is a very common type of manual (hand) volume control. Furthermore R_2 controls the C bias of the first and third tubes (reading from left to right is the usual procedure). To utilize the voltage drop provided by these resistors each grid (after tracing through the input devices) connects to the terminal which is negative with respect to the cathode.

The screen grid of the last (power) tube is connected to the *plate supply* terminal, but the screen grids of the other tubes must be operated at a voltage lower than the plate voltage. Therefore their common terminal is connected to the intermediate tap of a voltage divider, in this case R_6 and R_7. The negative terminal of the main supply is obviously a common terminal to all the electrode supply circuits. Therefore it should be grounded. But it would hardly be safe to make a direct connection so this negative terminal is grounded through the condenser C.*

I have been asked so often why this condenser is used that I am including Fig. *9* to help answer this question. I have shown a three wire distributing system for 110 and 220 volt power distribution.† Note that

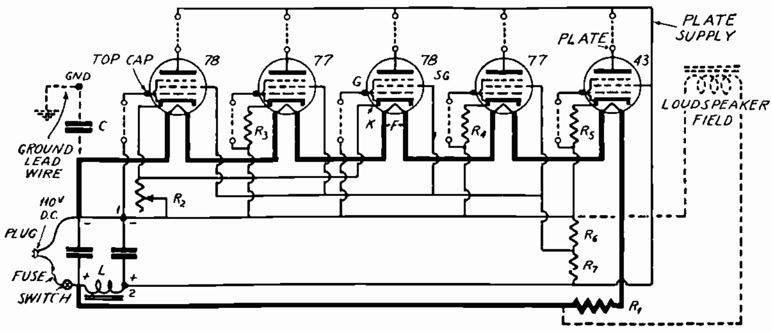

Fig. 8

the mid-wire is grounded, a connection made by the power company. When the receiver power plug is inserted into the wall socket you do not know whether you have made the right connection. If you happen to connect the — terminal to the + line, as shown in Fig. *9*, and the receiver has a direct ground, the line will be shorted, and the house fuses will blow out. By using condenser *C*, as in Fig. *8*, the short would not occur. The

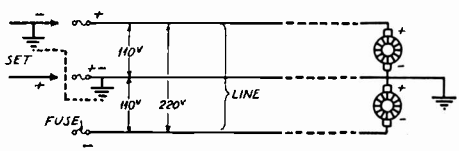

Fig. 9

receiver or amplifier would not work until the plug connections were reversed. While I am on the subject, I would like to explain why some sets show a spark when the ground wire is being connected. Refer to Fig. *8*. When the ground lead wire is attached to the GND receiver post, A.C. current in A.C. receivers and a charging current in the case of D.C. receivers flows to the condenser and creates the spark while a connection is being made. If you touch an ungrounded post you may get a slight shock as the current passes to ground through your body.

* Must have low reactance to the A.C. radio signal.

† May be A.C. or D.C. The condenser is also required in A.C. or universal receivers where the power transformer is omitted.

The only other power supply required for a D.C. receiver would be for the field of the dynamic loudspeaker. The field winding would normally be designed for 110 volts D.C. and connected directly to the main supply, as shown by the dotted lines in Fig. *8*.

THE UNIVERSAL RECEIVER OR AMPLIFIER

A radio receiver or amplifier for use only on a D.C. power outlet is the exception rather than the rule. People hesitate to buy a D.C. receiver, realizing that they may eventually move to a location where A.C. is available. The problem of making an amplifier or radio receiver work on either A.C. or D.C. power was first solved by engineers, when the midget portable receiver first made its appearance. This receiver was made to work in hotels (where D.C. power is usually found), in the home, or where 110 volt power of any type is to be found; and where the designer considered general utility (use) more important than good sound quality with volume (loudness).

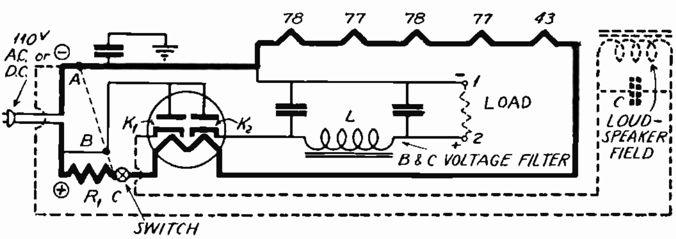

FIG. 10

Universal radio receivers and amplifiers for that matter, are designed just as if they were to be used on a D.C. line and then a half-wave diode rectifier is connected in series with the + supply lead to the tube electrodes. When the receiver is connected to an A.C. supply the rectifier tube converts the A.C. power to pulsating D.C. current and the filter (which must be better in a universal receiver than in a D.C. receiver) removes the ripple frequencies; when the receiver is connected to a D.C. supply the rectifier tube acts just like a resistor and reduces the available plate voltage. As the tubes used are of the heater type and the filaments have no connection to the signal circuits, either A.C. or D.C. power may be used.

Figure *10* shows the only changes required in the D.C. receiver given in Fig. *8*, to convert it to universal use. A twin heater type diode rectifier is employed, so one diode will furnish D.C. power to the tube electrodes, and one rectifier will feed D.C. current to the field coil of the dynamic loudspeaker. If you trace the rectifier circuits starting from the + line terminal you will in one case pass through the filament circuit (heavy black line); or going to the rectifier plate to cathode K_2, pass through the B and C voltage supply filter.

Although the dynamic loudspeaker field could be designed to have a very large ohmic resistance and connected to the output of the filter (terminals *1* and *2*), every attempt is made by the designer to reduce the filter load, so a large rectified output for the tube electrodes can be obtained. You, of course, know that where a condenser input filter is used, low loads (little current drain) will keep the voltage up to near peak A.C. value. Even when D.C. is used a large current will produce a large rectified voltage drop, which naturally is undesirable. Condenser *C* is connected across the field windings to bypass the ripple frequencies, while the inductance of the field chokes the ripple currents. But the coil and the condenser must not resonate to any ripple frequency component.

If you were to draw the tube circuits (except the loudspeaker field) to the right of terminals *1* and *2* of Fig. *8* (in light lines) connected to terminals *1* and *2* of Fig. *10*, you will have the power supply circuit diagram of a universal (A.C. or D.C.) receiver.

There are a few circuit details in a universal receiver or amplifier that I should like to have you recognize. As an extra filament is used in the circuit, which would not be required in a D.C. receiver, (in this case a tube having a 25 volt filament drop is used), current limiting resistor

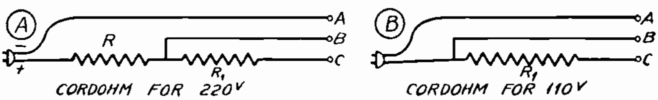

FIG. 11

R_1 cannot have as large an ohmic value as for a D.C. receiver. Furthermore, this resistor is quite often placed in the power cord. One commercial product is called a "cordohm." This scheme is quite good as the heat developed is quickly cooled by the air; the cord, of course, being exposed. Then too, the cord can be quickly removed and a cord with a large resistor used, so the universal receiver can work on 220 volts A.C. or D.C. Power cord connections are shown in Figs. *11A* and *11B*, connections *A*, *B* and *C* of the "cordohm" are made to the corresponding points in Fig. *10*.

A universal receiver or amplifier in which the rectifier feeds into a well designed condenser input filter, works better on A.C. than on D.C., simply because with rectified A.C. the peaks are used to give increased voltage. If a universal receiver supplies higher electrode voltages on A.C. than for D.C. will the C bias voltages be incorrect in one or the other condition? As the C bias resistors are in series with the plate supply (see resistors R_2, R_3, R_4, R_5 in Fig. *8*), a larger supply voltage will produce a greater plate voltage, which will produce a larger plate and C bias resistor current (both are about equal for a series divider connection) and hence the C bias voltage (resistance times current) will increase. By referring to any tube table you will learn that a higher plate voltage calls for a higher C bias voltage. This action for a series cathode resistor is automatic (within reasonable limits) and accounts for the ability of the circuits to adjust themselves to either A.C. or D.C. use. Incidentally, this type of C bias is often called "automatic C biasing," and is extensively used in all vacuum tube circuits.

THE MODERN AUTOMOBILE RADIO RECEIVER

The automobile receiver is no exception to the rule. It, too, must have a filament, a plate, grid, screen, and if necessary a loudspeaker field supply. Now, every car, bus or truck using a gasoline engine has a 6 volt storage battery, to supply the ignition voltage and to start the engine. This very same battery may be used to heat the filaments of tubes and to supply the exciting current to the field* of the dynamic loudspeaker. The real problem arises in getting high voltage continuous current. At first, B and C batteries were used but they were finally replaced by vibrator or small combination motor-generator supply systems which I am about to consider. The modern auto receiver still uses the car battery to supply power to tube filaments, and the loudspeaker field, and furthermore has a power conversion system which changes 6 volt D.C. current to about 250 volts D.C. current. The car battery is the primary source of electrical power.

But before I go into the supply system let me clear up a few misleading ideas that have crept into the average student's (and serviceman's) mind. The signal circuit of an auto radio receiver or amplifier is no different than any other receiver or amplifier. To be sure, the auto radio must work off a small antenna (usually a copper mesh in the roof of the car, or a V antenna under the body of the car), and therefore must be far more sensitive than the home receiver. Sensitive receivers are no different than those with less pick-up ability, except perhaps another radio frequency amplifier, or as is usual in an auto radio, a more sensitive radio frequency stage. But I am getting ahead of my study plan. Signal circuits are taken up in future lessons, yet I do want you to realize that there is no real important electrical difference, other than the supply system.

An auto radio is subject to constant mechanical vibration; so it must be assembled with lock washers or by rivets to keep the parts together; it must be water-proof and weather-proof to withstand all kinds of atmospheric conditions. Automobile tubes (the 6.3 volt series) are best because they were designed to withstand vibration. The receiver must be quite compact, because there is little room for a large machine. The circuits must be economical in their use of high voltage power, as

* Ampere-turns is the important factor, hence high voltage, low current; or low voltage, high current fields are possible.

the battery is the only source of power. But all this is a problem for the radio designer, and he has solved the problem with great success.

The spark plugs and the battery charging generator, the loose parts of the car body introduce interfering noises, which are readily picked up by a very sensitive receiver. This calls for a well shielded receiver and well shielded leads. Metal casings (shields) will block A.C. magnetic fields. And if these precautions do not suffice the interference must be reduced at the source, with condensers, resistors and coils. This is a subject that all students specializing in radio servicing will take up.

The 6 Volt Circuits. As the primary power source is a 6 volt storage battery capable of giving 10 amperes under continual load, the 6.3 volt filaments are connected in parallel, as indicated by the heavy lines in Fig. *12*. The 6 volt dynamic loudspeaker field is connected in parallel, as if it were an extra filament, and the input of the 6 to 250 volt D.C. converter is likewise connected in parallel.

This circuit shows the negative terminal of the battery connected to the car chassis. Hence a single lead from the + terminal to the receiver is required, the other receiver lead may connect to any metal

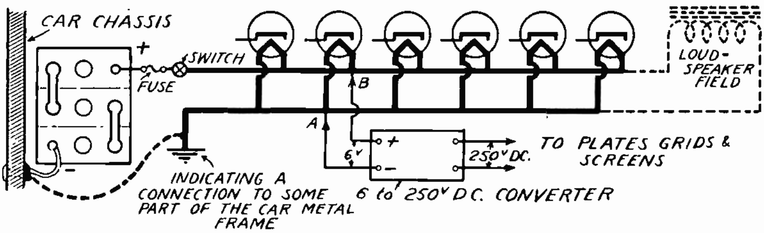

Fig. 12

part of the automobile provided it is welded, bolted or riveted to the car chassis. The return circuit (indicated by the heavy dash-dash line) is through the car, and is the usual procedure for all car electrical wiring. In some cars, the + battery lead instead of the — lead is connected (grounded) to the chassis. As far as the filaments and loudspeaker field are involved, the reversed connection is of no importance, simply because the signal circuit and the filament circuit are isolated by using the heated cathode type tube. But the converter connection may be incorrect. So when this condition is encountered in car installations, all you need do, in most cases, is to reverse the converter connections (*A* and *B* in Fig. *12*). A number of auto receiver makers are supplying battery leads long enough to connect directly to the car battery, in which case the battery lead connections may be reversed if necessary; and in other receivers the connection is immaterial. Although these are general instructions, I caution you to always follow the instructions sent with the auto receiver that you will install.

The Dynamotor. When the first automobile radio receiver was designed to operate without B batteries, a "dynamotor" was quite often used. As the word implies, this is a combined motor and generator. A dynamotor is a single unit, having one frame, one rotor and one electromagnet (field); but two armature windings and two sets of commutators each with its own brushes. One set of windings is designed for 6 volts and when connected to the car battery will set the rotor in motion. With the rotor set into motion the other windings while passing through the magnetic flux produced by the field develop a voltage. By building the second winding with many turns (about 42 times the 6 volt winding) it will generate 250 volts D.C. After passing the power through a filter to eliminate the commutator ripple, the high voltage system of the receiver may be fed by the usual series or parallel voltage divider methods.

A typical dynamotor now used in automobile radio receivers and receivers used on aircraft is shown in Fig. *13A;* a typical circuit diagram is given in Fig. *13B*. The dynamotor used for auto radios weighs about 10 pounds and is generally located near but not on the receiver chassis, although a number of receivers and power audio amplifiers have been made with the dynamotor fastened to the chassis of the device. In the latter case the dynamotor is suspended on a floating (spring) support.

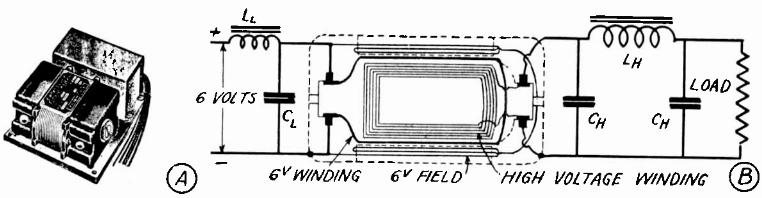

FIG. 13

Referring to Fig. *13B*, you will see the circuit diagram details. The output filter consists of the choke L_H and the condensers C_H. Sparking at the brushes is bound to create strong electromagnetic fields and shielding of the motor housing (using a closed frame) is important. Sparking results in sharp current changes which will get into the 6 volt and high voltage lines. At the output, the filter will suppress this possibility. At the input, a condenser C_L is always used to bypass any interfering current going out by this path, and quite often a low resistance iron core choke L_L is used. The latter is usually installed by the serviceman when its need is indicated. As a serviceman, you should see that the commutator is clean, level and the brushes fit snugly to the commutator.*

Incidentally, dynamotors are used to operate off of 2, 6 or 32 volts

* Place a piece of sandpaper around the commutator (dynamotor disconnected from the 6 volt supply) with the sandpaper towards the brush. Rock the rotor until the brush cuts clean and to shape. Rub *a little* vaseline on the commutator. If the commutator is badly worn, it should be taken to a motor repair man who will turn it down so it will have a smooth, round, uniform surface.

D.C. so battery receivers used on the farm may work without B and C batteries. No change in connections is required as these dynamotor units incorporate a voltage divider to supply all the necessary electrode voltages.

The Vibrator-Tube Rectifier Supply. Even though the modern dynamotor designed for mobile (automobiles, trucks and aircraft) use, is a model of mechanical quietness, the use of rotating machinery is not particularly favored by auto radio manufacturers. Engineers developed the vibrator which chops the 6 volts D.C. into A.C. and D.C. components (pulsating current) and then a transformer steps up the A.C. component before it is rectified with a tube rectifier.

A simple circuit is shown in Fig. *14A*. The primary of a step-up transformer is connected in series with a vibrator (or buzzer). Normally the spring of A, the armature (moving reed) keeps C_t in contact, thus completing the low voltage circuit (shown by heavy lines). If the primary circuit is connected to the battery, current will start to

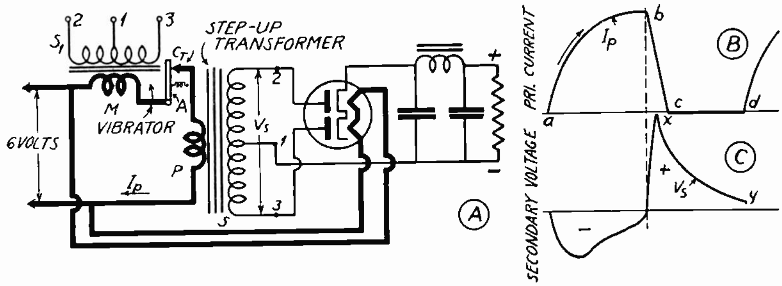

Fig. 14

flow, gradually reaching a maximum value as portrayed by a to b in Fig. *14B*. This delay in reaching maximum is due to the resistance in the circuit slowing up the storing of magnetic energy in the coil. Now the current in the electromagnet is sufficiently large to pull the armature A away from contact C_t, and the primary circuit opens. The current in the primary drops rapidly, as shown by the b to c portion of the curve in Fig. *14B*. Even after the current has reduced to zero value, the armature is moving away from the contact, and finally returns to its original position, in contact with C_t. This last travel or armature "excursion" is portrayed by portion c to d of the curve. The cycle then repeats itself.

Recall, if you will, that whenever the primary current changes, a voltage will be induced in the secondary of a transformer. While the current increases the voltage acts in one direction and when the current decreases the voltage will act in the opposite direction. With these facts in mind you can see that the secondary voltage curve could be like Fig. *14C*. This curve is a reproduction of what has been observed by a cathode ray oscillograph (the circuit eye) and represents a condition for a resistance load, which is exactly what exists when the rectifier is working into the supply circuits of a radio receiver. If it were not for this load, the peak at x would be much sharper, and higher, and the "drag out" from x to y would not exist. The resistance attempts to redistribute the energy originally in the peak.

Figure *15A* shows a modern vibrator supply circuit. You will observe that three contacts K_1, K_2 and K_3 exist at the vibrator, the primary circuit is mid-tapped, and the primary and secondary are shunted by condensers C_1 and C_2. I will explain R and K_p shortly. The condensers are used to store energy so the secondary voltages will be more regular, the primary condenser is also used to reduce sparking and the secondary condensers to protect the tube from sudden high voltages. The vibrator circuit $a \rightarrow K_4 \rightarrow K_1 \rightarrow C \rightarrow b$ is independent of the primary circuit; and normally has a high resistance so as not to short the source. In vibrating, the armature alternately connects contacts K_2 and K_3 to the source. Each half of the primary receives the full battery voltage, and the magnetic

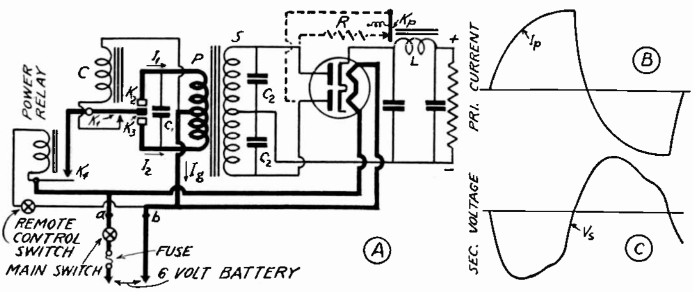

FIG. 15

flux produced in the iron core is in opposite directions. Thus a full-wave secondary voltage is produced. By using this circuit greater efficiency is obtained, more voltage is produced and the output wave form is more regular, see Figs. *15B* and *15C*.

To protect the rectifier tube from large voltages, relay K_p is used. Either a combined relay and choke, or a separate filter choke and relay are employed. When choke-relay L is not conducting current (the receiver tubes have not heated up), the relay spring closes the relay contact and resistor R (about 5,000 to 20,000 ohms) is shunted across the secondary. After the tubes heat up current is flowing through coil L, relay contact K_p opens and the receiver is then the only rectifier load. Condensers C_2 and relay K_p are often omitted in power packs where high vacuum rectifier tubes are used, but are absolutely needed for mercury vapor rectifier tubes.

Contact K_1 is always shunted by a condenser (omitted in the diagram for simplicity) to prevent sparking. Although a main switch suffices.

quite often a remote control switch is used (in which case the main switch is omitted). In this case a power relay is used to close the supply circuit, actuated by the remote off-on switch.

If you will refer again to Fig. *14A,* you will observe a secondary marked S_1. In a number of vibrator supplies the vibrator is a part of the power transformer, in which case connections *1, 2, 3* of the rectifier tube are made to connections *1, 2, 3* of the vibrator-transformer.

Vibrator-Vibrator Rectifier. Shortly after the vibrator-tube rectifier appeared in auto radio receivers, radio engineers started to develop the mechanical rectifier, reasoning that if one-half of the primary was carrying current, a corresponding half of the secondary could be mechanically connected with the proper polarity to the load. The vibrator-vibrator rectifier system is shown in Fig. *16,* and in this case only the necessary details are shown. The buzzer circuit works through contact K_1, which opens and closes the buzzer circuit as well as one-half of the primary. (This is modern practice for all vibrators to eliminate needless contacts.) When the armature A is to the right contacts K_1 and K_3 are made, a pri-

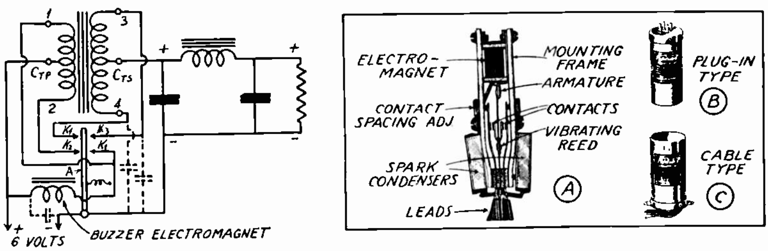

FIG. 16

mary and a secondary; when the armature is forced to the left contacts K_2 and K_4 are made. The transformer is so connected through the vibrator so the center tap C_{TS} of the secondary is always the plus terminal of the load. Condensers are shunted across each secondary contact, and a large condenser across the primary input. Additional chokes and resistors are often used to help reduce sparking, which if allowed to exist would cause serious radio interference.

In actual practice all three types of high voltage supplies are used in low power mobile installations, namely: *1,* the dynamotor; *2,* the vibrator-tube rectifier; and *3,* the vibrator-vibrator rectifier. Their electrical efficiency rarely exceeds 75% with the vibrator-vibrator rectifier slightly superior for small powers only. Both vibrator systems seem to be more popular than the dynamotor systems in factory made receivers. Vibrators are subject to wearing out, and although an expert can repair them, the only servicing that should be considered is cleaning the contacts with a fine hard flat file or a tool sharpening stone, adjusting the contact spacings, and if this does not suffice a replacement vibrator should be used. As a matter of fact, most servicemen prefer an immediate replacement, as repaired vibrators do not stand up well; and in most auto receivers a quick replacement is made by removing the vibrator unit which is supplied with prongs that fit into a tube socket.

32 VOLT D.C. FARM RECEIVERS

When a farm is equipped with a small power plant, you will generally find that a 32 volt D.C. system exists. This voltage is used for reasons of economy, initial cost and upkeep. A gasoline engine operates a 32 volt D.C. generator across which is connected a 32 volt storage battery (16 — 2 volt cells). The engine driven generator is used to keep the battery fully charged, and is set in motion only when the charge reaches a minimum value. A 110 volt D.C. system would be more satisfactory but 55 storage cells would be required, which in itself prohibits this voltage. A number of 110 volt, 60 c.p.s. A.C. engine driven systems are being installed, and the system is arranged so the turning on of a switch starts up the system. In the latter case regular 110 volt, 60 c.p.s. receivers or electrical farm equipment should be used.

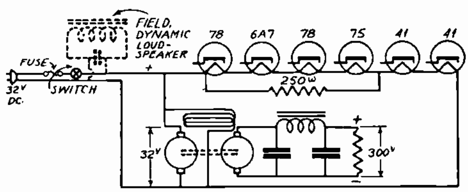

FIG. 17

However, the problem of supplying a 32 volt D.C. radio receiver equal in performance to any A.C. receiver is by no means a difficult task. From what I have already presented, I imagine you know what is done. The filaments are connected in series, or in series-parallel, the series connection not to exceed a 32 volt drop; the high D.C. voltage is produced by means of a dynamotor or a vibrator with a tube or vibrator rectifier; and the field of the dynamic loudspeaker is designed for 32 volt D.C. operation.

A typical power supply circuit as shown in Fig. *17* will help you fix the method in your mind. All tubes are of the 6.3 volt type, and here advantage is taken of the fact these tubes will work well with from 5 to 7 volts applied to the filaments. Using 6 tubes, each tube gets $32 \div 6$ or about 5.3 volts. But as the 41 power pentode tubes require .4 ampere, while the others need .3 ampere, the extra .1 ampere is shunted through a resistor equal to $5.3 \times 4 \div .1 = 212$ ohms. A value of 200 to 250 ohms suffices. The field of the dynamic loudspeaker shunts the 32 volt D.C line; while a 32 to 300 volt dynamotor produces the necessary high D.C. voltage.

I would like to mention that a number of storage battery receivers are being built along similar lines. A 6 volt storage battery feeds several 6.3 volt tubes connected in parallel, while a small dynamotor or vibrator-vibrator rectifier converts the low D.C. voltage to high D.C. voltage. In this case every precaution is taken to use as little battery power as possible, so the storage battery will not have to be charged too often.

ENGINE DRIVEN GENERATORS

Many situations arise when no source or an inadequate source of power to operate radio equipment exists. I have already indicated that when no power is available, a battery operated radio receiver or amplifier may be used. Where high power outputs are needed, these devices would be inadequate. Even though a car battery will satisfactorily operate an automobile receiver or public address amplifier, here too the possible power output may be insufficient if projecting sound (a public address

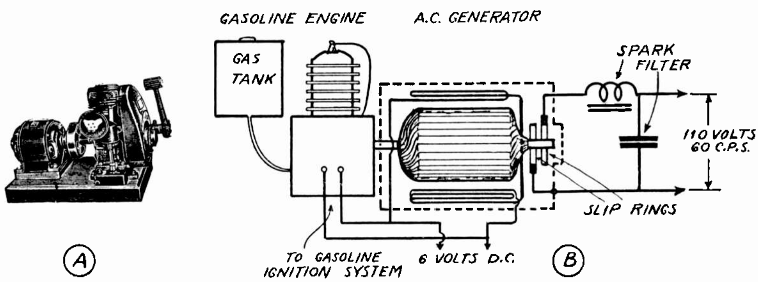

Fig. 18

or loudspeaker system) is the object of the installation. In such cases the logical procedure is to use a gasoline driven generator, and as electrical power is to be generated it seems logical to develop 110 volt, 60 c.p.s. power, so standard equipment may be employed. This frequency and voltage is considered standard because this power is universal in the U. S. A. Where other conditions are standard, a suitable generator should be considered.

A typical gasoline engine driven A.C. generator used by servicemen in mobile public address installations, is shown in Fig. *18A*. The unit is entirely self contained and is furnished with a gasoline storage tank. A switch-board is optional equipment. Although various sizes can be obtained, a 300 watt unit is quite common and satisfies most needs. The electrical connections are quite simple, as can be seen from Fig. *18B*. A 6 volt battery (usually a storage battery) is the only auxiliary equipment. It is needed to excite the electromagnets of the generator and to operate the ignition system of the gasoline engine. In an automobile installation the car battery may be used. The output of the generator has a simple spark filter (coil and condenser) to suppress interference. The engine ignition is treated like any automobile installation for elimination of interference, and this is usually made by the manufacturer of the power equipment. The gasoline engine is started by turning off the generator load, turning on the ignition and field source, and stepping on the pedal. Then the electrical load is applied. Power sources of this type are also used in aircraft, but the equipment is designed to have the lowest possible weight. The engine revolves at approximately constant speed as special speed governors are used, but as the frequency may not be exactly 60 c.p.s., the power pack of the radio equipment should not incorporate tuned filters.

If inefficiency of power development is not objectionable in a mobile installation, the gasoline engine of the automobile or truck may be used. Figure *19A* is a typical A.C. generator which is mounted so the fan belt of the gasoline engine runs over the generator shaft pulley. The car

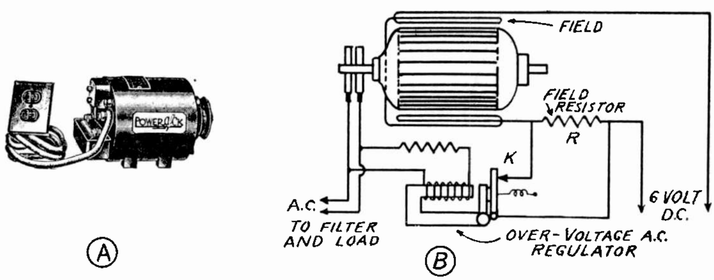

FIG. 19

battery furnishes the generator field current and the A.C. output is cabled to regular wall socket outlets. In this case the car engine must be in operation at all times when the radio equipment is used. As the engine speed will vary with the position of the car throttle and whether the car is at rest or in motion, the radio equipment must not incorporate power packs with tuned filters, and the generator must have some voltage regulator. The generator is designed to give from 50 to 70 c.p.s., from which well designed 60 c.p.s. equipment works.

A typical voltage regulator is shown in Fig. *19B*. An electromagnet designed for A.C. operation is shunted across the generator slip rings, having a current limiting resistor. When the A.C. voltage exceeds 110 volts the magnet draws the armature to its core, opening contact *K* which in turn puts the resistor *R* in the D.C. field circuit. When the resistor is in the circuit the field current is reduced and so is the generated A.C. voltage. The armature vibrates faster as the engine speed increases, tending to lower the voltage more times each second. Although the regulator is not exactly a radio subject, service and maintenance technicians should be acquainted with the means of getting constant voltage and current. I have therefore included this short description. Furthermore, relays can be made to operate on excessive current or voltage, or insufficient current or voltage, by using a low or high resistance field and locating the contact so a pull by the magnet either closes or opens the control circuit or the circuit of the control device.

THE TRANSFORMERLESS A.C. POWER PACK

Occasionally you will run across vacuum tube equipment which operates from an A.C. source and which employs no power transformer of any kind. You will find small radio receivers and audio amplifiers, and electronic (photocell or electric eye) equipment with such a power pack system or power supply unit. The elimination of power transformers reduces the weight and initial cost of the equipment, factors which are often very important. The output D.C. voltage, when the device is operated on 110 volt A.C. supplies, will vary from 280 to 120 volts, depending on the current load. A transformerless voltage doubler A.C.

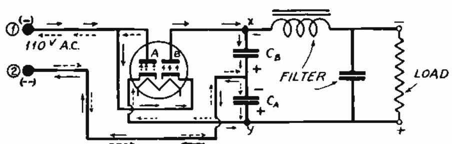

FIG. 20

power pack system uses two rectifier tubes, alternately charging two condensers. The latter are connected in series and if they feed a high resistance load their charge will leak off slowly enough so the voltage across each condenser will add. Only a limited load † (low D.C. current) may be realized from such a power pack.

A better understanding of the transformerless A.C. power pack can be obtained by referring to Fig. *20*,* which gives a typical "voltage doubler" circuit. Terminals *1* and *2* connect to the A.C. supply line. During one-half a cycle terminal *1* is negative and supplies electrons to the power pack; during the other half of the cycle terminal *2* is negative and supplies electrons. When terminal *1* is negative, electrons take the path shown by the *solid line* arrows, flowing from terminal *1* to the cathode and the plate of tube *B* of the double diode tube, then through condenser C_B and back to the other supply terminal (*2*). As you already know, electrons in flowing through a device (a load) always leave the

* In radio circuits it is customary to use a twin or double diode rectifier tube.

† For this reason a permanent magnet loudspeaker is generally used as no power is required for a field.

positive terminal; condenser C_B is therefore charged with the polarity indicated or, as you can see, electrons pile up on one side of the condenser making that side negative. C_B being connected to the LOAD, of course, discharges slowly, supplying a current. When terminal *2* becomes negative on the other half of the cycle, the electron flow (indicated by the dash-dash arrows) is through condenser C_A to cathode and plate of tube *A* and back to supply terminal (*1*). Condenser C_A is thus charged with the polarity shown. The alternating current supply rapidly charges each condenser (C_A and C_B) once each cycle; these two condensers are connected in series, with the — terminal of one connected to the + terminal of the other, so their voltages add. The polarities of the condensers do not change, so point x is always — and point y is always +. The voltage between points x and y, which is the D.C. voltage applied to the filter circuit and load, is therefore twice that which could be obtained from a single half-wave rectifier. It is the high resistance of the load that prevents the condensers from rapidly losing their charge. Condensers C_A and C_B should be as large as possible (16 to 32 microfarads). As the required voltage rating is low they are inexpensive.

The filament of the twin rectifier tube is connected in series with the filaments of the other tubes in the vacuum tube device and a series current limiting resistor used before this circuit is connected to the 110 volt supply; similar to a 110 volt D.C. receiver.

OPERATING EQUIPMENT ON SUPPLIES OTHER THAN FOR WHICH THEY WERE DESIGNED

I now want to tell you a few details that will be helpful and profitable in service work. You are bound to run across situations where a certain piece of radio apparatus was not designed for the power supply at hand. This condition usually arises when a customer has procured a receiver at some attractive price and without knowledge whether he can use it in his home; or the customer has moved to a place where a different

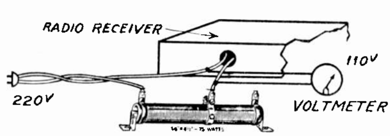

FIG. 21


FIG. 22

power supply exists. No sensible serviceman should recommend the rewiring of the receiver if the set can be adapted by some commercial device, or a simple adjustment can be made. I am now going to discuss these problems.

220 D.C. Volt Adaption. When a 110 volt D.C. receiver is to be connected to a 220 volt D.C. line, a series variable line resistor should be connected as shown in Fig. *21*. As the average modern 110 volt D.C. receiver draws about .5 ampere, a 75 watt — 250 ohm variable resistor should suffice. Mount the resistor in the cabinet, preferably on a rectangular piece of thin tinned sheet iron (to protect the wood from the heat); set the variable contact to the extreme right (all resistance in circuit); connect a 0-150 D.C. voltmeter as shown to the power supply input of the receiver; insert the plug in the wall; and move the contact to the left (reduce resistance) until the voltmeter reads 110 volts (the voltmeter will start with some low reading, 50 volts, and increase in value). When the meter reads 110 volts tighten the contact and the job is finished. Throughout these adjustments the receiver should play. If you get a shock, pull the plug out from the wall socket before making an adjustment.

220 Volt A.C. Adaption. If you run into a job where a 110 volt A.C. receiver is to be adapted to a 220 volt A.C. line, the scheme shown in Fig. *21* may be used. However, the set may draw as much as 1 ampere. You should first make the adjustment using a 250 ohm resistor, and when the adjustment has been completed measure the amount of resistance used with a ohmmeter and procure a 75 or preferably a 100 watt variable resistor with nearest higher resistance value. The resistor may be worked slightly over rated value, but if fully exposed to the air, and the wood of the cabinet protected by sheet iron, a little overload will do no harm.

But the best plan is to use a 220 to 110 volt step-down transformer, a typical one shown in Fig. *22*. Be sure you get one for the frequency of the line.* Merely insert the receiver plug in the receptacle on the transformer, and the transformer cord plug into the wall socket. As a transformer will conserve power, its initial cost will be paid back many times by the power saved. Some step-down transformers have a variable contact switch so the system can be adapted to line voltages of 150 to 240 volts.

Adapting to a Line of a Different Frequency. Occasionally you will have to install a radio receiver on a line having a frequency other than that for which the receiver was designed. In general you will encounter 25, 40 and 60 c.p.s. lines. Can a receiver designed for one frequency be used on another? Yes and no! Transformer equipment designed for low frequency will work at higher frequencies (within reasonable limits) but the reverse condition is not true. That is a 25 or 40 c.p.s. A.C. receiver will work with a slight change on 60 c.p.s., but a 60 c.p.s receiver should never be run on 25 c.p.s or 40 c.p.s. ‡ They may operate

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* I will shortly consider sets operating off of other than the designed frequency.

‡ A change-over may be made by installing a 25 or 40 c.p.s. transformer with equivalent outputs and improving the filter system.

for a while but in a short time the transformer will burn up. Here is the reason. Low frequency transformers require many more turns per volt † (about 2.5 times) for a given core area (cross section) when used on 25 c.p.s. than for 60 c.p.s., or for the same number of turns per volt the core area must be greater; otherwise large useless currents will be drawn from the line. Usually a compromise is made between turns and core cross section but you will find the low frequency transformer quite large and heavy. If a 60 c.p.s. transformer is connected to a 25 c.p.s. line the fact that there are insufficient turns (low reactance) will cause large, useless current to flow, overheating the transformer. Furthermore a radio receiver designed for 60 c.p.s. will not have a ripple filter sufficient to handle 40 or 25 c.p.s., although additional condensers can be easily inserted in shunt with those used (tuned filters must be carefully adjusted for the new frequency).

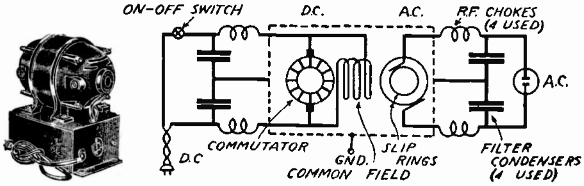


Fig. 23.—The rotary converter, employing a D.C. motor and an A.C. generator winding in the same armature slats. Filter housed in the steel box supporting the rotary converter. Input and output spark filters used.

When a 25 c.p.s. or 40 c.p.s. receiver or amplifier is to be operated from a 60 c.p.s. line, it is wise to use a line regulator (variable resistor). Connect a 0-10 A.C. voltmeter across the filament terminals of one of the tubes and adjust the resistor until slightly less than normal voltage is indicated across the filament.

D.C. Equipment on A.C. Lines. More often than any other condition, a person moves from a 110 volt A.C. district to a 110 volt D.C. district, or from a D.C. to an A.C. region. It is the latter case that I want to discuss first. Frankly I would personally recommend getting an A.C. receiver because the latter will be so much better than the D.C. receiver. But if the customer is satisfied with his D.C. receiver (and it is a D.C. set, not a universal receiver) you could, although I doubt if you would, recommend a small A.C. motor driven D.C. generator. This equipment is so costly that many expert servicemen prefer to rewire the supply system if an A.C. receiver cannot be sold. Study carefully what I have said about universal receivers and make a change to this

† The primary turns divided by the primary voltage.

system.* You will need a twin rectifier tube of the cathode type, a larger choke but with low resistance, and perhaps larger filter condensers. Each conversion job will require special study; but be sure that an inexpensive A.C. receiver would not be more acceptable. When you run across an old D.C. receiver with filament type tubes, do not try to convert it to A.C. operation, unless you have enough design ability to make the change, in which case you will know what to do.

A.C. Equipment on D.C. Lines. Without doubt this problem will, as an average, be encountered more often than any other receiver adaption. As a rule, A.C. receivers are so much better than D.C., universal and battery receivers, that it is quite common to adapt a new good A.C. receiver to 32, 110 and 220 volt D.C. lines by means of the two devices I am about to discuss, instead of buying a receiver designed for these special

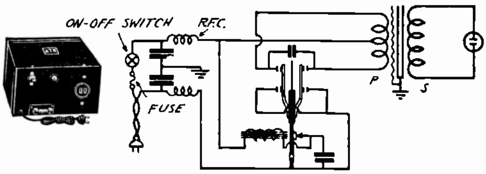


FIG. 24.—A magnetic vibrator type converter or inverter. Similar to auto radio vibrators except secondary rectification is omitted, thus providing A.C. output. Vibrator usually made with double contacts to handle high voltage. Input spark filter required, as well as contact spark eliminating condensers. An electrostatic shield is wound between the primary and the secondary, a wire mesh, or a thin sheet of copper which does not make a contact where they lap. Often a variable primary resistor, or secondary taps are provided to regulate the output voltage.

voltages. Two procedures are possible. Use a D.C. to A.C. rotary converter, a combination D.C. motor and A.C. generator; or a magnetic vibrator type D.C. to A.C. converter (often called an inverter). Both devices are shown in Figs. *23* and *24*, and the general scheme of connections is given to the right of each illustration.

For the average receiver a 100 watt converter or inverter will suffice. The adaption is simple. Insert the receiver power plug into the receptacle of the converter; push the plug of the converter into the D.C. line; and if a ground terminal is provided on the converter connect a wire from it to the regular ground. The rotary converter is costly, but has a long life and can be had in any power rating for receivers or public address equipment; the magnetic vibrator inverter is comparatively inexpensive,

* So if the customer moves to a D.C. district, no change will be required.

its power capacity is limited to 200 watts maximum and the vibrator must be replaced about once a year, a simple task if a plug-in vibrator is used.

Loudspeaker Field Supplies. Although it is customary to design radio receivers so the power pack supplies the necessary excitation current for the field of the dynamic loudspeaker,* this practice is not generally followed in public address amplifiers. In this case a separate supply unit is used with the loudspeaker. Although the field may be designed for any D.C. voltage, standard designs are for 110 and 6 volt sources. Where D.C. is available the problem is merely a matter of making a connection; if A.C. is the only source then a rectifier system is required.

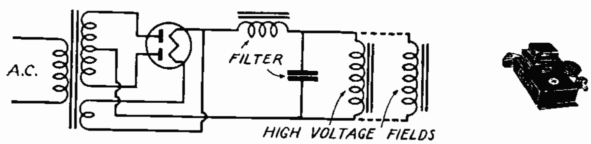


Fig. 25

For the high voltage field a tube rectifier is used, a typical circuit and supply unit shown in Fig. *25*. But for a low 6 volt field, a special, so called copper oxide rectifier is used.

No one has fully explained the behavior of these devices but from long experience it is known that if a pure copper disc is oxidized on one side and a voltage supply is applied, one terminal to the copper surface and the other terminal to the copper oxide surface, electrons will flow from the copper to the copper oxide under normal applied voltage, but not in the reverse direction. If the voltage is made high enough electrons will flow in either direction. When large voltages are to be rectified

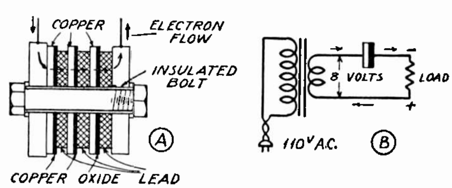


Fig. 26

(100 volts would be high) several elements are used in series. In an actual rectifier, a rectifier unit is made by processing copper washers so one surface is oxidized, stringing each such element on an insulated bolt, separating each element by a lead washer (to get better over all contact

* In some receivers, particularly battery types, magnetic or permanent dynamic loudspeakers are used. They require no current for producing a magnetic field, the necessary magnetic field being produced by permanent magnets.

to the oxide surface) and bolting the elements together, as shown in Fig. *26A*. A simple rectifier circuit is shown in Fig. *26B*.

However, it is customary to build copper oxide rectifiers for full-wave operation and Fig. *27* is a typical full-wave bridge circuit. Note particularly that two (*A* and *B*) units are used placed "back to back" so electrons can flow from the center to the ends. Study the connections of the load (field) and the low A.C. voltage supply, as you may sometimes

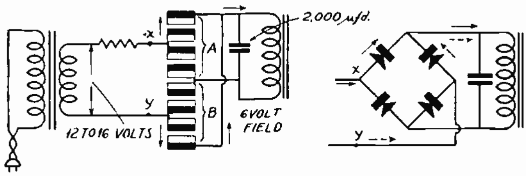


FIG. 27

have to make a connection to one of these rectifiers. (Note: The two ends are connected together to one terminal of the load, the center to the other load terminal; the A.C. source is connected to the two off center terminals.) For purposes of simplicity, the special symbols shown to the right are used in circuit diagrams.

Large copper processed washers are used for large current rectifiers, small washers are used for low current rectifiers, particularly in A.C. rectifier voltmeters. In the loudspeaker supply system, a large electrolytic condenser of the dry type having a capacity of 1,000 to 2,000 microfarads is shunted across the field for ripple bypassing.

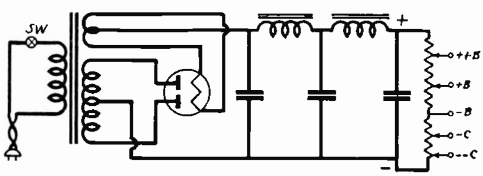


FIG. 28

B Eliminators. Although the so called B eliminator (a device which operates from an A.C. power outlet replacing B batteries) is now a rare device you may encounter it on some jobs. From what I have already explained, no further details are necessary. In general you will find a full-wave rectifier, a condenser input filter and variable voltage divider as shown in Fig. *28*. The cable leads from the battery receiver are connected to the various $++B$, $+B$, $-C$ and $-B$ terminals and the potentiometers varied so correct voltages are applied. A high resistance D.C. voltmeter should be used in making these adjustments.

TEST QUESTIONS

Be sure to number your Answer Sheet 13FR-1.

Place your Student Number on every Answer Sheet.

Never hold up one set of Lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson. In this way, we will be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. Should a battery supply lead resistor be used when an air cell battery is connected to 2 volt tubes?

2. What is the purpose of resistor *R* in Fig. *6?*

3. How are the tube filaments of a 110 volt D.C. receiver connected?

4. What would be heard if the electrodes of a D.C. receiver were operated directly from the 110 volt D.C. line?

5. How does the half-wave diode rectifier act in a universal receiver when it is connected to a D.C. source?

6. What is the primary source of electrical power in an auto receiver?

7. What three types of high voltage supplies are used in low power mobile installations?

8. If an engine-driven generator is to be used, what voltage and frequency should it supply so that standard equipment may be employed?

9. What parts are used in the transformerless voltage doubler A.C. power pack system?

10. May a 60 c.p.s. receiver be safely operated on a 25 c.p.s. line?

INTRODUCING YOU TO RADIO

1FR-2

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

GET THE HABIT

In each lesson of the fundamental course, you will find an interesting message on this page. Get the habit of reading it before you take up the lesson. I may have a few words of advice which will help make you a better radio man, or I may have a few words of explanation regarding the lesson you are about to study.

Right now let me tell you about the first lesson.

This lesson is divided into two sections. In the first few pages my instructors discuss the opportunities in radio and how men are promoted to better positions, or how they develop their own businesses. It is "straight from the shoulder," and you must admit, quite encouraging. There is, in this section, more about how the course is presented, and what you should do to make the most of your study. Read it so you will get our viewpoint.

The second part of this lesson is devoted to important facts in radio, especially the behavior of electrons. This may, at first, seem quite unimportant; for you may ask: "What have electrons to do with fixing a radio receiver or adjusting a radio transmitter?" Electrons have a lot to do with radio, your chosen profession. For servicing a receiver or adjusting a transmitter is, after all, a matter of making the electrons "behave."

Every fact in our course is included to make you a better radio man. You will appreciate what is being presented after your training is complete. Now give each lesson your earnest attention.

You will find in your assignment of first lessons a pamphlet on "How to Study." Be sure to read it.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE WHICH TRAINS YOU TO BECOME A

RADIOTRICIAN & TELETRICIAN

(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

JD15C341

Printed in U.S.A.

Introducing You to Radio

RADIO IS A GROWING FIELD

Even after these many years of close association with the radio field, I still get a real thrill out of being in the midst of its ever-growing activities. It truly seems that radio is one profession that "gets into your blood," and stays there. And for this reason there is an unusually close relationship between radio men. They look upon each other as friends, and as fraternal brothers.

Successful men will tell you: to succeed, you must love your work. There is very little doubt in my mind that once you get started in radio you will, as we often say, "eat, talk, sleep and live radio." Others may prefer golf, tennis, stamp collecting, model building and other "what-nots" as a hobby; yet I wager that radio, to you, will be a hobby as well as a business. Selecting radio as a career is a fortunate choice.

What do we mean by—RADIO? To some folks, radio just means a receiving set—to others a broadcasting station or a transmitter aboard a ship, an airplane—and so on. But as you become familiar with this field, radio to you will mean the operation, use, repair, construction and maintenance of all kinds of apparatus which originally were created or designed for sending and receiving intelligence (words, music, pictures, code messages, etc.) through space. This naturally includes radio sound broadcasting and reception; transmission and reception of visual programs, better known as television; and code (telegraph) communications through space. Sending of intelligence by radio waves may take place at long, medium, broadcast, short and ultra short wave lengths. Perhaps you prefer to think of this all-wave classification as: low, medium, high and ultra high frequencies, as they are very often designated in the daily newspapers. Radio must not be restricted to one range of radio frequencies, as the all-wave receiver has clearly proved.

But the sending and receiving of intelligence is a small part of the radio field; in fact, only the starting point of a very vast and ever-growing field associated with it. To be sure, you may make your entrance to these allied fields through radio servicing or station operation but many go into them directly. For example, many servicemen branch out into the loud speaking or public address field, or take up electronics (vacuum tube controls); some radio operators go into police radio, aircraft radio, or facsimile (picture transmission) station operation; radio servicemen build their businesses up as dealers of radio receivers and allied products, others become parts jobbers or wholesale radio set servicers; radio operators become station managers, radio showmen, copy writers, continuity writers, "gag" writers or program planners. Some of these fields require more and some less radio knowledge, but all of them are based on a firm knowledge and background of radio theory

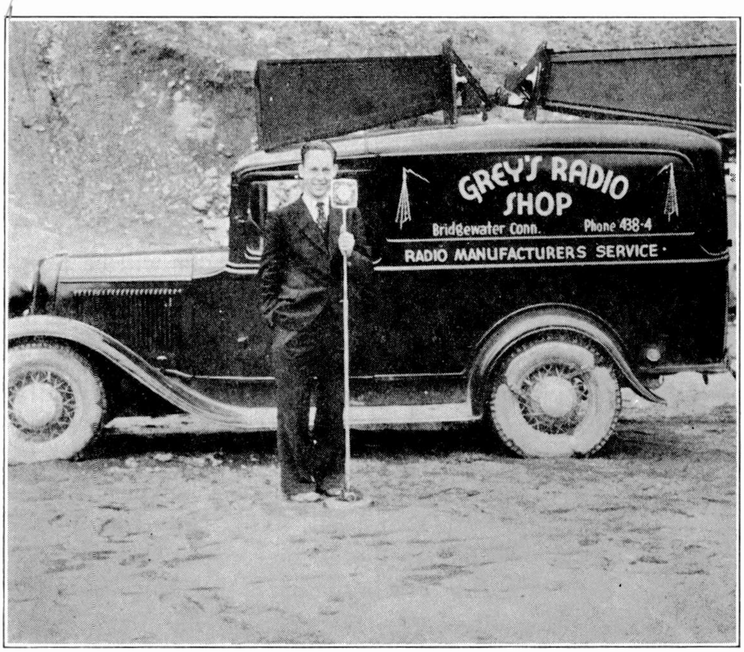
A Radio Service Shop—An N.R.I. Graduate

and experience. The man who trains himself from the ground up, equips himself for the higher positions. This course is planned to give you a bed-rock foundation.

OPPORTUNITIES TO YOUR LIKING

I distinctly remember when radio meant a pair of ear-phones clamped over your head, with your fist on a telegraph key, intelligence sent by a dot and dash code. The crashing *da—dit—da—da* was then the only form of conveying intelligence. Still an important phase of radio, although refined and improved to a point that amazes an "old timer," it is only a small part of this vast field of radio. I have already suggested some of the modern branches, but let me tell you more about them.

Radio Receiver Servicing may be to you the most important branch. Because they see the need for radio service work everywhere, men just starting in radio will most often select this branch, which includes the installation, maintenance and repair of all kinds of radio receivers. Today most receivers are of the sound type, but in a short while television receivers will be equally as important. Simultaneous picture and sound transmission will soon be as commonplace as sound broadcasting is at present.



A Public Address System Using a Truck—An N.R.I. Graduate

Midget, mantel, console radios—long, broadcast, short, ultra shortwave and all-wave receivers—alternating current, direct current, universal, battery, farm and auto receivers—low, medium, high fidelity sound and sight receivers—may all be included in a day's work for the expert Radiotrician. Should a radio man work on two similar receiver makes in a single day, he would consider it a rare coincidence. If you want variety in your work, servicing is one branch of radio where you will get it—plenty of it.

Public Address Systems is another interesting and profitable field and a branch of the servicing business that many men take on as a full time or associated activity. This brings you in close contact with the business, social and educational world. Business men who want to advertise their service or product by loud-speaking systems; club managers, musical and entertainment directors, and educational supervisors who want to make their presentation clearly understood by the large attendance—are the people you will contact. Some will rent a system for a few hours, a few days or several weeks; others will want permanent installations. Every job will involve tens—and hundreds of dollars and when large expenditures arise only the expert stands a chance of getting the business. This course, followed from start to finish, will make you a radio expert.

The Radio Business attracts thousands of energetic men. Can you imagine a man buying, stocking, selling, and advertising hardware, farm equipment, or seeds and plants without a technical knowledge of his business? The successful business man knows all phases of his chosen field. Successful radio business men know radio and merchandising methods. One is no more important than the other; both are equally as important. At the right point in this course, if the servicing field is your goal, proper business methods will be presented for study; for even if you remain a serviceman, you should know the business side of the work.

Servicemen often find others coming to them for help and parts. Thus they grow into wholesale radio servicers and distributors of radio parts. Others do not wait, but rather establish themselves in this wholesale activity. But the owner of a wholesale servicing and parts business cannot command the respect of radio technicians if he is not a "cracker jack" or super expert himself. The trained man succeeds, because he in turn is able to train those who come to him for the product, for the testing equipment, or for the parts that he sells.

The radio serviceman is the logical salesman for replacement receivers. He is "called in" to service a radio set, finds it out-of-date or hardly worth repairing, and in complete fairness to his customer suggests and often sells a modern machine to replace the old one. Or he takes the receiver out of the home for repairs, leaving a midget or mantel receiver to hold the customer's interest while the set is in the shop for repairs. This quite often sells the customer on having a second receiver. A television receiver will be wanted, and with confidence and mutual understanding already established by fair dealing, the serviceman will more than likely make the sale.

Some servicemen say "I service exclusively, that is why I am successful;" others say "I render a complete service to my customers, and my business has expanded." I cannot foretell which policy you should consider for your business. But every serviceman in business for himself has an opportunity to establish himself as a radio dealer; every serviceman in the employ of a radio dealer owes it to his employer to boost receiver sales or the sale of any other equipment that the man he works for handles.

Radio men become radio salesmen for dealers, wholesalers and factories; some become managers, sales representatives, radio advertisement copy writers—and in my experience those who know radio do and have a better job.

Radio Factories employ thousands of radio technicians, and in every case factory managers prefer a technically trained man. Foremen and superintendents are generally technical radio men with a further interest in mass production methods. Inspectors and alignment men are expert servicemen working on a production line. Men are promoted from the factory to the designing and testing laboratories because of their special ability; and only technically trained men are wanted in technical jobs. Men from the ranks often become section and department chiefs; I know many who have become the chief engineer. Technically trained men are needed in radio factories as technical correspondents.

Courtesy P. R. Mallory & Co., Inc.

Condenser-Testing Section of a Radio Factory

Perhaps you would like to work in a radio receiver factory, a radio parts factory, a tube factory, a meter or servicing instrument factory

Of course, there are less of these jobs than there are service jobs, but the man with a healthy experience as a serviceman gets first choice. Just as in any other industry, men step up to better jobs if they train themselves.

Electronic Controls opens a new spare- and full-time activity for radio servicemen. Some day there will be as many in this field of work as there are radio servicemen today, and I feel sure that many will be trained Radiotricians and Teletricians. The factory, the store, the home is just beginning to appreciate the need for electronic controls, which quite often use the photoelectric cell (often called the electric eye) and various other radio circuits to control a set of events, test material, or safeguard life. You will be prepared to enter this field when the opportunities arise.

RADIO NATURALLY DIVIDES INTO TWO BROAD GROUPS

Radio receiver servicing, public address systems, radio merchandising, electronic controls and to some extent radio factory jobs are occupations that bring you in contact with the public. Hence I like to call them the public service branch of radio. In these activities you are at the service of any one who writes, calls or telephones for your service. Furthermore, you deal with equipment that is to be used by the general public. On the other hand, radio includes transmitting, an activity which in general limits your contact with the general public. You are here under supervision, and act according to rules laid down by the company for which you work, and the laws enacted by the Federal Government.

Accordingly, radio naturally divides itself into two broad fields, namely: *one,* public service; and *two*, communications. From my extensive experience with radio men active in the field, I have found that men in a natural manner either prefer and practice in the *servicing* and *merchandising* branch of the radio art (public service), or the *communications* field. My course is divided into these two branches, because I want to give each man as much in the branch he prefers as I can, rather than allow him to "skim over" the surface of both fields.

However, the fundamental course which every one must take before specializing in his preferred branch, covers the basic facts for either endeavor and even after graduation it is not difficult to change your activities.

RADIO COMMUNICATIONS

Radio Communications is the other broad field of work drawing on capably trained radio men. Before you can go into this field the Federal Government examines your technical ability, and if you are well trained, you are issued a license or "ticket." There are several classes or grades, but the wise radio man takes the simple examination first, gets a job and after a year or two of experience goes after a higher grade. Even in the communications field, the richest rewards go to

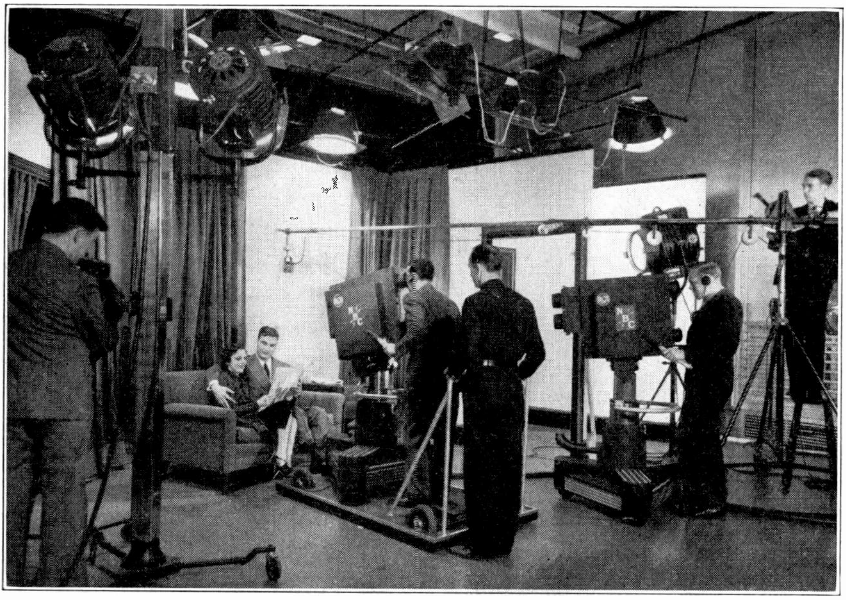
A Seagoing Radio Operator and Station

the ones who are qualified to step up—and they are the technically trained men.

Radio Operation Aboard Ship has fascinated many young men. Seeing the world from a radio room and numerous dockings, builds character and a balance in the right way of living. The pay is not enormous but you are given a berth, food and medical attention, compensating a good deal for what we may call purely money income. Radio ship operators step up to better and more profitable land jobs.

Shore to Ship Operators are connected with the communication companies at their shore radio stations. This is the link between the sea and the various industries and persons on land.

Point to Point Radio Communication is rapidly handling the world messages. Newspapers, large industries are connecting their far-flung branches by short-wave radio. One nation is in contact with another with the instantaneous connection afforded by short and long wave radio. This branch growing year after year affords new jobs for trained technicians with a suitable Government ticket of accepted ability. Facsimile transmission is a growing phase of point to point communication. Copies of pictures, drawings, documents, finger prints, even messages in original form or typed on regular communication forms are received at a remote point *via radio.*



Courtesy National Broadcasting Co.

Picking up a Television Program

Radio Broadcasting is an important and interesting field but not as large as the other fields of communication. There are thousands of radio operators in this one branch, and as they are promoted to chief engineers, monitor men, field checkers, station managers, program directors and the other kindred activities, new men come in to take their places.

And as television finds its full place in the broadcasting scheme of affairs, the number of opportunities in the broadcasting station will be increased many times, for each broadcasting station will have a sound and a sight transmitter with extra operators, managers, directors, planners and rehearsal technicians. The fact that one foreign television broadcasting station employs a staff of over two hundred and fifty trained technicians gives some idea as to the number of positions which will be open to expert Radiotricians and Teletricians in the near future. Television has an important place in this course, and your training will be technically complete.

Aircraft Radio is one of the more recent additions to the communications field. Operators are required to man Government operated radio

Courtesy Western Electric Co

An Aircraft Radio Station Showing Dispatcher in Action

range-beacons and weather broadcasting stations. Co-pilot radio operators are in demand in the transport service. Radio operators at airport and airway land stations are needed for land-to-plane and station-to-station communication needs of the transport companies flying the airways. Radio servicemen are required at each airport to inspect, repair and make test runs on the airplane's radio equipment, which must be serviced and checked periodically and not when a breakdown occurs—an important precaution in safeguarding life and property.

Police and Harbor Radio is a public servant that helps to keep our complex life running in smooth order. The lawless are caught in the act, the harbor boats are under supervision from the home office, and as police and harbor radio gains wider acceptance more and more radio men will find municipal and state positions. In this branch of radio, servicemen take care of the police car radios, service and check the transmitter, and take care of the ultra short-wave two-way car-to-station communication systems. The United States is fast becoming a complex network of interlocked police radio systems, ready to track or trace any person over the entire country.

Other Allied Fields exist. Motion pictures accompanied by sound is a large industry that once drew many radio men out of the existing field. When this field first started radio men had the exact qualifications needed and many of them were absorbed. Electronic controls, which I already mentioned, will some day attract thousands of men from the radio field. Medical and agricultural science is adopting radio technique and jobs will be available. The mining and oil industry is gradually calling on radio to help in the prospecting of the natural resources. You, the men who prepare today, are the ones to be taken in, as these fields expand or open.

Inventions are constantly making for a bigger and better radio field. You too may invent something of worth. A broad radio training will fit you to recognize new needs and to invent the necessary equipment.

Some day ships, torpedoes, airplanes, automobiles and machines will be monitored or directed by electronic or radio devices. Are you going to be in the midst of this progress? All this is possible by diligent work in mastering what you have elected to make your life's work—RADIO. My sole aim is to help you make a just and correct start, to encourage you over the rough roads.

THE CORRECT ROAD TO A RADIO CAREER

Without a doubt there is some branch of the radio field that fascinates you, makes you anxious to start, and you will start your radio training in this first lesson. But it will not be long before you will say: when do I study all about television or about servicing a radio receiver, or operating a transmitter? I assure you that you will study television before this course is completed; you will learn the correct methods of servicing; and if you elect *communications* as your special field, you will get all the information on transmitters that you will need to enter this branch of the industry.

You cannot correctly analyze a defective receiver for trouble, nor make a repair, nor restore its original operating qualities until you have mastered *fundamental radio facts.* Even the Government, before it will issue a second-class commercial operator's license, insists that you be able to answer questions on the fundamentals of radio. When we get into the actual practice of radio, we are going into it with "both feet" and at that point in your course I do not want to stop to explain this and that basic fact. You should know these facts. I want you to be able to talk to other radio men in their language, for contact with them will give you ideas to help build your success. I want you to be able to read your favorite technical magazine and get the real meaning out of

Courtesy General Electric Co.

Police Radio Car—Two-Way System

the articles you read. When you graduate I want you to be able to "stand on your own feet" and make your own way. This course is laid out as it is, to accomplish these essentials.

Each and every one of you will first study the fundamental course. At the start you must learn how electrons behave; that a flow of electrons is an electric current; that various kinds of currents exist in a radio circuit; how these currents behave when they encounter a coil, or a condenser, or a resistor, or a transformer. In fact, you must learn all about radio parts and particularly how they work. Then you will learn how various radio devices work together; and after you master how the many vacuum tubes operate, you will learn how tubes and these parts work in a variety of radio circuits. After this point we will study whole radio circuits like receivers, public address amplifiers and transmitters.

You must master the basic facts about magnetism, radio waves, photocells, measuring instruments, loudspeakers, microphones, television pickup and image reconstruction devices and hundreds of special but fundamental facts—before you can learn how to correctly service and operate radio equipment. To be sure, there will be "loads" of practical information throughout this presentation, but the fundamental facts will be the all-important ones.

After you have completed a few of the first lessons you will receive one of your home experimental outfits, the first of the five you will receive. With them you will learn: how to handle and connect radio apparatus, and how radio devices and circuits behave. You will make simple but useful testing equipment. This part of my training gives you valuable practical experience which will instill confidence, so necessary in your radio work.

As you study your fundamental course, you will receive "job sheets" on practical radio work, to help you get experience and to permit you to earn spare-time money. There will be, later in the fundamental course, a number of "Radio Servicing Jobs" and these will give each and every one of you your first introduction to radio receiver servicing. Then too, along with the fundamental course, several reference books will be sent to you. You should carefully read them, as they contain necessary information—a little advanced, that is why there are no examination questions with them.

Every one is required to study or read what has been mentioned. Even those of you who choose *communications*, learn how to service a radio receiver. But after you have mastered the fundamental course, you may choose either the *Servicing and Merchandising Course* as your final step of your training; or you may study *Communications*. It is in these lessons that you round out your practical knowledge and prepare for a career in RADIO.

A few words of advice. Study slowly. Each lesson should first be read quickly to learn what it contains; a second reading is imperative, to absorb the facts; a third reading is advisable, so as to master the details. It is not necessary for you to understand everything in each lesson—as there are many facts in every one. If you are able to answer the questions at the end of each lesson, and submit each lesson in the order they are numbered, you have mastered as much of this course as I feel is necessary for the time. Of course, the more study you give each lesson the more you will learn, and each lesson has enough in it to be used as a reference text after you graduate. You can always go back to a previous lesson, read it, and with the knowledge gained from the later lessons, read the earlier ones and learn a lot more than you did the first time you studied them. Read every lesson, every job sheet, reference text and letter we send you—as they contain valuable technical information and friendly advice. Now, let us start our study of radio.

A Few Very Basic Radio Facts

TWO KINDS OF ELECTRICAL PARTICLES

Strange as it first may seem, everything around us, even our very selves, may be reduced to two small particles of electricity—with the exception of that something which we call "life." And these two small particles of electricity have a great attraction for each other. To distinguish them we call one *positive* electricity, the other *negative* electricity. To be sure, technicians call the positive electric particle a *proton;* while a negative electric particle is called an *electron.* Yet the idea of calling one positive and the other negative is quite helpful as we can in drawing radio circuits refer to protons, or anything that behaves like a proton as positive electricity using the sign (+) meaning *plus* or positive; and refer to electrons or anything that behaves like negative electric particles by the sign (—) meaning *minus* or negative.

The idea of calling one (—) minus, the other (+) plus, has a real connection with their attractive properties. The idea that opposites attract is fully appreciated by most of us. In fact, we often illustrate this by saying: "Blondes are attracted to brunettes,"—usually adding a word of explanation that opposites attract.

MATTER AND WHAT IT CONSISTS OF

What I am about to say is not easy to prove to you. These facts have been discovered and checked by the greatest scientific minds and their acceptance as a truth gives us a new insight into the science of radio. In a short while, you too, will accept these facts and never doubt their truthfulness. You will have to use your imagination—so set your mind free.

Let us take a common substance—water, for example. We recognize water in its three forms; ice, a solid; water, a liquid; and steam, a gas. In each case we have water and when we have a large quantity we call it a *mass*—a mass of water. Perhaps you know that water is a mass of small particles. When they are cold they hug to each other appearing as a mass of ice; when they are warm they move freely although close enough to one another to result in a liquid mass; and when they get real hot they get so full of "pep" the individual particles of water jump long distances, separate and we have steam, or a mass of gas.

We still have water in all three states; only the shape of the mass has changed. And the smallest possible particle of water is called a water *molecule*. To break up a molecule of water, we must do more than add or subtract heat energy. One of the simplest ways of doing this is to pass electricity through it. Why or how is not important to us, the fact that it is possible to break up water particles is of interest. What do we get? Two substances—hydrogen and oxygen, substances that we breathe into our lungs each moment of our lives, particularly oxygen, the one thing that is essential in maintaining life. By cooling or compressing hydrogen or oxygen we can turn these gases into a liquid and a solid—and in a liquid or solid state they are only used in laboratories.

When a water molecule is broken into these two substances we obtain two *atoms* of hydrogen and one *atom* of oxygen. Perhaps you know that water is written by chemists as H_2O, H standing for hydrogen, the subscript *2* meaning two of them, and O standing for oxygen.

Let us examine an atom of hydrogen, as it is the simplest and the lightest of all atoms known to human beings. Now we will have to use our imagination and believe what the best authorities have to tell us. We are told that it is made of two distinctly different particles of electricity, namely; the proton or positive particle and the electron or negative particle—one each.

So small are these protons and electrons that no human being has ever seen them, although scientists can tell you many things about them and how they behave. For example, they will tell you that the proton *

(Signs such as *, †, #, **, and so forth, are to call your attention to an additional thought or explanation at the bottom of the page, starting with the same sign.)

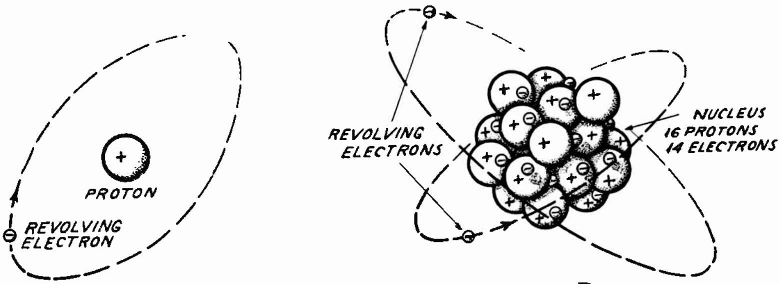
is 1,840 times as heavy as an electron; that the electron because of its lightness is the most active member; that the electron is attracted to

* Within the last few years the proton has been further investigated in laboratories. It has been found, contrary to the opinions of scientists a few years ago, that it can be divided. Curiously enough, the proton divides itself into two parts, one a small electrical particle just like the electron, only with a positive charge. It is called the *positron*. To divide the proton it requires super forces to tear the positron away from the other part of the proton, which is really the smallest particle of matter without any charge. The positron so far has no practical importance in radio and electricity, so it is not considered. The proton (which is the smallest particle of matter plus a positron) is important.

a proton with a tremendous force; that the electric current we use is nothing more than a movement of electrons; that moving electrons produce magnetism and radio waves; and devices which can collect quantities of electrons are electric generators.

So you see that these very basic ideas have a definite bearing on your chosen field—RADIO. But let us get more of these basic facts, as without them many important radio principles will not be fully appreciated.

Going back to our hydrogen atom, we are told that the electron revolves around the proton millions upon millions of times each second. The clearest picture I can give you of what happens is to refer you to the moon revolving around the earth, speeded up a tremendous amount. The moon is attracted to the earth but its rapid motion around the earth



A

An imaginary construction of a hydrogen atom.

B

An imaginary picture of an oxygen atom. The electrons in the nucleus may also be traveling in circular paths.

FIG. 1

tends to throw the moon away from the earth (centrifugal force), and both forces create a balance and the orbit (route) of the moon is fixed.

Now returning to the other atom produced by the breaking up of a molecule of water; namely the oxygen atom. Oxygen is a more complex atom, for it contains 16 protons and 16 electrons. The simplest picture is a center mass of 16 protons and 14 electrons, bunched in the center and 2 electrons revolving around the mass. The central mass is called the *nucleus*. The idea of the two revolving electrons was brought about by the fact that they can be removed by chemical means. Figures *1A* and *1B* give a general idea of a hydrogen and oxygen atom.

But the nucleus cannot be easily subdivided by any means yet known. If we could, hydrogen and helium (also a gas) could be made from oxygen; gold could be made from lead—as all substances are different because of the different amounts of protons and electrons. Water is a close combination of two hydrogen atoms and one oxygen atom; table salt is a combination of two chemicals called sodium and chlorine;

wood, rubber, bakelite are a complex combination of atoms and molecules and for that reason are referred to as *compounds*.

ELECTRONS AT WORK

Free Electrons. We must not confuse the behavior of a part, with the action which may take place in the whole mass; a fundamental fact which scientists are learning to appreciate more and more every day. The behavior of an atom inside a mass may not necessarily tell what happens within the mass—it may help as you will shortly learn.

Assume we have a mass of copper. Chemists tell us that each atom contains 63 protons and 63 electrons. Frankly no one dares to picture their distribution, although they know that in some cases a copper atom

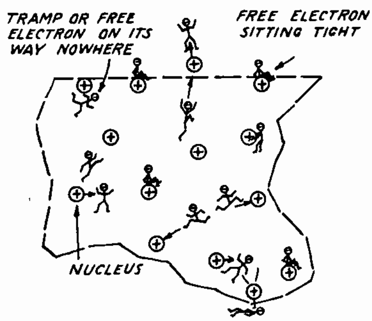


Fig. 2

will chemically relieve itself of two or four electrons. These are the removable electrons. The removable electrons in a mass of copper behave in a manner which is highly important to us as radio men. There are millions of them, each one first visiting one copper nucleus and then another. They are on a "tramp" and like tramps, they will move, but don't like to work. But they will go to work under force.

It is important to get a clear picture of these *"free electrons,"* as they are called. Imagine millions of toy balloons floating in the air so there is quite a bit of space between balloons. Bees could easily fly around in this mass if they dodged those in their way. This is really the make-up of a piece of copper, the balloons representing the copper nuclei*; the bees the free electrons. Figure *2* is another helpful picture of the same idea, the free electrons on a tramp going everywhere but nowhere in particular. It is hard to believe that there is so much space between copper atoms, but it is a matter of what you are able to see. A sponge looks to us as solid as a rock one hundred feet away.

* Plural of nucleus.

What do you think makes the free electrons move about? Simply heat. As you make the atoms hotter, the free electrons jump off their nuclei, just as you would if you sat on a hot stove. A wire heated sufficiently will emit free electrons from its surface; and if there is no opposition in space (molecules of hydrogen, nitrogen, oxygen, and water vapor—air) they will be emitted more freely. By removing the air surrounding the metal, that is, creating a vacuum, emission of free electrons takes place more readily. And this is one reason why the filament of a radio tube is surrounded by a vacuum.

An Electric Current. These free electrons jumping around in an indefinite manner can be tamed and put to work. Now let me present a simple mental picture which will help you grasp what takes place. Figure *3A* shows a machine to produce electrons. I have drawn it as

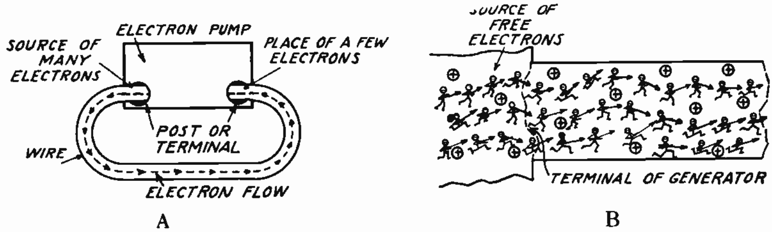


FIG. 3

a box, as I am not ready in this lesson to describe it in detail. For the present let us call it an electron pump or electron generator. It has two metal posts. At one post there are millions of electrons, the other post has hardly any electrons. Now we connect a copper wire between the two posts or terminals as they are called. Immediately the electrons in the terminal with an abundance of electrons rush into the wire, and naturally encounter the free electrons running wild in the copper. Like soldiers with bayonets thrust forward (see Fig. *3B*), the wild electrons come to order and march forward. The soldiers cannot turn around, otherwise they will run into the bayonet—so the electrons "march" on to the terminal which has no electrons and the electron pump forces them back to the starting terminal through the inside of the generator. A complete circuit, therefore when you connect a *metal* wire to the two terminals of an electron generator you complete the electric circuit.

The idea of a source with an abundance of electrons feeding a place with a very few electrons is often explained in this manner. Imagine two tanks on level ground, connected at their bottoms by a pipe. One is filled with water, the other tank is partially empty. Of course, you know that water will flow from the tank filled with water to the other one—until both are equally filled.

When the wire is connected between the two terminals of an electron generator, the flowing of electrons takes place at once, the action being relayed almost with the speed of light—almost 186,000 miles per second! This idea is easy to grasp. Imagine a long line of soldiers with bayonets fixed. If the rear end is given the command "march," the entire line moves, otherwise some one will be stabbed in the back. This instantaneous action can be illustrated in another way. Assume, as shown in Fig. 4, a long pipe with an elbow at both ends, and to one end a funnel is attached. The pipe is filled with water until the far end is filled to the brim. Now water is poured into the funnel, and as you would expect, water instantly flows out of the other end. Not the water you poured in, but the water at the other end that is pushed out. By thinking of the pipe as the conductor, the water as free electrons, you get a picture of the action in a conductor. All we need is a pump to complete the circuit.

The flow of free electrons is the electric current that is so important in radio circuits. The movement of each electron is only a fraction of an inch a second, but, as you now know, the flow is relayed at a tremendous speed.

Resistance to Electron Flow. Of course, you will quickly recognize that in the rush through the wire, electrons will hit against each other and the millions of nuclei. This is the opposition to a smooth flow of electrons—or *resistance* as we call it. If it were not for this resistance more electrons would flow under a small amount of electron push at the source end.

Metals like silver, copper, gold, aluminum, nickel, iron, and mixtures of the basic metals (called alloys) are conductors which offer various degrees of resistance to electron flow. The lower the resistance a given metal has, the better a conductor it is; but quite often a part of a radio system needs a high resistance conductor, and in such cases they use a conductor with lots of resistance.

What happens when two objects collide? Try this experiment, if you have not done so already. Pound a piece of metal with a hammer. In a short while the metal will get warm and then hot, because it resisted the hammer. And the resistance offered to electron flow produces heat. This and the fact that the greater the resistance the less the flow for a given electron push (electric force) are important facts to remember.

As the metal becomes hot, the free electrons in it move around more violently, and a greater electric force is required to make them flow in one direction through the conductor. This heat may be produced by the electrons flowing through the conductor or by locating it in a hot place. And if you place a metal wire in a cold spot, the free electrons "calm down," the resistance to flow is reduced, and less electric force is required to make them move in a desired direction.

A comparison of this resistance is quickly shown by imagining the pipe in Fig. 4 to be filled with pebbles. Water flows through the pipe with difficulty. In fact, a pump (extra force) may be necessary to cause an appreciable amount of water to flow through the pipe.

Non-Conductors or Insulators. Electrons will, when forced, flow through any material that contains many free electrons, and these conducting materials are generally metals and metal alloys. How about non-conducting materials such as cotton, silk, enamel, varnish, rubber, bakelite, paper, asbestos, sealing wax, paraffin, and wood? They are materials with complex combinations of molecules and atoms tightly bound together. Free electrons exist but are extremely scarce. A free electron would have a difficult time getting through the complex structure, like a soldier through a barbed wire entanglement. The name given to a material in which free electrons will not flow freely is, a *non-conductor* or *insulator.*

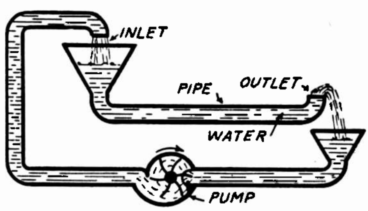


FIG. 4

Insulators are necessary in radio and electric circuits to make free electrons take definite desirable paths. Metal wires are wound in coils; or run to and from various parts on a radio chassis; or electrons are made to flow from a radio aerial down a definite wire to the receiver instead of to the rain spout or gutter on a house. That is, electrons must take definite paths if they are to be put to work. Covering the wire, or supporting the wire on non-conductors is a necessary precaution and in doing so we insulate the conductors from each other.

The Electron Generator. Just as it is important to get a good picture of a conductor and a non-conductor, it is important to be able to visualize an electron generator. Always think of it as a source or a device having two terminals, one with a super abundance of electrons, the other with normal or a below normal amount of electrons. How this condition is brought about is a subject for study in a future lesson, but now the basic idea should be firmly grasped in your mind.

In a generator we have a condition of unbalance, and true to nature a decided tendency to equalize exists. A rock on the edge of a cliff exerts a pressure on its support, a push will release its "pent up" energy. The electron generator is trying to exert a pressure or force even before the two terminals are connected by a conductor, only its ability to do work is not used—we say potential work, ability to work, exists. This ability to work on free electrons is called an electro-motive force, e.m.f. for short.

Attraction and Repulsion. Perhaps the simplest generator would be two pith or cork balls, each one supported from an insulator (silk thread), see Fig. *5A*. One ball marked (—) has an excess of free electrons, in fact, acts as one large electron; the ball marked (+) has lost some of its free electrons and it behaves like a large proton. Naturally they attract each other. If both balls have an excess of electrons, as shown in Fig. *5B*, or both have lost electrons as shown in Fig. *5C*, they repel each other. When both balls contain a normal amount of electrons

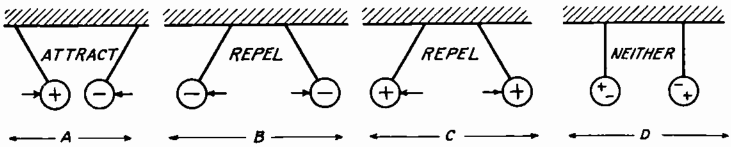


Fig. 5

they have no effect on each other, as shown in Fig. *5D*. These are the natural actions of bodies with and without free electrons—laws of nature that defy explanation, and you must simply memorize these facts.

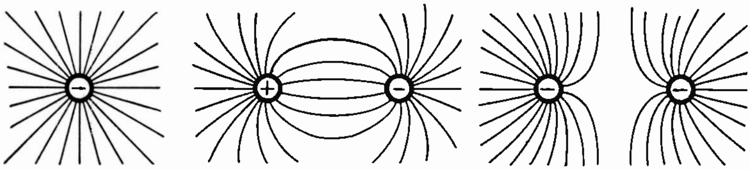
A body with excess free electrons is said to be charged negatively; a body without free electrons is charged positively; and a body with a normal amount of electrons is said to be in a neutral state. Hence, we may say:

a. Two bodies with the same kind of electrical charge (both + or both —) repel each other; and,

b. Two bodies with opposite electrical charges (one + and one —) attract each other.

The reason why two charged bodies attract and repel each other was not so easy to grasp, and to aid himself to visualize this condition, Faraday, the greatest electrical experimenter of the 19th Century, conceived of *lines of force* extending between the charged bodies. He called them electric lines of force. Thus he pictured, as shown in Fig. *6A*, lines of force around a charged body running out like legs from the body of a spider; embracing and pulling each other together as shown in Fig. *6B* when they are two bodies with opposite charges; and, as shown in Fig. *6C*, repelling each other if they are of like charge. Although lines of force are imaginary, they are helpful in a study of charged bodies.

A Flying Electron. If the charge on two oppositely charged bodies is made extremely large, so there are many free electrons on the (—) one and very few on the (+) one, the electrons will actually fly from the negatively charged body to the positively charged body, and we see a spark. The pressure of equalization is too great to be held back by the

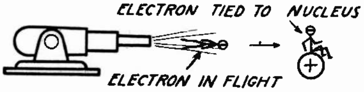


A B C

Fig. 6

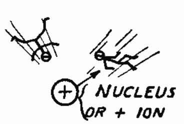
air. This is only one way electrons will leave one body for another. Free electrons emitted from a hot metal body will be attracted to another metal body if the latter is made positive, that is, the free electrons are pumped out of it. The latter is the condition existing in a radio tube.

But while an electron is in flight through a vacuum tube, two things may happen. First, consider the space through which the electrons are moving. Even if it is a vacuum there will be a few oxygen atoms. Or we may find as we do in some tubes, mercury vapor atoms in the space.



A

Something is going to happen.



B

A perfect shot, creating ionization by collision.

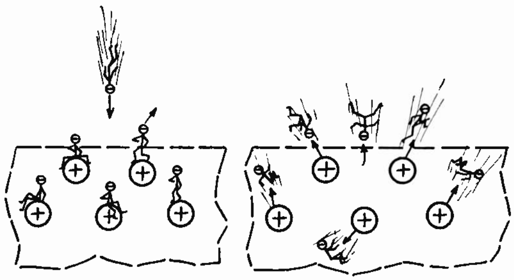
Fig. 7

Sure as fate, the flying electron is going to hit some atom, and knock off its free electron. The impact is so great that light, a form of energy, is produced. That is why we see a spark or a glow. Figures *7A* and *7B* will help you remember what happens. The oxygen or mercury atoms are deprived of their negative charge and are therefore charged positively by this collision. As an atom with either an excess* or

* This condition usually occurs when certain chemicals are dissolved in a liquid. For example, take salt dissolved in water. This divides the salt into: sodium with one positive charge (positive ion), and chlorine with one negative charge (negative ion). Of course, the parts combine as rapidly as they divide.

absence of electrons is said to be ionized; technicians refer to the action (phenomenon) just described as "ionization by collision." This is an important concept (idea) that we will meet time and time again in our study of radio tubes.

Second, let us consider the electron that actually reaches the metal surface, arriving with a terrific speed. Electrons will travel through



A
A crack-up is about to happen.

B
Electrons knocked out of their atoms.

FIG. 8

a vacuum with a speed of as much as 40,000 miles a second. But before I tell you what occurs, what do you imagine will happen if a handful of mud is thrown with a terrific force into a mud puddle? There would be a large mud splash. And when a metal surface full of free electrons is hit by a speeding electron, several of the electrons on the surface of the metal are splashed out (emitted). Or, as radio men say: secondary

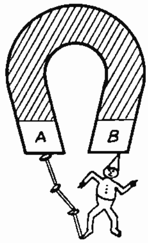


FIG. 9

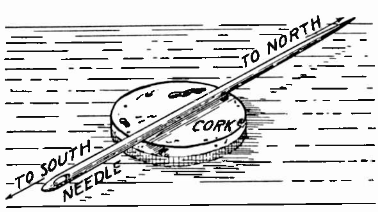


FIG. 10—Floating Magnet

electron emission takes place. Figures *8A* and *8B* will help you carry this idea in your mind.

Magnets. In order to tell you more about the property of an electron in motion, I am going to start with facts known to almost everyone. Surely you have seen children play with toy horse-shoe magnets, as shown in Fig. *9*. Perhaps you played with one yourself—I did. You probably discovered that it attracted steel or iron nails or other small objects of the same metal—snapping them up to the "poles" marked *A* and *B*. Copper, brass, wood, paper, in fact all other materials would not be attracted.

The Greeks had a name for it—*magnes*, because we are told material which had the property to attract small pieces of iron was discovered by the ancient Greeks in the land of Magnesia. We, the English speaking people had to Anglicize the word, and we called material with this property, magnets—and the action magnetism.

Centuries ago, it was discovered that hard steel, when touched to a pole of a magnet, would itself become a magnet. Some diligent experimenter further discovered that if a steel needle, magnetized in this way, was placed on a floating cork, no matter how he would originally set it, the needle would always place itself in a definite direction. Naturally the direction was in terms of North, South, East, and West. He discovered that the needle pointed North and South. (See Fig. 10.)

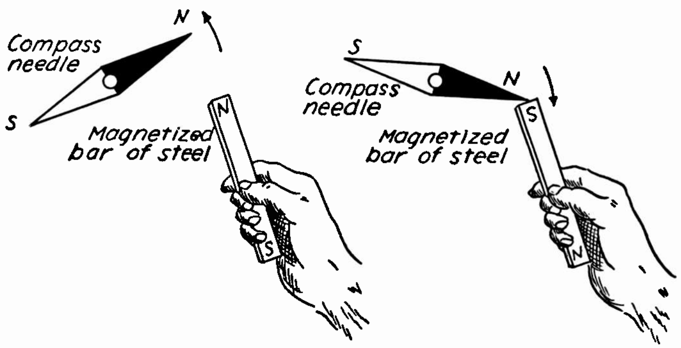


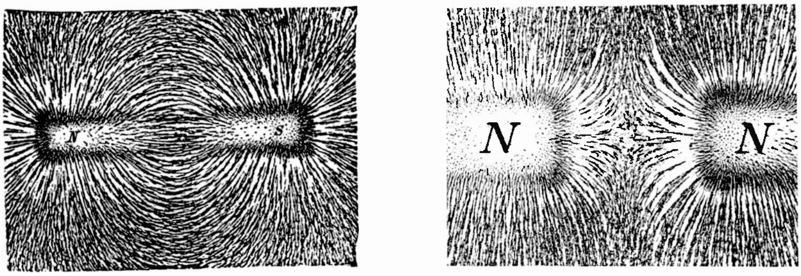
Fig. 10A　　　　Fig. 10B

A simple method to demonstrate the law of repulsion and attraction of like and unlike poles.

As the tips or poles of the magnet only exhibited the ability to attract, and as they identified the poles by the directions they took, it was only sensible to call that pole that pointed to the north, the north pole; and the end that pointed to the south, the south pole. They could call one (+) and the other (—), but they did not. So now when we say a magnet pole is a south pole, we mean it will point to the south if we repeat the experiment.

This discovery in those days was considered a wonder, more important than the discovery of radio to us was a few years ago. Mariners were supplied with magnetic compasses and they could sail out of sight of land and know how to get back to land.

But let us study the action of a compass and a long magnet, a bar magnet, because magnetism has a lot to do with radio. The poles of both the compass and the bar magnet are marked, *N* to identify the north pole, and *S* to identify the south pole. We might ask ourselves, what would happen if an *N* pole is brought near an *N* pole? Figure



A B

Fig. 11—Formation of iron filings around magnet poles.

10A is what we would observe—the two north (*N*) poles repel each other. And when an *S* pole is brought near an *N* pole they attract one another, as shown in Fig. *10B*. The laws of attraction and repulsion are fixed in nature and this applies to magnets, as well as to electrons and protons. We may therefore say:

a. Two similar magnetic poles repel each other.

b. Two unlike magnetic poles attract each other.

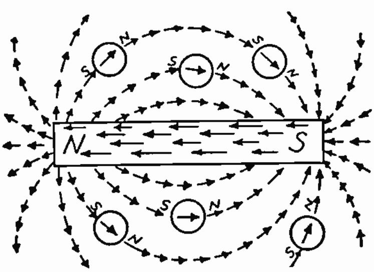


Fig. 12—Magnetic lines around a bar magnet.

Another great experimenter, Gilbert by name, placed iron filings on a thin piece of cardboard, then put the cardboard over a bar magnet. After a few slight tappings of the cardboard, the iron filings arranged themselves as shown in Fig. *11A*. Faraday, who also studied this experiment, reasoned that these filings arranged themselves because of the influence of the poles existing in space, and the lines suggested to him the name "magnetic lines of force." He repeated the experiment with two like poles and obtained the pattern shown in Fig. *11B*—a pattern like hundreds of arms pushing each other, repelling each other and the poles.

In these days when any object can be made as small and as large as we wish, we can easily get a compass no larger than the diameter of a pencil. By moving this small compass between the *N* and *S* poles of a bar magnet the compass needle assumes various positions, as shown in Fig. *12*. It traces out the lines of force. *And the compass is only influenced by magnetic lines of force*—an important fact to help me show you what an electron in motion will produce.

Electromagnets. Now we can go back to our discussion of the moving electron. Oersted discovered, in 1820, that an electric current in a

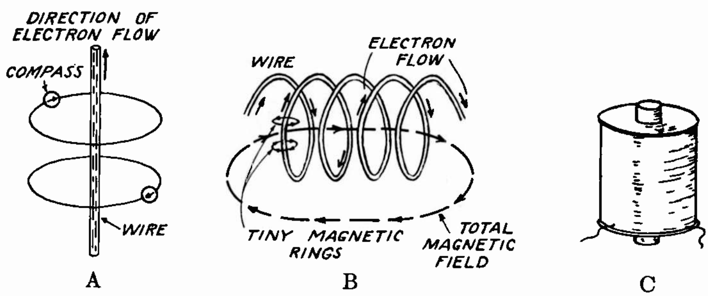


FIG. 13

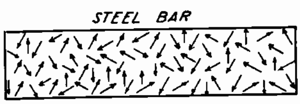
wire would show magnetic effects, and a compass placed near the wire would trace circular magnetic lines of force, as shown in Fig. *13A*. This clearly proves that electrons in motion will produce magnetic effects just like a bar magnet.

In those days, scientists merely knew that battery terminals connected by a metal wire produced a flow of something in the wire, and they were studying the effects. One of the effects was magnetism. They called that flow in the wire a *current,* probably after a water current (flow). The idea of *electron* flow did not come until Stoney in 1891 suggested it as the smallest negative electric particle.

The magnetic lines produced by electrons flowing in a metal wire can be concentrated by winding the wire in spirals as shown in Fig. *13B*. The tiny magnetic whirls or rings acting in the same direction, bundle themselves together to give many magnetic lines of force, threading through the center of the coil. Technicians say that the magnetic lines of force (or magnetic field) are concentrated through the center of the coil. A piece of soft steel placed in the center of the coil becomes magnetized and a more powerful magnet is obtained. As soon as the current stops, the coil and its iron or steel core (center) loses its magnetism. As the magnetic action is exhibited only when an electric current flows, we call these devices *electromagnets.*

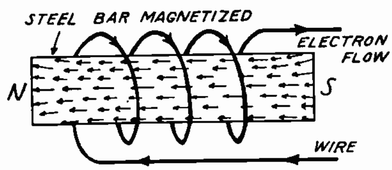
Electromagnets powerful enough to lift several tons of iron and steel are in daily use; small magnets are used in earphones, or loudspeakers, or relays, or automobile vibrators, or as deflecting coils in television pickup and image reconstruction devices. Figure *13C* is a small open magnet used extensively in radio. Two of them connected at the top with a soft steel bar duplicate a horse-shoe electro-magnet, and many in this form are used.

But why does a piece of iron or steel become a magnet? In the light of modern electron action, this question can be answered. In an earlier



A

Imagine that atoms are tiny magnets arranged "helter-skelter" like this.



B

They line up like this under the influence of a magnetic field.

FIG. 14

portion of this lesson I pointed out that the outer electrons in an atom revolve around the nucleus. Obviously this should make an atom a tiny electromagnet. It does. But remember I also stated that you must not judge the whole from a part. These electron electromagnets are arranged in a "helter-skelter" or chaotic manner, so the magnetic field of one atom is cancelled by another.

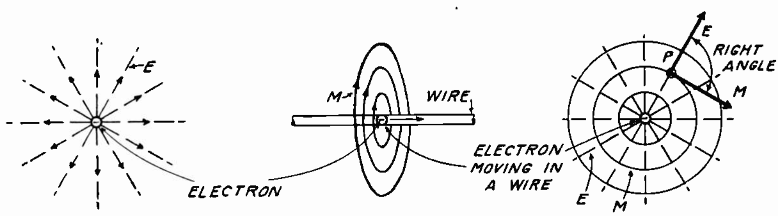
Only *iron, steel,* and to a lesser extent *cobalt* and *nickel* have the ability to become magnets simply because when placed in a magnetic field the tiny magnets within the mass will line up to form a large magnet. The fields of these tiny magnets add up to form one large field coming out of the ends or poles. If the steel is hard, the line-up remains, resulting in a permanent magnet. In fact, permanent magnets are produced by placing hard cobalt steel* in the center of a powerful electromagnet. Figures *14A* and *14B* tell the story in a schematic manner.

These tiny magnets lined up, explain why a bar magnet cut into sections results in separate magnets.

* Steel mixed with a little cobalt.

Electrons Moving in Jerks. Now we are going to pry into the innermost secrets of radio waves. Almost everything I have so far explained has some important bearing on what I will say. Study carefully what is now to be said. If you skip any step you will lose the entire idea.

I previously said that an electron had an electric field or electric lines of force running straight out from its center in the directions shown in Figs. *6A* and *15A*. In considering the effects of a moving electron, see Fig. *13A,* I explained that circular magnetic lines of force were produced around the moving electron. The idea is reproduced again in Fig. *15B*. But I should have said, to be complete, that when an electron is moving, both the electric and magnetic lines of force exist. Therefore at any point in the space around a moving electron, such as *P* in Fig. *15C,* we have two forces, *E,* an electric force, and *M,* a magnetic force.* These two fields are at right angles, a peculiarity of nature.



A B C

A cross section through a wire with a current flowing

FIG. 15

Now let us imagine ourselves standing up on an open truck. We are moving along smoothly; suddenly the truck speeds up or comes to a sudden stop. What happens? If it speeds up, we are thrown off the rear of the truck. If it stops, we are thrown to the front of the truck. In the very same manner, if we *jerk* the electron (make it speed up or slow down by varying rapidly the electromotive force applied to the circuit)—the two fields (electric and magnetic lines of force) "peel off" and travel on in space, because there is nothing to hold them back. The work done to speed up the electrons, or the work done by the electron in slowing down, peels off into space and we say electromagnetic energy or a radio wave is radiated in space. And the easiest way to jerk an electron is to produce an electron generator which will make the elec-

* The line *E* with its end arrow point is used to indicate the direction and strength of repulsion or attraction that would be created if an electric charge were placed at *P*; the arrow line M indicates the direction and strength of the action on a tiny magnetic pole. Both represent potential energy, ability to do work.

trons vibrate rapidly to and fro, or as we say, have a high frequency vibration.

This is the true story of the electron and how it produces the radio waves, so important in our chosen profession.

Looking Ahead. In the next lesson I am going to take you on a special kind of a tour through a radio broadcasting station. I will show you how sound or a scene can be picked up in the studio, how it is worked on by the radio equipment before it is "shot" through space as a radio wave, how it travels through space to your home, and finally how the radio receiver allows you to hear or see what took place in the studio. The next few lessons which follow will tell you about the different ways in which electricity can be produced or generated for use in radio systems, how radio devices and sources of electricity (such as batteries) are connected together for various purposes, how meters, resistors, coils, condensers, vacuum tubes and transformers are constructed and how they are used in radio circuits. Naturally I cannot explain in detail, in these elementary lessons, how all of the various radio devices operate, but I promise that you will find full explanations in the later lessons in the Fundamental Course and in your Advanced Course.

New subjects are presented to you in a very definite and logical order, to make learning as easy as possible. This lesson and the one which follows are intended to give you a general picture of the entire field of radio, arousing your interest and bringing to mind many questions. You will be pleasantly surprised at how simply and interestingly these questions of yours will be answered in the lesson texts which follow these first few lessons.

TEST QUESTIONS

Be sure to number your Answer Sheet 1FR-2.

Place your Student Number on every Answer Sheet.

SPECIAL NOTICE

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. Into what two broad fields does radio naturally divide itself?
2. What is the negative electric particle called?
3. What happens to the free electrons in a wire if the wire is heated?
4. Why is the filament of a radio tube surrounded by a vacuum?
5. Is a metal with low resistance a good conductor?
6. What is the name given to a material in which electrons will not flow freely?
7. Why are insulators necessary in radio and electric circuits?
8. Will two bodies with the same kind of electric charge (both + or both —) repel each other or attract each other?
9. Will free electrons emitted from a hot body be attracted to another metal body which is positively charged?
10. What four materials have the ability to become magnets?

HOW SOUND AND TELEVISION RADIO PROGRAMS ARE SENT FROM THE STUDIO TO YOUR HOME

2FR-4

PIONEER HOME STUDY RADIO SCHOOL

NRI

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Now you are investing approximately $100 in your radio training. If you do as well as many N. R. I. students do, you'll make $5 to $10 a week in your spare time while you are still studying. Let's say you average $5 a week or $260 a year. In one year, your investment will have returned 260%.

But you haven't even touched the real money in radio yet. When you graduate and go into radio full time, either working for some one else or in business for yourself, the returns should be much larger.

Let's be conservative, however, and say that you increase your salary only $10 a week. At the end of one year, your investment will have earned an additional 520%. That's real profit. In twelve years at the $10-a-week rate, your $100 investment, instead of returning a $100 profit such as it would at 6% compound interest, will have brought you $6,240!

Yes, an investment in knowledge can bring you surprisingly great profits. Make your spare minutes count. Study diligently and regularly.

J. E. SMITH

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WASHINGTON, D. C.

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How Sound and Television Radio Programs Are Sent from the Studio to Your Home

Introduction

AN on-the-spot radio announcer in some far-off city watches history-making events build up to a climax, while maintaining communication with radio engineers in this country. Suddenly he shouts, in a voice throbbing with excitement:

"Give me the air! Give me the air!"

In less than thirty seconds, great nation-wide networks of radio stations are cleared of whatever programs they may have been carrying. The announcer then gives, to millions of listeners sitting tensely before loudspeakers, a detailed word-picture of what is taking place.

But how many of these interested listeners give a thought to how they are able to hear a person who is, at that same instant, thousands of miles away? Not very many, for radio is today looked upon as a normal part of everyday life. Like the electric light, the telephone and all the other great inventions, radio has emerged from the miracle-and-luxury stage to become a great and necessary industry.

Your career in radio will take you behind the scenes of history-making radio broadcasts. *Somewhere along the path which radio signals take from the microphone to the listeners, there is a job for you.* It may be at the transmitting end, where you assist in getting a program "on the air"; it may be at the receiving end, when you adjust and repair radio receivers; it may be in some great factory, where you assist in constructing radio transmitting and receiving equipment for this studio-to-home path. (See Fig. *1*).

Courtesy RCA Mfg. Co., Inc. *Courtesy General Electric Co.*

FIG. 1. A sound radio program originates at a microphone which is usually located in a broadcasting studio; on special occasions, however, this microphone may be set up at any point to which man can travel—above, under or on the face of the earth. From this microphone, the program travels over a long and fascinating path to the loudspeakers of countless radio receivers. Somewhere along this path, or along the corresponding path which links the television camera with the screens of television receivers, there is a successful career in radio awaiting completion of your training.

Regardless of which branch of radio you eventually enter, you will want to know the story of what goes on behind the scenes. A general understanding of the entire field of radio will make your study of specific radio subjects in later lessons far easier and much more interesting.

In this lesson, we will start at a radio broadcasting studio in which a radio program is originating, and follow this program from the microphone right through the various parts of the transmitter until we arrive at the huge antenna tower which sends the radio waves out into space. Through the sky we will trace the radio waves as they travel to the receiving antenna, then keep right on the trail of the program until it emerges from the loudspeaker as sound again.

In much this same manner, we will then trace a television program from the television camera in the studio to the image or picture-reproducing tube in the television receiver.

Read this lesson slowly from beginning to end the first time, in order to get a general idea of its contents, then start at the beginning again and study one section at a time until you feel that you have mastered all of the essential information. *Remember, however, that this lesson is only a "bird's-eye view" of radio, in which many details have been omitted; you will take up these details in later lessons.*

Starting with Sound

When a person talks or sings, our ears recognize the result as sound. We expect sound, and do hear it, when some one beats a drum, rings a bell or blows a whistle. All this is so natural that we rarely give a moment's thought to what sound really is.

In radio, the exact nature of sound is of extreme importance. We start with sounds at the microphone, and must end up with these same sounds at the loudspeaker. Furthermore, we must work with the electrical equivalent of these sounds all through the radio system which links together a microphone and loudspeaker.

Definition of Sound. According to the radio scientist, *sound is a vibration of a body at a rate which can be heard by human ears.* This body may be either a solid, a liquid or a gas. When we talk, it is the vocal cords in our throats which *vibrate* and produce sound. When we blow a whistle, it is the air inside and outside the whistle which *vibrates* and produces sound. When we strike an anvil with a hammer, both the hammer and the anvil *vibrate* and produce sound. A drop of rain falling into a lake sets the water into *vibration*, producing sound.

How Sound Travels. Sounds produced by vibrating bodies must usually travel some distance before they reach human ears. Sound can travel *through anything which possesses the ability to vibrate;* sound can therefore travel through gases like air, through liquids like water, or through solids like wood or metal, for all of these materials are elastic enough to vibrate. Sound cannot travel through a vacuum, because nothing is there to vibrate. These and other interesting characteristics of sound are illustrated in Fig. *2*.

Sound usually travels through air. When an object is set into vibration, it alternately pushes and pulls *particles of air* in the vicinity, thereby setting these particles into vibration.* These vibrating particles in turn act upon other air particles which are farther away, with this process continuing in all directions away from the source of sound. These vibrations traveling away from the source of sound are often called *sound waves*.

It is important for you to realize that the air particles themselves do

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* Technically speaking, air is a *mixture* of dust particles and many different gas molecules, the most important of which are oxygen, nitrogen, water vapor and carbon dioxide. A "particle of air" is a general term referring to any of these molecules or dust particles.

not move outward from a vibrating body at the speed of sound; the vibrations are simply *transferred* from particle to particle by the collisions between particles.

Speed of Sound. Sound waves travel through air at the rate of approximately 1,089 feet per second, with the exact speed varying somewhat with temperature. Compare this figure with the speed of radio waves (186,000 miles per second); obviously, sound travels so slowly in comparison to radio waves that you may actually hear the words of a speaker from your radio loudspeaker before these words are heard by persons at the back of the auditorium, or in the outermost seats of a stadium.

How We Hear Sound. The outer passage of the human ear is closed by a thin membrane called the *eardrum*. When the eardrum is set into vibration by sound waves which travel through air and enter the ear, the motion is transferred through a series of small bones to the fluid in the inner ear, in which are the sensitive fibers of the auditory nerves. These nerves convey to the brain the impression of sound.

The human mechanism of hearing is extremely complex, and different people may hear the same sounds differently. This explains why a radio receiver may sound perfectly satisfactory to one person, even though a musician having highly trained and perfect hearing would recognize severe distortion.

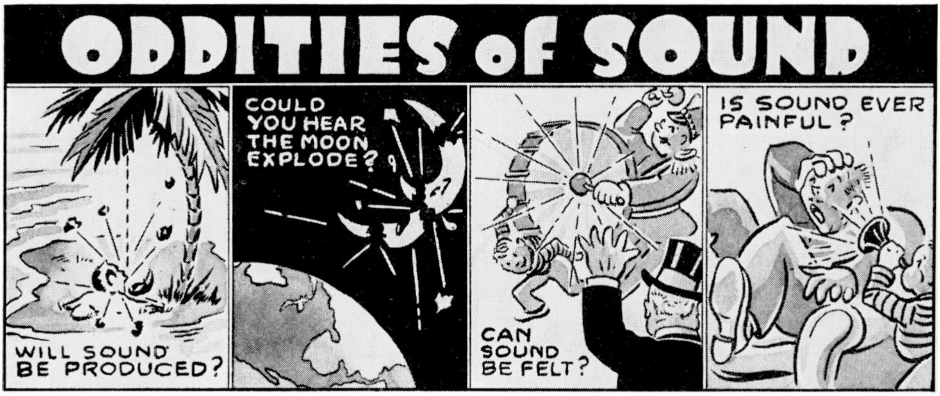


FIG. 2A. The radio scientist says *YES*, because he knows shattered pieces of coconut will vibrate *at a rate which can be heard by human ears*. The medical scientist says *NO*, because he defines sound as a vibration acting on and audible to human ears, and there are none on this uninhabited South Sea isle near the Equator.

FIG. 2B. No matter how violent an explosion of the moon might be, neither you nor any other person on this earth could hear the sound of the explosion. The reason is simply that sound travels only through materials which can vibrate, and there is nothing in the ethereal space between us and the moon—just vacuum.

FIG. 2C. When a large drum is struck vigorously, the stretched diaphragm of the drum vibrates in and out. This action alternately compresses and rarifies air particles in the vicinity of the drum, creating a sound wave which travels away from the drum. Your hand definitely *feels* the varying air pressure of this sound wave.

FIG. 2D. If some husky youngster should blow a large whistle or horn close to your ear, you would definitely agree that sound *can be painful* to the eardrums if sufficiently loud. This is why artillery men must stuff cotton into their ears or use special ear plugs when firing big guns during land warfare or naval maneuvers.

Wavelengths and Cycles. If our sense of touch were sufficiently delicate, we could stand in the path of a sound wave and feel every variation above or below normal air pressure. We would feel an increase in pressure (*compression*), followed by a return to normal, then a decrease from normal pressure (*rarefaction*), and a return to normal again. The entire sequence of increasing and decreasing pressure would then repeat itself over and over again.

One complete sequence of compression and rarefaction, corresponding to one complete vibration back and forth of the sound source, is known as a *cycle* of the sound wave.

The distance traveled by the sound wave *during one cycle* is known as a *wavelength*. In other words, the distance in space between two adjacent compression peaks of a traveling sound wave is equal to *one wavelength*.

Frequency of Sound. The number of complete sound wave cycles which pass a fixed point in one second is called the *frequency* of a sound. Likewise, the number of complete vibrations per second of the sound source is the *frequency* of a sound. The lowest sound frequency which a person can hear is *about 20 cycles per second;* the highest is *about 20,000 cycles per second*. The higher the frequency, the more shrill the sound is to our ears.

The approximate range of frequencies which can be heard by the human ear is thus *between 20 cycles and 20,000 cycles;* this range is sometimes called the *audible range*. Any frequency in this range is an *audio frequency*, abbreviated *a.f.* Of course, these figures represent the extreme limits of hearing, and the average person will have a considerably narrower hearing range. Furthermore, the characteristics of the human ear vary with age, so that older persons have difficulty in hearing the higher audio frequencies.

The *human voice in normal speech* varies between about 200 cycles and 3,000 cycles. Since telephone equipment is intended to handle only voice messages, it possesses this extremely narrow frequency range. This explains why a whistle or a musical program does not sound natural when heard over the telephone.

Whenever radio programs are to be sent over telephone wires, special equipment must be used so as not to distort the higher frequencies in the musical program. Ordinary radio broadcasting systems are usually designed to handle from about 80 cycles to about 5,000 cycles, while frequency modulation broadcasting systems handle from about 30 cycles to about 15,000 cycles. This increased frequency range makes programs seem far more natural when heard with frequency modulation receivers than when heard with ordinary broadcast or all-wave receivers.

How a Microphone Works

The first device in a radio broadcasting system is the *microphone*.

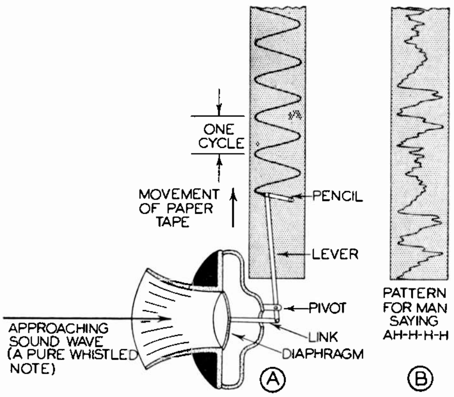


Fig. 3. With the simple diaphragm and lever mechanism at the left, we can trace the characteristics of a sound wave on a moving paper tape. When the sound source is a single frequency such as a pure whistled note, the symmetrical wavy line at *A* is obtained; when a man saying "ah" continuously is the sound source, the pattern is considerably more complicated, as at *B*.

We will first study the effect of sound waves on a simple microphone mechanism, then take up a typical radio microphone.

Effect of Sound Waves on a Diaphragm. Any flexible, light-weight object will vibrate when struck by a sound wave in air. Every microphone has one flexible part called a *diaphragm*. This is usually made from a special aluminum alloy, and is designed to vibrate when in the path of sound waves traveling through air.

The special mechanism shown in Fig. *3A* illustrates how the diaphragm in a microphone reacts to sound waves. The diaphragm in this case is a round disc, with a thin metal rod or link attached to its center. This link is coupled to a pencil through a pivoted lever. A little study of this link and lever mechanism will show you that the pencil will move sideways when the diaphragm vibrates in and out under the influence of approaching sound waves.

If we simply hold a sheet of paper under the pencil in Fig. *3A* while the diaphragm is vibrating, the pencil will trace a line over and over again; if we use paper tape and pull it under the pencil at a uniform speed, however, the pencil will trace a wavy line on the paper.

If the sound wave in question is produced by a tuning fork (such as piano

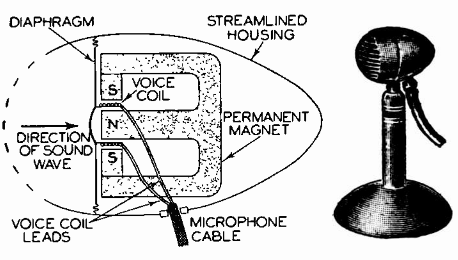
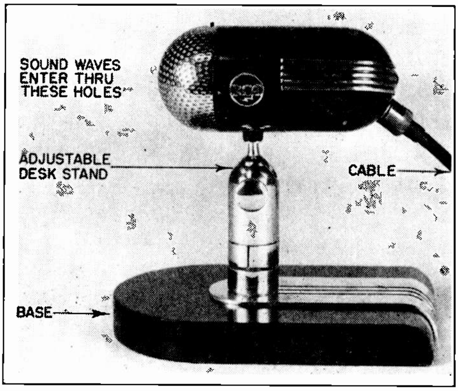


Fig. 4. Cross-section diagram of a typical dynamic microphone, showing the essential features which would be visible if we sliced vertically through the center of the microphone. When the voice coil of a dynamic microphone is moved in and out by sound waves, *a voltage is generated in the coil.* The sketch at the right shows this type of microphone mounted on a desk stand.

tuners use), or by whistling a single pure note, this device will trace a symmetrical wavy line like that shown on the paper tape in Fig. *3A*. If, however, the sound wave in question is produced by a man saying "ah" continuously for several seconds, the tracing on the paper tape might be as shown in Fig. *3B*.

Purpose of a Microphone. The mechanism shown in Fig. *3* is useful only for demonstrations. The important purpose of a microphone is *to convert sound waves into corresponding variations in an electrical signal.* Let us see how this is accomplished.

Construction of a Dynamic Microphone. The important features of one



Courtesy RCA Mfg. Co., Inc.

Fig. 5. Typical modern dynamic microphone.

widely used type of microphone, known as a *dynamic microphone,* are shown in Fig. *4*, and the microphone itself is pictured in Fig. *5*. Sound waves entering the microphone through the slots in the housing make the thin circular metal diaphragm vibrate.

Attached to the back of this diaphragm is a small coil of wire called the *voice coil,* with its two leads going to the *microphone cable.* This coil is made from insulated copper wire almost as fine as a human hair, wound on a thin bakelite coil form only about one-half inch in diameter, so that the entire moving system, including the coil and diaphragm, is extremely light. Surrounding the coil are the poles of a permanent magnet, arranged in such a way that magnetic lines of force pass through the coil at all times.

Principle of a Dynamic Microphone. Now we are ready for the simple but highly important fundamental principle of a dynamic microphone: *When the voice coil is moved through magnetic lines of force, a voltage is generated in the coil.*

When the diaphragm of the dynamic microphone is set into vibration by a sound wave, the voice coil moves in and out between the poles of the permanent magnet. The wire on the coil thus moves through the magnetic lines of force, and *a voltage is generated in the coil.*

In a properly designed microphone, this electrical signal voltage varies in exactly the same way as the sound wave which produced it. A dynamic microphone thus converts a sound wave into corresponding variations in an electrical signal. (This electrical signal is commonly called the *audio signal,* since it has the same audio frequency as the original sound wave.)

Microphone Output Is Weak. The varying audio signal voltage produced even by the best microphones is quite weak, and must be built up in strength before it is useful for radio purposes. This building up of the voltage must be done without appreciably changing the manner in which the voltage is varying, for otherwise the audio signal would be distorted (would not correspond to the original sound.)

Before explaining in detail how the output voltage of a microphone can be boosted, let us first get acquainted with the two common radio parts used for this purpose, the *radio tube* and the *transformer.*

The Radio Vacuum Tube

Construction of a Radio Tube. A cut-away diagram showing the construction of a typical radio tube is shown in Fig. *6*. There are four important parts in this tube. In the center of the tube is the *filament,* which becomes red-hot while the tube is in operation. Surrounding the filament is a cylindrical part called the *cathode,* which emits electrons when heated by the filament. The other two parts encircle the cathode. The outermost is a metal cylinder called the *anode,* and serves to attract electrons. Between the cathode and the anode is a spiral wire arrangement called the *grid,* which serves to control the number of electrons moving from the cathode to the anode.

The important parts of a vacuum tube are enclosed in either a metal or glass housing called the envelope, from which all air has been pumped out during manufacture so as to give a vacuum. In the case of a metal envelope, the leads going to the electrodes pass through glass inserts.

The cathode, grid and anode are the *electrodes* of a vacuum tube. The filament is considered . an electrode only in a tube which does not have a separate cathode; tubes for battery receivers are made in this manner, and the filament then serves also as the cathode. *The electrode which emits electrons in a vacuum tube is always called the cathode.*

The smallest number of electrodes a tube can have is two (a cathode and a plate). There is no definite limit to the maximum number of electrodes, but radio receiving tubes usually have somewhere between two and six electrodes. A tube can have two or more different types of grids, but for the present we will consider only tubes having one grid.

Now let us consider the important parts of the vacuum tube in Fig. *6* individually, along with their effects upon the performance of the tube.

Filament. The filament in a heater type tube like that in Fig. *6* is a fine hairpin-shaped wire, with a heavier wire lead going from each end of the filament to one of the prongs on the base. The fine filament wire becomes red-hot when filament current is sent through it by a battery or other voltage source.

The filament voltage source is commonly designated by the letter "A"; thus, either an A battery or an A voltage supply can be used to send current through the filament.

Cathode. Surrounding the filament of the tube in Fig. *6* is a metal sleeve about one-sixteenth inch in diameter, serving as the cathode. This cathode sleeve is coated with special chemicals known as barium oxide and strontium oxide; these have the ability to give off large quantities of free electrons when they are heated by the red-hot filament. Remember that *the electrode which emits electrons is always called the cathode.*

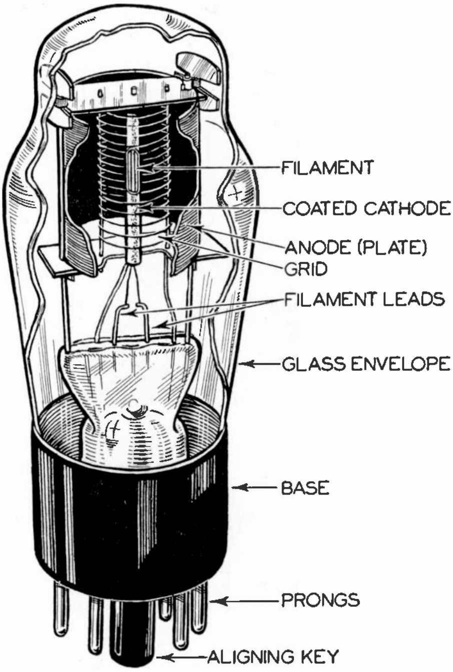
Anode. The metal cylinder farthest away from the cathode is the anode. When the tube is in use, this anode is at a high positive potential with respect to the cathode. *The anode in a vacuum tube thus attracts the electrons which are emitted by the cathode.* The anode is sometimes called the *plate,* because in the very first vacuum tubes made for radio purposes, this anode was usually constructed in the form of a small plate rather than a cylinder.

The plate voltage source is commonly designated by the letter "B"; thus, either a B battery or a B voltage supply can be used to provide a high positive potential for the anode. The positive terminal of the B voltage supply is usually marked "B+," and the negative terminal is marked "B—".

Plate Current. When a vacuum tube is properly connected to its voltage sources, the electrons emitted by the cathode will be attracted by the anode. This electron flow (current) through the tube is commonly called the *plate current* of the tube, since it is the current drawn by the plate or anode.

The plate current which flows through a tube is determined by the plate voltage value and by the characteristics of the tube. The higher the plate voltage, the higher will be the plate current.

The Grid. A radio tube must have one additional electrode besides the plate and the cathode before it can act as an amplifier for electrical signals.



Courtesy National Union Radio Corp.

FIG. 6. Cut-away diagram showing the construction of a typical radio tube. Part of the cylindrical plate electrode is cut away to show the grid and cathode, and part of the cathode is cut away to show the filament wires.

This additional electrode is the *grid;* it is usually in the form of a coil of fine wire mounted between the cathode and the anode, with considerable space between the turns of wire as shown in Fig. *6*.

The name "grid" comes from the fact that in early radio tubes, this in-between electrode was a screen or grid of wires. When there is no electrical charge (no voltage) on the grid, electrons can readily pass between the grid wires when traveling from the cathode to the anode.

It is only when a charge is placed upon the grid that there is any effect upon the electron flow from the cathode to the anode. *The grid in a vacuum tube then serves to control the number of electrons moving from the cathode to the anode.*

If a positive charge is placed upon the grid, it will attract electrons; if a negative charge is placed on the grid, it will repel electrons. This is simply an application of the fundamental electrical law that like charges repel and unlike charges attract. In radio work, however, *a positive charge is very rarely used on the grid, for it usually causes distortion of the signal.*

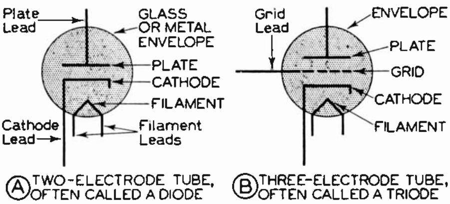


FIG. 7. Symbols commonly used to represent two types of radio tubes. These symbols are easy to recognize once you study them a few times. Each line on a symbol tells its own story. Actually, symbols are a form of "shorthand" used by radio men to describe radio circuits simply but completely.

When a negative charge or voltage is placed on the grid, so that the grid has more electrons than normal, the electrons on the grid repel the free electrons coming from the cathode, and actually prevent some of these free electrons from passing through the grid wires. Since the grid is located closer to the cathode than is the plate, the grid has considerable influence on the emitted electrons. *The greater the negative voltage on the grid of a radio tube, the less is the electron flow through the tube.*

We can place a negative charge on the grid simply by connecting the negative terminal of a voltage source to the grid, and connecting the positive terminal of the voltage source to the cathode. When the grid of a radio tube is made negative with respect to the cathode in this manner, we say that the grid has a negative *bias.*

The grid voltage source is commonly designated by the letter "C"; thus, either a C battery or a C bias source can be used to make the grid negative with respect to the cathode.

Vacuum Tube Symbols. It is inconvenient to draw a pictorial sketch of a vacuum tube when you wish to present its circuit on paper. For this reason, radio men use symbols to represent vacuum tubes and other radio parts.

The symbol for a two-electrode vacuum tube having a heater-type cathode (a cathode heated by a filament) is shown in Fig. *7A*. The filament is shown as a V-shaped wire projecting inside the circle which represents the envelope of the tube. (Ordinarily, the two filament leads are shown unconnected in circuit diagrams, and it is assumed that they will be connected to a suitable filament voltage source.) The cathode is shown as a heavy line tending to surround the filament, just as it does in an actual tube. The plate is another heavy, straight line, parallel to the cathode and some distance away from it.

The symbol for a three-electrode vacuum tube having a heater-type cathode is shown in Fig. *7B*. The grid is shown on this symbol as a dotted (dash-dash) line located between the cathode and the plate.

Tube Circuit Diagrams. As you have just learned, a three-electrode radio tube requires three separate voltages. When these are provided by batteries as they are in modern portable receivers, we need an A battery for the filament, a B battery for the plate, and a C battery for the grid. The actual connections of these batteries to the tube terminals might be as shown in Fig. *8A*, but there is no need to draw pictorial sketches of batteries when we can tell just as much with the battery symbols in Fig. *8B*.

Even the drawing of simple long and short-line battery symbols is unnecessary and often omitted. It is entirely sufficient to indicate the terminals in the vacuum tube circuit which should go to voltage sources, as shown in Fig. *8C*. Usually, even the lettering A— and A+ on the filament leads is omitted, for there is no difficulty in recognizing these leads. Just remember that the notations A—, A+, B—, B+, C— and C+ on radio circuit diagrams indicate connections which are to be made to A, B and C voltage sources.

Amplification. Both the plate voltage and the grid voltage affect the electron flow through a three-electrode vacuum tube. Since the grid is closer to the cathode, a small variation in the grid bias voltage will change the electron flow through the tube far more than will that same variation in the plate voltage. For instance, a 1-volt change in the grid voltage may affect the electron flow just as much as does a 10-volt change in the plate voltage; we say that the tube is able to *amplify* ten times.

If we apply the varying output signal voltage of a microphone to the grid of a tube along with the fixed C bias voltage, the electron flow through the tube will vary in exactly the same manner as the microphone output voltage. With proper circuit connections, we can secure from a three-electrode radio tube a much larger signal voltage than is delivered by the microphone; in other words, *we can use a three-electrode tube to amplify the microphone signal.*

It is not ordinarily practical, however, to connect a microphone directly to a radio tube; the connection is usually made through a simple device known as a *transformer,* in order to increase the voltage of the audio signal produced by the microphone. Since a transformer is a highly important

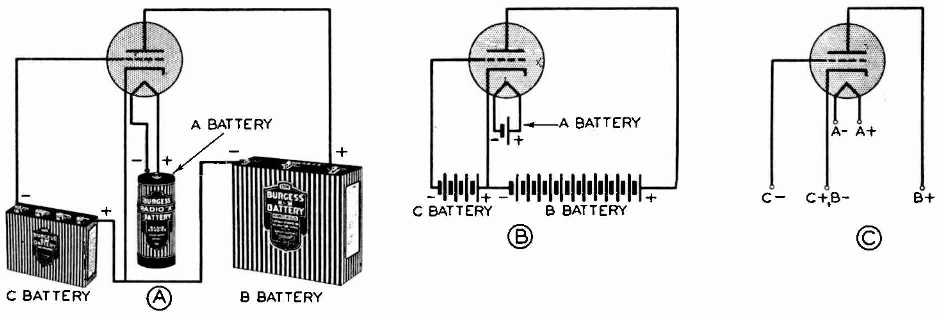


FIG. 8. These three types of diagrams each contain exactly the same amount of useful information about a vacuum tube circuit. Obviously, the diagram at *C* is the simplest to draw; for this reason, you will encounter diagrams like it very often in your radio studies and radio work. There is no need to waste time making fancy diagrams like that at *A* when a simple diagram will serve just as well.

radio device, it will be worth while to consider briefly here its general characteristics.

The Transformer

What Is a Transformer? A transformer in its simplest form is nothing more than two coils of wire mounted close to each other. The coil across which we apply the input voltage is called the *primary coil* or *primary winding*. The coil from which we take the output voltage is called the *secondary coil* or *secondary winding*.

The material on which the coils of a transformer are wound is known as the *coil form.* When the coils are wound one over the other on a paper form inside of which are thin iron sheets, we have what is known as an *iron-core transformer.* A typical transformer of this type is shown in Fig. *9.*

If there is only insulating material like paper or fiber inside the coils, we have what is known as an *air-core transformer,* or more commonly as a *radio frequency transformer.*

Iron-Core Transformer. When an electric current is sent through the primary coil of an iron-core transformer, the iron will become magnetized. If the electric current is varying, as it is in the case of the microphone signal, the number of magnetic lines of force

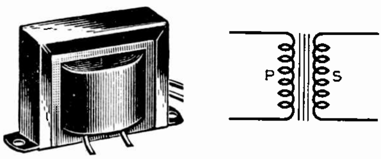


FIG. 9. Appearance of a typical iron-core transformer, and the symbol used in radio diagrams to represent this transformer. The primary coil is wound on the iron core, and the secondary coil is wound over the primary coil.

flowing through the core will vary in a corresponding manner. It is these varying magnetic lines of force, passing through the secondary coil, which make it possible to transfer an electrical signal from one coil to another even though there is no direct wire connection between the two coils.

Whenever the number of magnetic lines of force passing through a coil of wire is varied in any manner, a voltage is set up in the coil. In the case of an iron-core transformer, we secure varying magnetic lines of force in the iron core by sending a varying electrical signal through the primary coil. The varying magnetic lines of force passing through the secondary coil cause a voltage to be induced (produced or set up) in that coil.

If the secondary coil has more turns of wire than the primary coil, the voltage induced in the secondary will be greater than the signal voltage applied to the primary winding; under this condition we say that the voltage has been stepped up. In transformers designed to transfer signal voltages, the secondary invariably has more turns than the primary, in order to give this highly desirable voltage step-up.

The symbol used to represent an iron-core transformer on a circuit diagram is also shown in Fig. *9.* One coil is sometimes marked *P* for primary, and the other marked *S* for secondary. The straight lines between the two coils indicate that the transformer has an iron core.

Common Abbreviations

Direct Current. When electrons are flowing continuously in one direction through a circuit, we have what is known as a *direct current.* The voltage which sends this current through the circuit is known as a *direct current voltage,* commonly abbreviated *d.c. voltage.* Whenever you encounter the abbreviation *d.c.,* remember that it stands for *direct current.*

Alternating Current. When the electron flow through a circuit changes its direction from instant to instant, we have what is known as an *alternating current.* The voltage which sends this current through the circuit is called an *alternating current voltage,* commonly abbreviated as *a.c. voltage.* The abbreviation *a.c.* therefore stands for *alternating current.* Here is an example: A microphone produces an a.c. voltage, and this voltage sends an alternating current through the microphone circuit.

Audio Frequency. As you have already learned, a frequency in the audible range (from about 20 cycles to about 20,000 cycles) is known as an *audio frequency* (abbreviated *a.f.*).

Radio Frequency. A frequency above the audible range is known as a radio frequency (abbreviated *r.f.*), as it is used primarily in radio. Thus, radio frequencies between 550,000 cycles per second and 1,600,000 cycles per second are in the range known as the *broadcast band,* in which most of our radio listening is done. Each broadcast station has a particular assigned frequency in this range, to which we tune our radio receiver when we want to hear a particular station. Foreign short-wave stations have even higher assigned frequencies.

Kilocycle. Since it is inconvenient to deal with large numbers, we often use a larger unit of frequency than the cycle when we wish to specify a radio frequency. One widely used unit is the *kilocycle,* which is equal to 1,000 cycles and is abbreviated as *kc.* Expressed in kilocycles, the broadcast band would extend between 550 kc. and 1,600 kc.

Megacycle. The *megacycle* is another widely used unit of frequency. This is equal to 1,000,000 cycles, and is abbreviated *mc.* One megacycle is equal to 1,000 kilocycles. Expressed in megacycles, the broadcast band extends between .55 mc. and 1.6 mc.

Strictly speaking, a designation of frequency should always be followed by the words "per second." However, since the second is the only time interval used in radio for designating frequency, no confusion can result from omitting the phrase "per second." You should realize, however, that when we speak of a certain number of cycles, we really mean cycles per second. Likewise, "kilocycles" means "kilocycles per second," and "megacycles" means "megacycles per second."

You have undoubtedly noticed that the radio station listings in newspapers and magazines, as well as the tuning dials of radio receivers, are oftentimes marked in meters as well as in kilocycles or megacycles. There

Courtesy Western Electric Co.

FIG. 10. The monitor man in the control room watches the performers in the studio through a large glass window, and hears them only through a special loudspeaker located behind him near the ceiling of the control room. Truly, this man is dictator of the airways, for a radio program takes shape under his delicate touch on the controls. The small microphone at the left of the control unit is used principally for intercommunication between the monitor room and studio prior to a broadcast or during rehearsals, for the wall between the two rooms is sound-proof.

is a simple and definite relationship between these two units.

Frequency-Wavelength Relationship. Electrical energy and radio waves both travel at a definite speed corresponding to the speed of light, which is roughly 186,000 miles per second. One cycle of variation in an electrical signal takes a certain definite amount of time, and electricity can travel a certain distance in this time. This distance which can be traveled in the time of one cycle is called *one wavelength.* It could be expressed in feet or inches, but radio men find it more convenient to express the distance of a wave length in terms of *meters,* the scientific unit of length. One meter is equal to 3.28 feet, and hence is just a little longer than one yard.

The lowest broadcast band frequency of 550 kc. corresponds to a wavelength of 545 meters, while 1,600 kc. corresponds to 188 meters.* The broadcast band thus covers the range of 188 meters to 545 meters.

Amplifying the Microphone Signal

Having become acquainted with radio tubes and transformers, let us return to the *microphone* in the radio broadcasting studio, and begin tracing our signal through the various stages of the transmitter. Radio men refer to this electrical signal as the *audio signal,* so let us use this same language.

The audio signal voltage existing at the two terminals of the microphone in the broadcasting studio is fed through a two-wire microphone cable to the control room which adjoins the studio. There is a glass window in the wall separating the two rooms (see Fig. *10*), so the control room operator can watch the artists and announcer in the studio while he is "riding gain" (adjusting the studio volume control to correct for excessive changes in the loudness of the program).

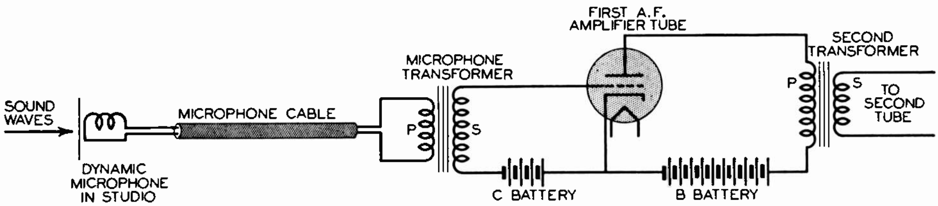


FIG. 11. Simplified circuit diagram showing the first part of the path taken by signals in traveling from the studio to your home. Only the most important parts of the circuit are shown here; the complete circuit will be taken up in advanced lessons.

Microphone Transformer. In the control room, the audio signal encounters an iron-core transformer known as the *microphone transformer.** The two wires in the microphone cable are connected to the two ends of the primary winding, as shown in Fig. *11,* so that we have a complete closed circuit over which electrons can travel. Since the audio output voltage of the microphone is reversing its

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* A simple arithmetical relationship exists between frequency and wavelength. To find the frequency in kilocycles when you know the wavelength, simply divide the number 300,000 by the wavelength in meters. To find the wavelength in meters when you know the frequency, simply divide the number 300,000 by the frequency in kc. Example: 1,500 kc. is equal to 300,000 ÷ 1,500, or 200 meters. 500 meters is equal to 300,000 ÷ 500, or 600 kc.

* Sometimes two iron-core transformers are used, one in the control room and the other built right into the microphone. The transformer at the microphone then serves to transfer the maximum possible microphone signal energy to the microphone cable, and the other transformer serves to transfer the maximum possible signal energy from the cable to the grid of the first tube in the control room. In this lesson, we will consider only the system employing one transformer.

polarity many times each second in accordance with the variations in the sound waves, the electron flow over this circuit will likewise reverse in direction many times each second.

The varying electron flow through the primary winding *P* of the microphone transformer induces an audio signal voltage into the secondary winding *S*. This stepped-up audio voltage is applied to the grid and cathode of the first a.f. amplifier tube, as shown in Fig. *11*. Since the tube has amplifying ability, it delivers an even larger audio output voltage.

A microphone transformer and amplifier tube together (constituting one audio amplifier stage) may amplify our signal voltage several hundred times, but this is not enough. Before the a.f. signal has any value for radio broadcasting purposes, it may have to be amplified more than a million times. To do this, the output of the first amplifier tube can be fed into a transformer similar to the microphone transformer, with this transformer in turn feeding into the second amplifier tube. This process is continued with additional tubes and transformers (additional a.f. stages) until the desired amplification is obtained.

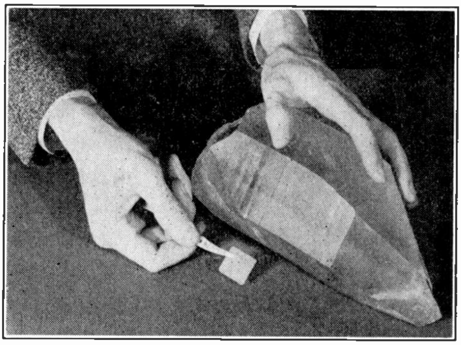
Generating R. F. Currents

Up to this point in our lesson, we have dealt with a.f. signals, and have traced them from the microphone through the audio amplifier stages. We are now ready to consider r.f. signals, which are the only signals capable of producing useful radio waves.

How Radio Waves Are Produced. Radio waves are produced by feeding an a.c. signal to an antenna (a wire or a steel tower supported in space). The electrons in the antenna move back and forth at the frequency of the alternating current. The sudden reversals in the direction of motion cause their associated electric and magnetic fields to be jerked loose into space, and these fields travel away from the antenna in all directions as radio waves.

At audio frequencies, radio waves travel for only a few hundred feet even under ideal conditions; the frequency must be considerably higher before radio waves will "go places." We must employ a much higher frequency, known as the *r.f. carrier frequency,* to carry our audio signal through space to receiving antennas.

Generation of an R. F. Carrier Frequency. There are two practical methods of generating an r.f. carrier frequency. One method employs only a vacuum tube in a circuit known as a *vacuum tube oscillator.* The other method employs a quartz crystal and a vacuum tube in a circuit known as a *crystal oscillator.* Since it is the crystal oscillator which is commonly used in modern broadcasting stations, this is the type we will consider in this lesson.



Courtesy General Electric Co.

FIG. 12. A quartz crystal slab, after being ground to the correct dimensions, is here held by tweezers alongside a piece of quartz as found in its natural state.

Quartz Crystals. The important part in a crystal oscillator is the crystal itself. This crystal is usually cut from natural quartz, then ground into a thin square sheet or into a round disc about the size of a U. S. fifty-cent piece. The completely ground crystals look very much like frosted glass.

Quartz as found in nature is shown in Fig. *12,* along with a completed crystal ready for use. Natural quartz is mined in South America. The crystal slabs must be cut out of the quartz

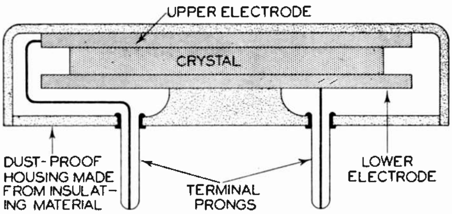


Fig. 13. Cross-section view of a quartz crystal in its holder. The electrodes are simply brass discs slightly larger than the crystal.

rock in a special way in order to be useful for radio purposes.

Crystal Holders. Quartz crystals are always used in special holders. A cross-section view of a typical holder is shown in Fig. *13;* the crystal is sandwiched in between two metal discs called *electrodes,* which serve to make contact with the faces of the crystal. The discs are connected to the two terminal prongs of the crystal holder. The crystal is completely enclosed in its holder in order to give protection from dust and dirt. The general appearance of typical crystal holders can be seen from Fig. *14.*

Action of a Vibrating Crystal. When a quartz crystal is connected into a suitable crystal oscillator circuit, electrical energy from the circuit sets the crystal into vibration. It then vibrates very much like a strip of stiff spring steel, but moves so rapidly and for such a short distance that the eye can see no movement.

When the crystal vibrates in one direction, the free electrons in the crystal tend to pile up on one of the flat faces; when the crystal vibrates in the other direction, the free electrons pile up on the other flat face. The vibrations push the electrons from one face to the other continually, and consequently a face and its electrode are charged positively one instant and negatively the next instant.

Frequency of a Crystal. Each crystal has its own natural frequency of vibration. This depends upon the size of the crystal, particularly its thickness. It is not at all difficult to grind a crystal to a shape which will vibrate naturally millions of times per second. The energy from the associated circuit keeps the crystal vibrating at its natural frequency. The rapidly reversing positive and negative charges on the electrodes of a crystal holder are the equivalent of an a.c. voltage having the same frequency as that at which the crystal is vibrating.

The voltage which can be generated by a quartz crystal is very, very small. Vacuum tubes must therefore be used to amplify or build up this voltage sufficiently for transmitter requirements.

Operation of a Crystal Oscillator Circuit. You already know that when an a.c. voltage is applied between the

Fig. 14. Typical crystal holders. These are plugged into sockets in the same manner as radio tubes, and can be removed or interchanged in a few moments whenever it is necessary to change the carrier frequency of a transmitter.

grid and cathode of a vacuum tube, the electron flow through the tube and its plate circuit will vary at exactly the same frequency as the a.c. grid voltage. In the simple crystal oscillator circuit shown in Fig. *15,* the a.c. voltage generated by the crystal is applied to the grid and cathode of the vacuum tube. The result is a varying electron flow through the plate circuit.

Observe, however, that we have a variable tuning condenser and one winding of an r.f. transformer in this plate circuit. A glance at Fig. *16* will acquaint you with the appearances of these two common radio parts, and you will then be ready to see what this coil-condenser combination does in our crystal oscillator circuit.

Whenever a coil and condenser are connected together in the manner shown in Fig. *15*, there will be one definite frequency at which a very large alternating current flows through the coil. We can make this frequency correspond to the frequency of the vibrating crystal simply by varying the electrical size of our condenser. We do this by rotating one set of condenser plates in or out with respect to the other; this is called "tuning" the coil-condenser circuit to the crystal frequency.

Importance of Tuning. There is a highly interesting reason why we need

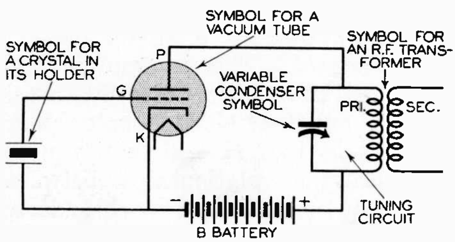


Fig. 15. Simple crystal oscillator circuit which keeps the quartz crystal vibrating at its natural frequency. The B battery feeds energy to the crystal through the tuning circuit and the vacuum tube.

Letters are often used to designate the important electrodes in a vacuum tube symbol; thus, *P* in the diagram identifies the plate, *G* stands for grid, and *K* stands for cathode.

Note the resemblance between the crystal symbol here and the cross-section diagram in Fig. *13*. Yes, the two thin outer lines in the symbol represent the electrodes, and the short, heavy line between them represents the crystal.

a coil-condenser tuning circuit in our crystal oscillator. A crystal has a definite fundamental frequency of vibration which depends upon the dimensions of the crystal. At the same time, however, the crystal will vibrate at a number of different higher frequencies known as *harmonic frequencies.*

Each harmonic frequency is a multiple of the original fundamental frequency. In other words, each har-

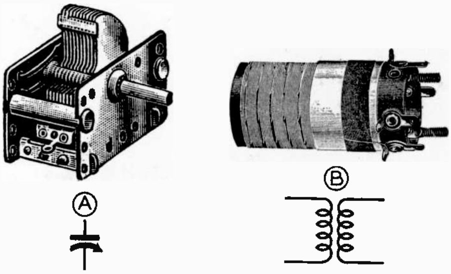


Fig. 16. A typical variable tuning condenser with its symbol (*A*) and a typical r.f. transformer with its symbol (*B*). The curved arrow in the condenser symbol is the clue telling you that the condenser is variable. Note that except for the omission of the three thin straight lines, this r.f. transformer symbol is exactly like the iron-core transformer symbol in Fig. *9*.

monic frequency is a definite whole number of times greater than the fundamental frequency. Thus, if our fundamental crystal frequency is 1,000 kc., the crystal will at the same time vibrate at its harmonic frequencies of 2,000 kc., 3,000 kc., 4,000 kc., 5,000 kc., etc. By tuning this coil-condenser combination to the fundamental frequency, we secure a high current through the coil at that frequency, and very little coil current at any of the undesired harmonic frequencies.

Purpose of R. F. Amplifier Stages. The desired large alternating current flowing through the primary coil of the r.f. transformer in Fig. *15* produces varying numbers of magnetic lines of force through both the primary and secondary coils. As a result, an a.c. voltage of the desired frequency is induced in the secondary coil. This a.c. voltage is still too weak for broadcast purposes, so it is sent through r.f. amplifier stages.

In a moderate-sized broadcasting station, as many as five or six of these r.f. amplifier stages may be required. Each succeeding tube must be larger than the preceding, so it can handle a larger r.f. current without getting hot.

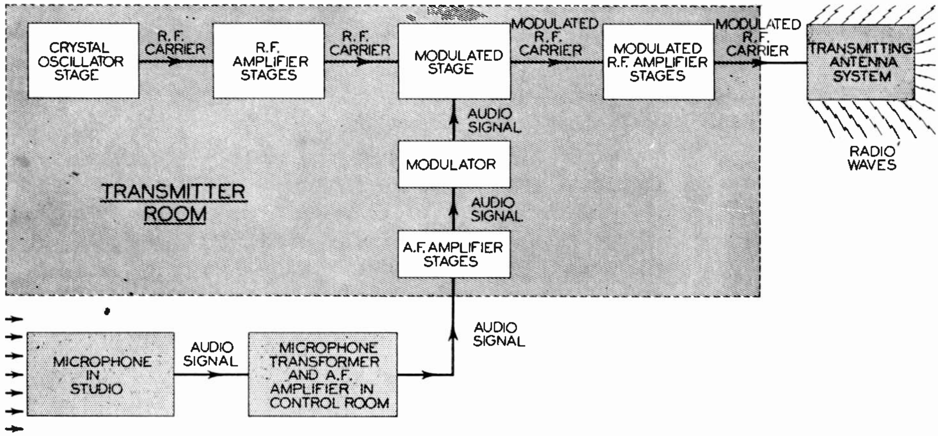


FIG. 17. Block diagram for a broadcast transmitter. Arrows indicate the direction in which signals travel from one stage to another. The heavy arrows at the left of the microphone represent sound waves.

How Audio and Carrier Currents Are Combined

You have now traced through two complete sections of a radio transmitter. One of these sections amplified the audio output signal of the microphone, and the other amplified the radio frequency output voltage of the crystal oscillator.

The remaining steps in the transmitting process involve combining these r.f. and a.f. currents, to give what is known as a *modulated r.f. carrier signal.* This is amplified by additional tubes, then fed to the transmitting antenna. The simple block diagram in Fig. *17* will help you to visualize the relationships between the main sections of a broadcast transmitter.

It is customary to represent the r.f. voltage at any one point in a circuit by a diagram like that shown in Fig. *18A*. On this diagram, two adjacent voltage swings, one upward and the other downward from the horizontal center-line, represent one cycle. Distances along the horizontal line represent time; only a short period of time is represented by this diagram, for there are only 24 cycles shown, and radio frequencies can be millions of cycles per second.

When the sound being picked up by the studio microphone is a simple constant-frequency tone, the a.f. voltage can be represented by the diagram in Fig. *18B*. Only one cycle is shown.

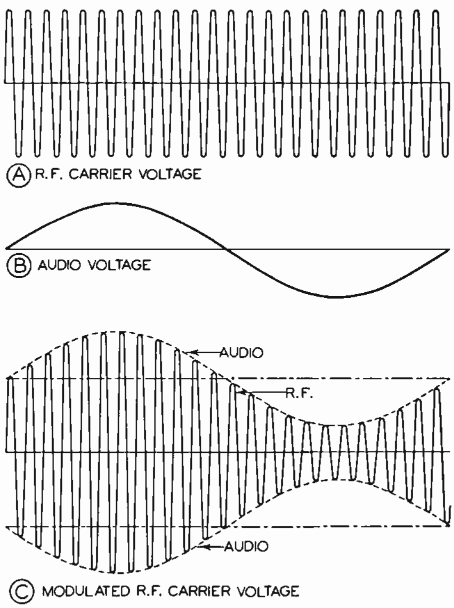


FIG. 18. These diagrams will help you to understand how the modulated r.f. carrier voltage (*C*) can have the characteristics of both the r.f. carrier (*A*) and the audio signal (*B*).

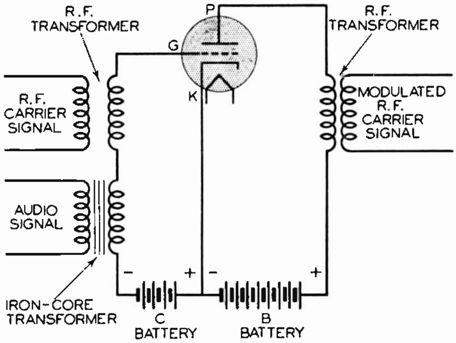


FIG. 19. Simplified circuit diagram showing the essential features of a typical modulated stage in a radio broadcast transmitter.

Modulation. If we combine the r.f. voltage of Fig. *18A* with the a.f. voltage of Fig. *18B* in such a way that the r.f. voltage will vary in magnitude in the manner shown in Fig. *18C*, the variations in magnitude for each individual cycle will correspond to the characteristics of the a.f. voltage. We will then have a combined signal which can be radiated through space and can be converted into sound by a radio receiver. This is exactly what is done in a radio broadcasting transmitter, and the process involved is known as *modulation*. In effect, we are *modulating* the radio frequency voltage with the audio frequency voltage.

The essential features of one common method for producing modulation in a transmitter are shown in the circuit diagram in Fig. *19*. This vacuum tube circuit is fed simultaneously (at the same time) with the audio signal and the r.f. carrier signal. Actually, the a.f. voltage is induced into the grid circuit by means of an iron-core transformer, and the r.f. voltage is induced into the grid circuit by means of an r.f. transformer. Both voltages then act upon the grid of the tube along with the C bias voltage, with the result that the desired modulated r.f. carrier signal is present in the plate circuit.

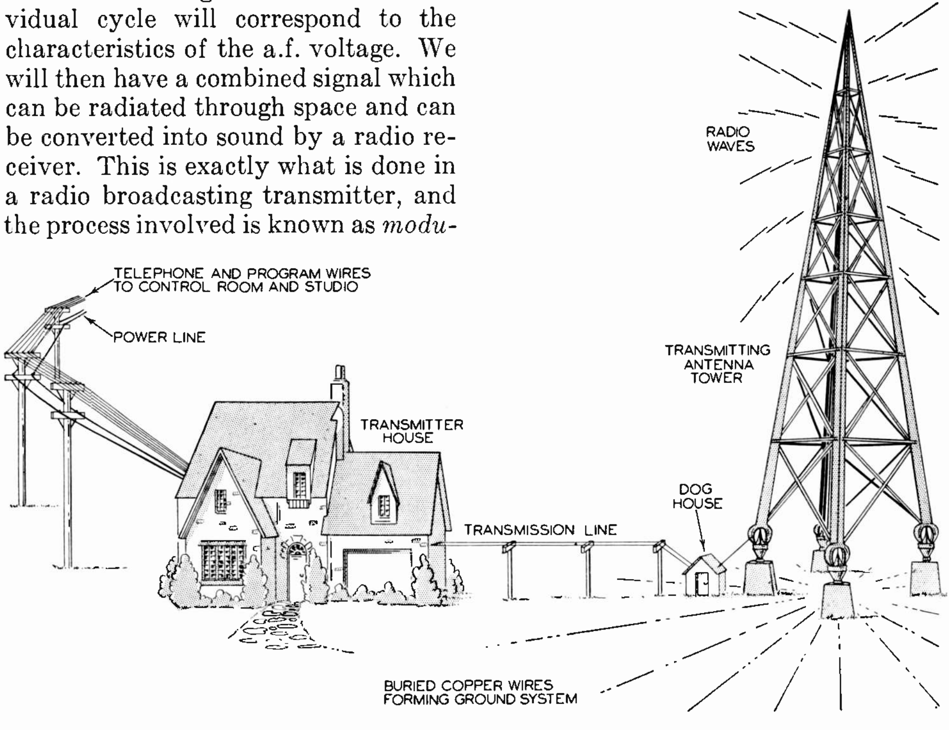
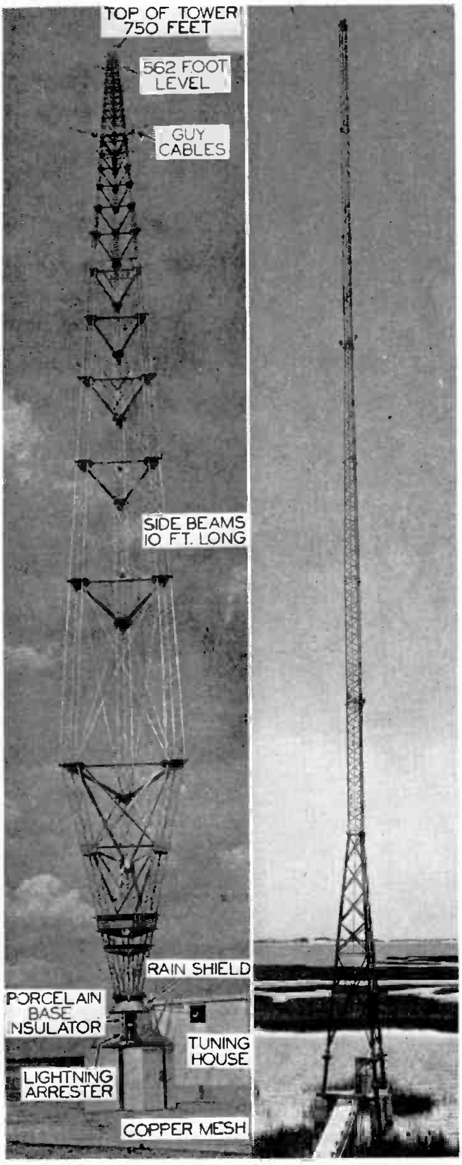


FIG. 20. Essential features of a typical transmitting antenna set-up. Only switches, meters and antenna tuning coils are kept in the small tuning house at the base of the tower, but radio operators persist in calling this the *dog house*. Oftentimes, the transmitter and dog house are located in the middle of a swamp (so as to get a better ground connection); a boarded footpath supported above the mud on stilts then runs from the transmitter to the antenna. During blizzards and bad weather, the radio operator on duty must trudge out to the dog house at regular intervals, to make sure the antenna has not been thrown out of tune by sleet or rain.



Courtesy Chicago Tribune & WGN. *Courtesy Station WFOY.*

FIG. 21. Left: An impressive close-up view of the famous 750-foot high steel transmitting antenna of radio station WGN in Chicago. Buried copper wires radiating from the tower connect to the copper mesh at the base. A single porcelain insulator supports the 65-ton weight of the tower. Two sets of guy wires hold the tower erect.

Right: Self-supporting 200-foot high steel tower of station WFOY in St. Augustine, Florida. The salt-water marsh surrounding this tower improves the effectiveness of the ground system. The entire tower is supported on three insulators. The dog house is directly under the tower, with a cat-walk running from it to the transmitter.

The modulated r.f. signal is usually sent through one or more modulated r.f. amplifier stages before being fed to the transmitting antenna. In a broadcast transmitter, these stages employ huge vacuum tubes which are cooled either by blower fans or by a circulating water system; this is particularly true of the final tubes in the transmitter, for these must handle the entire output power of the transmitter.

Producing Radio Waves

The transmitting antenna system of a modern radio broadcasting station is usually a single steel tower insulated from the earth by means of huge insulators. The modulated r.f. carrier signal at the output of the radio transmitter is fed to this tower over a special two-wire transmission line, as shown in Fig. *20*.

Electrons vibrating up and down in the tower structure "shake off" their electric and magnetic lines of force, and these lines of force travel through space to make up the radio waves. The steel mast acts simply like a large vertical conductor through which can flow the electrons making up the modulated r.f. carrier current.

The transmitting antenna tower and the nearby ground area are together equivalent to a coil and condenser acting just like a tuned circuit. Maximum current flows through the antenna when this antenna circuit is exactly tuned to the r.f. carrier frequency. The antenna can be tuned to this frequency at the time of installation by varying its height; this is sometimes done by means of a telescoping metal pipe or mast at the top of the main tower structure. Two typical radio transmitting antenna towers are shown in Fig. *21*.

Sky Waves and Ground Waves. The radio waves which leave a transmitting antenna are directed up into the sky as well as along the ground. Those traveling skyward are not lost, however; there is a region, between about 30 and 80 miles above the earth, which contains layers of electrons and ionized (charged) gas molecules. These *ionized layers* are capable of bending radio waves back to earth. Waves which travel skyward and are reflected in this manner are known as *sky waves.*

All long-distance radio reception is by means of sky waves. Transmitting antennas for short-wave stations are usually designed to radiate chiefly sky waves, for long-distance transmissions are desired here. In the case of broadcast stations or police radio stations serving a limited local area, the transmitting antennas are designed to radiate ground waves or a combination of ground and sky waves. Sky wave reception is often accompanied by fading and excessive static, hence ground wave reception is more reliable.

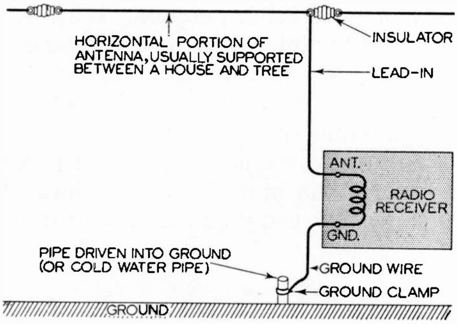


FIG. 22. Simple receiving antenna system, showing complete path from antenna to ground for modulated r.f. currents set up in the antenna by radio waves.

The Receiving Antenna

When a radio wave encounters a receiving antenna after traveling through space, its electric and magnetic lines of force cause the free electrons in the receiving antenna system to vibrate at the frequency of the r.f. carrier. We thus have an alternating current flowing in the receiving antenna system; this is a modulated r.f. current like that in the transmitting antenna, but very weak.

Consider the typical receiving antenna system shown in Fig. 22. When no radio waves are present, the free electrons in the antenna wire wander about between the copper atoms in a haphazard manner. Each of these moving electrons has its own electric and magnetic fields.

When a radio wave arrives, its electric and magnetic field interact with the electric and magnetic fields of the free electrons. The result is that the electrons in the wire are moved back and forth *along the wire* at the frequency at which the radio waves are vibrating. One electron transmits its vibration to the next, so that we have electrons vibrating throughout the entire antenna system, giving a flow of radio frequency current. The complete circuit for this current is from the antenna down to the receiver, through the first coil in the receiver to the receiver ground terminal, and from there through the ground wire to a water pipe or other ground connection.

From an electrical standpoint, a receiving antenna is equivalent to a condenser and coil just as is a transmitting antenna. If the receiving antenna happens to be the correct length for a certain carrier frequency, the radio waves will be exactly tuned in and will produce a strong r.f. current in the antenna. *You will learn later in your course how a variable condenser or a coil can be used to tune a receiving antenna.*

Exact tuning of a receiving antenna is not particularly important in the case of broadcast band reception, for local and near-distant stations today put out sufficiently strong signals for loudspeaker volume with modern high-sensitivity receivers. In the case of all-wave reception, however, the antenna is often made a definite length in order to give maximum pick-up of a particular frequency or group of frequencies.

In commercial radio systems which are intended to receive only messages coming from one station, the receiving

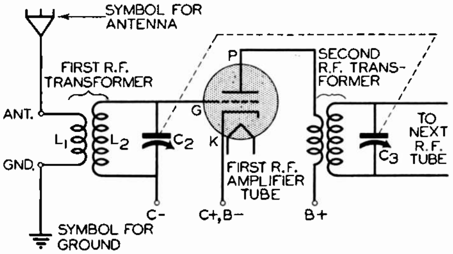


Fig. 23. Simplified circuit diagram showing the antenna system and the first r.f. amplifier stage of a typical tuned radio frequency (t.r.f.) receiver. The dash-dash line connecting the two tuning condensers indicates that they are both controlled by one knob.

antenna is invariably tuned exactly to the frequency of that station, in order to secure the strongest possible signal.

The R. F. Amplifier in a Radio Receiver

Now let us see what happens to the modulated r.f. carrier signal once it enters the radio receiver. We can follow this signal most easily by referring to the circuit diagram in Fig. *23*, which shows the first vacuum tube stage in a typical tuned radio frequency receiver.* Note the use of symbols to represent the antenna and the ground connections; this is very common in radio circuits.

Inside the receiver, we find that the primary winding of the first r.f. transformer is connected directly to the antenna and ground terminals. The modulated r.f. antenna current flows through this coil (L_1), with the result that a corresponding modulated r.f. voltage is induced in secondary coil L_2 of this transformer.

You will observe that variable tuning condenser C_2 is connected across secondary coil L_2. By rotating the movable plates of this condenser, we can vary the electrical capacity of the condenser and thus tune this coil-condenser circuit to a particular desired frequency. This is exactly what you do when you tune a radio receiver to a station.

Why Tuning Circuits Are Needed. Here is why we need a tuning circuit in the first stage of a radio receiver. At any one time, a large number of stations are "on the air," sending out radio waves. Waves from a great many different stations thus act upon any one receiving antenna. We have many different modulated r.f. carrier signals, each with its own carrier frequency and own sound components, in the antenna system of the receiver.

Naturally, we do not want to listen to more than one of these stations at a time. By using one or more tuning

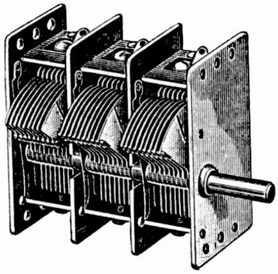


Fig. 24. Three tuning circuits in a radio receiver can be adjusted simultaneously with this three-gang tuning condenser. A knob or dial is placed on the shaft at the right; rotating the knob changes the positions of all three sets of movable plates, for they are all mounted on the common shaft.

circuits, a receiver can be made most responsive to the one desired frequency. This one carrier frequency is then amplified so much in the tuning circuits and vacuum tubes that the programs from the other stations are ordinarily not heard at all. Thus, *tuning circuits are needed to reject the signals of undesired stations.*

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* In this lesson, we are considering only the simplest form of modern radio receiver, known as a *tuned radio frequency* or *t.r.f. receiver*. In later lessons, you will learn about the other popular type of receiver, called the *superheterodyne receiver*.

Tuning circuit L_2-C_2 in Fig. *23* feeds a stepped-up modulated r.f. voltage to the grid and cathode of the first r.f. amplifier tube. As a result, we have in the plate circuit of this tube a stronger modulated r.f. current than originally existed in the antenna system.

One stage of r.f. amplification is ordinarily insufficient, so we feed the signal into additional r.f. amplifier stages, each consisting of a tuned circuit and a vacuum tube. In the old days, each tuned circuit was tuned separately when changing from one station to another, and consequently old receivers had many tuning dials. Modern sets use gang tuning condensers like that shown in Fig. *24;* with these, we can tune several different circuits at once simply by rotating a single knob.

For the present, it is sufficient for you to understand that a tuning circuit accepts and steps up the voltage of a desired radio signal, while tending *to reject undesired signals.* By using a sufficient number of tuned stages, complete rejection of undesired stations can be obtained.

What the Detector Does

Once the modulated r.f. carrier signal has been amplified sufficiently in the r.f. amplifier stages of a tuned r.f. radio receiver, we are ready to *separate the sound signal from the r.f. carrier signal.* A vacuum tube operated in a special manner in a *demodulator or detector* circuit is used for this purpose.

Basically, a detector tube cuts off half of the signal, for it allows current to pass in only one direction. This fact is illustrated in the simplified detector circuit of Fig. *25;* the signal being fed to the detector tube swings in both directions from its center line just like a typical alternating current, while the signal delivered by the detector tube swings only in one direction.

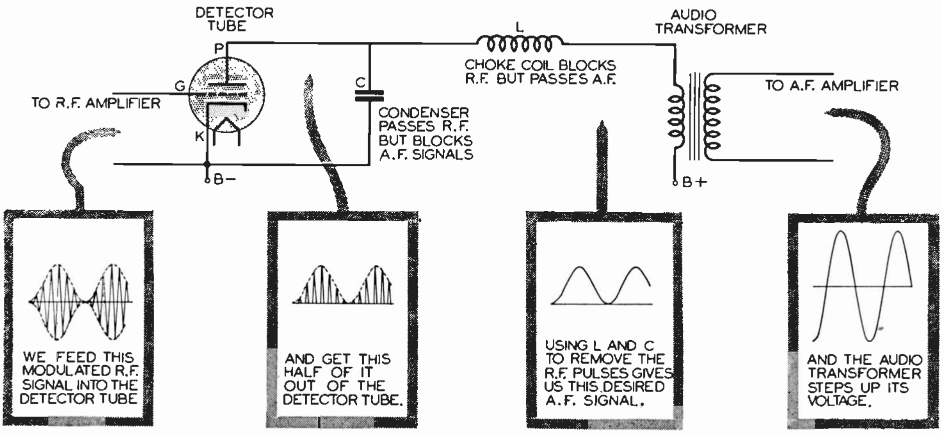


Fig. 25. Simplified detector circuit of a radio receiver, with diagrams showing the nature of the signals at various points in the circuit. Always start at the left when studying a circuit diagram, just as if you were reading a line of print.

Since we want only the sound signal, without the r.f. pulses shown at the detector tube output, we send this signal through a coil and condenser circuit. Condenser *C* in Fig. *25* provides a short-cut path back to the tube for the high-frequency r.f. pulses, but does not pass any of the sound signal. Coil *L* passes the sound signal but chokes back the r.f. pulses. We thus secure from the detector circuit an audio signal like that produced by the microphone. Remember that the purpose of the detector in a receiver is *to separate the sound signal from its r.f. carrier.*

The A. F. Amplifier

The audio output signal of the detector stage in a receiver is strong enough to operate headphones for local-station reception, but is usually too weak for loudspeaker operation. We build up the strength of this audio signal in exactly the same way that we build up the microphone output signal in the transmitter.

The audio signal is first fed through an iron-core transformer known as an *audio transformer,* to secure a certain amount of step-up in voltage. It is then sent into a vacuum tube amplifier stage called the *first a.f. stage.*

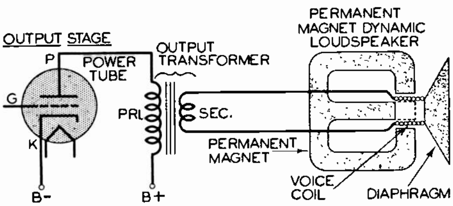


Fig. 26. Here is a simplified version of the very last stage in a radio receiver. It connects the power tube (the last tube in the audio amplifier) to the loudspeaker.

Additional audio amplifier stages, each consisting of an audio transformer and a vacuum tube, can be employed to step up the voltage still more. Finally, the signal is sent into a powerful tube called the *power tube,* which delivers the strong audio frequency current required for operation of a loudspeaker.

The Loudspeaker

In the plate circuit of the power tube we have another iron-core transformer, called the output transformer. The audio output current flowing through the primary winding of this transformer induces in the secondary winding an audio voltage which acts directly on the loudspeaker, for this secondary winding is connected to the loudspeaker terminals. The circuit arrangement for this is shown in Fig. *26.*

Although there are several different types of loudspeakers in common use, we will consider only a type known as a *permanent magnet dynamic loudspeaker.* This consists essentially of three parts, a powerful *permanent magnet,* a paper *diaphragm,* and a *voice coil* which is mounted at the center of the paper diaphragm and located between the poles of the permanent magnet, as indicated at the right in Fig. *26.*

When audio frequency current is sent through the voice coil by the secondary winding of the output transformer, a magnetic field is produced by the coil. This magnetic field reacts with the magnetic field of the permanent magnet, with the result that the coil is pushed either in or out. Since the diaphragm is attached to the coil, the diaphragm moves also.

The movements of the voice coil correspond exactly to the variations in the audio current passing through the coil, and consequently the diaphragm vibrates at audio frequencies and produces sound waves.

The sound as reproduced by the loudspeaker of a radio receiver will be identical with the original sound picked up by the microphone in the broadcasting studio only if no distortion has been introduced along the path of our signal between these two points. One improper adjustment or one defect anywhere along this path can destroy the faithfulness of reproduction of the sound, making repairs necessary.

As a Radiotrician, it would be your duty to maintain the receiver end of this radio broadcasting chain in perfect condition, and as a communications expert you would be intrusted with the care of the transmitter end. The only part of the path which is completely out of the hands of radio men is the space between the transmitting and receiving antennas. Nature produces static interference and causes fading by changing the heights of the ionized reflecting layers in the sky from time to time, but radio engineers are designing equipment which at least partly offsets these interfering effects.

Controlling the Volume

Maximum possible loudness or volume from the loudspeaker of a radio receiver is seldom desirable. For this reason, a device known as a *volume control* is used in every radio receiver. This device is usually a sort of voltage divider which makes it possible to reduce the a.f. voltage to any desired lower value. Another type of volume control serves to vary the amount of amplification which one of the r.f. amplifier tubes produces.

A. C. Power Pack and On-Off Switch

The modern tuned r.f. receiver, such as we are considering in this lesson, obtains its power from the a.c. power line in the home. A special section in the receiver, known as the *power pack,* is provided to change the a.c. line voltage into the various a.c. and d.c. voltages required by the tubes in the receiver. Thus, the filaments of the tubes will receive the correct a.c. voltages from the power pack, while the various tube electrodes will receive d.c. voltages.

A special type of vacuum tube, known as a *rectifier,* is employed in the power pack to convert the a.c. line voltage into a pulsating d.c. voltage.* This pulsating voltage is smoothed out by a coil-and-condenser circuit known as a *filter,* and is then divided into the required d.c. voltages by a resistor arrangement known as a *voltage divider.*

A receiver can be turned off simply by interrupting the source of power. This is done by placing a switch in one of the leads of the receiver power cord; when this switch is open, the receiver gets no power and consequently does not operate.

You undoubtedly know that receivers are also made to operate from other types of power. All of these, including portable battery-operated receivers, universal a.c.-d.c. receivers, auto radio receivers, etc., will be taken up later in your course. You will find that these receivers have essentially the same signal circuits, and differ only in the type of power pack used to provide the voltages required by the vacuum tubes.

A Review

A brief review of the process of sending and receiving a radio broadcast will tie together in your mind the various steps involved in sending a sound radio program from the studio to your home.

Starting at the studio, the performers produce sound waves. These are picked up by the microphone and converted into an audio signal having the same characteristics as the sound waves. This audio signal travels through the microphone cable to the control room, where it is amplified many times by vacuum tube amplifier stages consisting of iron-core transformers and vacuum tubes.

The amplified audio signal is then fed over telephone lines to the transmitter proper, which may be many miles from the control room and studio. The audio signal undergoes additional amplification at the transmitter before it is fed into the modulator stage of the transmitter. This modulator stage feeds a strong audio signal into the modulated stage. A radio frequency carrier voltage, produced by a crystal oscillator and amplified by various r.f. amplifier stages, is also fed into the modulated stage.

The modulated r.f. output signal of the modulated stage is amplified

* A voltage which rises and falls but its polarity does not change.

further by r.f. amplifier stages, and the resulting strong modulated r.f. carrier signal is then fed to the transmitting antenna. The electrons vibrating in the transmitting antenna under the influence of this modulated r.f. carrier current produce vibrating electric and magnetic fields which travel out through space as radio waves.

At a receiver location, the free electrons in the receiving antenna wire vibrate at the frequency of the radio waves. The result is a very weak modulated r.f. carrier current in the receiving antenna. This is amplified thousands of times by the r.f. amplifier stages in the receiver, after which the signal is sent into the detector.

The detector stage separates the sound signal from its r.f. carrier, and feeds only the audio or sound signal into the audio amplifier. The audio amplifier in turn delivers a strong audio frequency current to the loudspeaker; this current causes the loudspeaker diaphragm to push and pull against the surrounding air, creating sound waves which are a true reproduction of the sound produced by the performers in the broadcasting studio.

How Television Programs Are Sent From the Studio to Homes

In a television system, we use a *television camera* at the transmitter to convert the scene into a corresponding electrical signal, and we use a special *picture-reproducing tube* in the receiver to convert this electrical signal back into the original scene. These are the only important parts of a television system which are basically different from the parts employed in a radio system. Consequently, you can get a good idea of how a television system works by studying briefly the operation of the television camera, then considering the television receiver and its picture-reproducing tube.

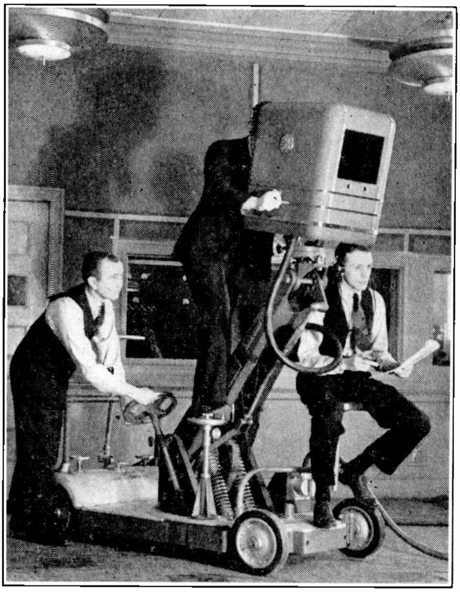
The Television Camera

A television camera, which converts a scene into an electrical signal, is essentially a large box which is mounted on a moving truck or tripod somewhat as shown in Fig. 27, so that it can be swung in all directions to follow the action of a program. The special cathode ray tube employed in this camera is usually called an *iconoscope.*

At one end of the camera housing is a lens system which focuses the televised scene upon a flat plate mounted inside the iconoscope. This flat plate is in the form of a mica sheet on which are deposited millions of tiny drops of silver. The surface of each silver drop has been chemically treated so that it is sensitive to light.

When an image is focused upon the light-sensitive plate of an iconoscope, some drops will have bright portions of the scene, and others will have dark portions. Each drop acquires an electrical charge *depending upon the amount of light falling on it.* As a result, we have the lights and shadows of the televised scene transformed into corresponding electrical charges on the light-sensitive plate in the iconoscope tube.

Unfortunately, there is no simple scheme whereby we can transmit these millions of different electrical charges over a radio system simultaneously. In a practical system, we can transmit only one charge at a time. Naturally, the charges must be removed and transmitted in a definite order, and must be reassembled in that same order at the receiver during the process of reconstructing the televised scene.



Courtesy General Electric Co.

FIG. 27. General Electric television camera mounted on a dolly (small truck), being used in the G. E. television studio in Schenectady, N. Y. The camera mounting is raised or lowered by the man at the left. The camera is kept in focus and aimed at the scene by the operator directly behind the camera. At the right is the television program director.

The individual charges are removed from the light-sensitive plate of an iconoscope by means of an electron beam which sweeps across this plate (scans the plate) in much the same way as your eye goes along one line and back to the start of the next line when reading a page of this lesson. The result is a varying electrical signal at the iconoscope output terminals.

A modern television system employs a 441-line image, scanned completely thirty times each second. This means that the electron beam in the iconoscope touches each of the light-sensitive drops of silver once while sweeping over 441 fine parallel horizontal lines from left to right, just as if you were reading a page having 441 lines of type. (Actually, the electron beam skips every other line the first time it goes from the top to the bottom of the projected image, then covers only the skipped lines the second time it moves down on the image; this is called *interlaced scanning.*)

The essential features of a typical television camera are shown in Fig. *28*. The electron beam is produced by the electron gun located in the long, narrow neck of the iconoscope tube. This gun has an electron-emitting cathode heated by a filament, just like an ordinary radio tube. Cylindrical electrodes in front of this cathode speed up the emitted electrons and focus them into a narrow beam. A photograph of an iconoscope is reproduced in Fig. *29*.

A highly important part of a television camera is the *synchronizing signal generator.* It produces the synchronizing (timing) signals which make the television camera and the image-reproducing tubes in television receivers keep in step. The synchronizing signal currents are sent through deflecting coils which surround the neck of the iconoscope in the television camera, and the resulting magnetic fields make the electron beam sweep back and forth across the light-sensitive plate in the desired manner.

Since a television broadcast is always accompanied by sound, a microphone must be placed near the performers in the television studio, but out of range of the television camera. Usually the microphone is placed over-

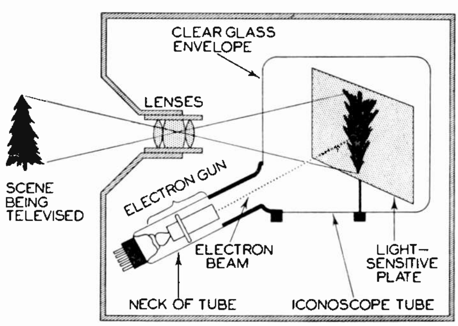
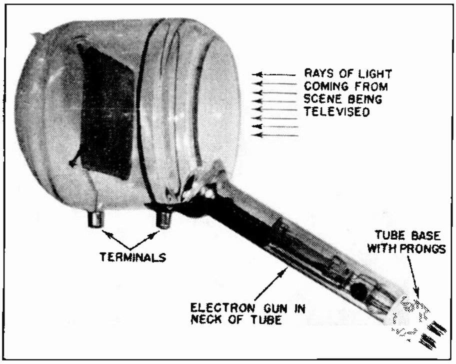


FIG. 28. Simplified cross-section diagram showing the essential features of a modern television camera. Focusing is accomplished by sliding the lens unit in or out, just as in an ordinary camera. The deflecting coils which surround the neck of the tube are not shown in this diagram.

head, somewhat as shown in the simple diagram in Fig. *30.* *A separate sound broadcasting transmitter is used* in transmitting the sound portion of a television program. The audio signal is amplified in the control room and sent over a telephone line to the sound transmitter, where it is placed on an r.f. carrier and fed to the sound transmitting antenna.

From the output terminals of the television camera, the picture signal passes to the picture amplifier in the control room, then travels over a spe-



Courtesy RCA Mfg. Co., Inc.

FIG. 29. Standard RCA iconoscope tube for use in television cameras. Note the rectangular light-sensitive plate supported in the large cylindrical part of the glass envelope.

cial *coaxial cable* (a wire mounted inside a length of copper tubing which serves as the other wire) to the picture transmitter. Here it is combined with the various synchronizing impulses required by the receiver, then combined with an r.f. carrier signal so that it will be radiated through space when fed to the picture transmitting antenna. Usually the sound and picture transmitting antennas are located fairly close together, at the top of some high building such as a New York skyscraper.

The Television Receiver

A single *receiving antenna* is used to pick up the two radio waves which are traveling through space in a television system. The television receiving antenna feeds both modulated carrier signals into an *r.f. amplifier* which boosts their strength and at the same time rejects undesired signals which may be present in the antenna.

Next, the sound carrier is separated from the picture carrier by a *signal separator* circuit, as indicated in Fig. *30.* The sound carrier passes through another *amplifier* into a conventional *detector stage for sound,* and the a.f. output signal of the detector is fed through a conventional *audio amplifier* to a loudspeaker.

The picture carrier signal travels through a *picture carrier amplifier* into a *detector stage for the picture signal.* The picture signal proper then passes through a *picture amplifier* to the *picture-reproducing tube.* The synchronizing signals which have accompanied the picture signal go through separate circuits (not shown in Fig. *30*) and eventually control the movements of the electron beam so as to recreate the televised scene on the screen of the picture-reproducing tube.

Since radio waves travel through space at a speed of 186,000 miles per second, one complete television scene can be sent from the studio to the receiver in considerably less than a thousandth of a second. In other words, a television receiver shows just about what you would see if you were in the studio—there is essentially no delay in time.

A photograph showing two sizes of picture-reproducing tubes (often called *kinescopes*) appears in Fig. *31.* The electron gun in each of these tubes is essentially the same as the electron gun employed in the iconoscope tube in the television camera. The picture signal output of the picture amplifier is applied to one grid in the electron gun, making the number of electrons in the beam vary exactly in accordance with the variations in the picture

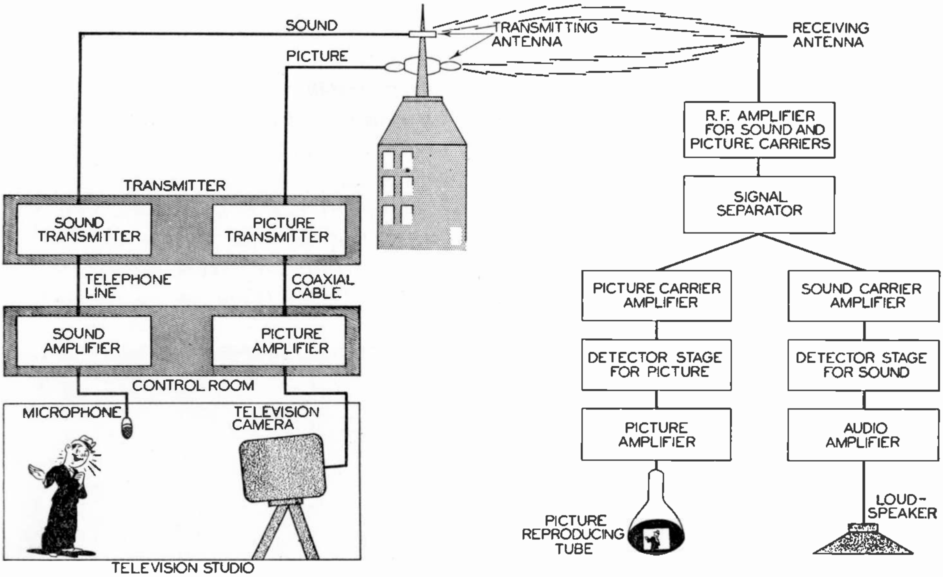


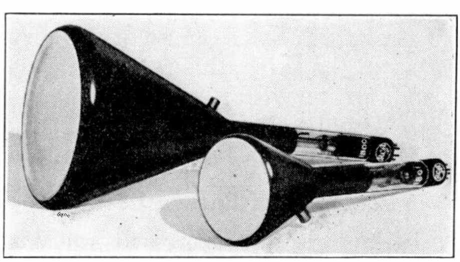
Fig. 30. Block diagram of a complete television system which can bring sounds and scenes from a studio to a home. Note that a separate sound broadcasting transmitter is used for transmitting the sound portion of the television program.

signal. In other words, when the electron beam in the camera tube is scanning a bright portion of the scene, the electron beam in the kinescope will have a maximum number of electrons.

The more electrons in the beam of a kinescope, the brighter is the spot appearing on the screen at the curved end of the funnel-shaped glass tube. This screen becomes fluorescent (glows) when hit by electrons, for the energy of impact sets into vibration the electrons in the chemical coating, making them give off light.

While the picture signal is making the electron beam vary in strength in accordance with what the camera tube sees, the synchronizing system in the receiver is sending through the deflecting coils of the kinescope (coils surrounding the neck of the tube) the proper currents to make the electron beam sweep back and forth so as to reproduce the original scene on the screen of the television receiver.

You may wonder how it is possible to take a picture completely apart in a television system, then put it together again *one element at a time* and get what appears as a complete scene to our eyes. The answer is simply that the human eye automatically remembers, for a certain length of time, anything which it sees. This characteristic of the eye is known as *persistence of vision.* Furthermore, the fluorescent screen in a picture-reproducing tube glows for a short time after the electron beam has passed. Thus, the eye sees a complete



Courtesy RCA Mfg. Co., Inc.

Fig. 31. Two sizes of television cathode ray tubes for television receivers. The scene being televised appears on the white coating (the screen) which is on the inside surface of the curved large end of the tube.

picture even though the electron beam is hitting only one spot on the screen at any one instant.

A typical modern television receiver in a home is pictured in Fig. 32, with the screen clearly visible on the front panel.

In television we depend exclusively upon ground waves for reception. Furthermore, at the carrier frequencies employed in modern television systems, radio waves travel essentially in straight lines. Because of the curvature of the earth, this means that dependable television reception cannot ordinarily be obtained outside a radius of about fifty miles from a transmitter.

Courtesy Allen B. DuMont Laboratories, Inc.

FIG. 32. We end the second lesson in your course with this view of a modern television receiver in a typical American home. This is a DuMont set, using a 14-inch diameter picture-reproducing tube.

Previews of Future Lessons

In later lessons, you will study in detail the subjects which could be covered only briefly in this general picture of sound and television broadcasting systems. Complete lessons will be devoted to individual subjects such as radio tubes, condensers, coils, transformers, etc., with emphasis on the information really needed to prepare you for a successful career in the radio profession.

Thus, in the next lesson, you will study the various types of voltage sources used in radio receivers and transmitters. This is an important lesson, for as a Radiotrician you will be working with these voltage sources every day. You will also study briefly a number of the more unusual ways of producing electricity, such as from the sun (photovoltaic cell), by heat (thermoelectric generator), and by rubbing two materials together (friction generator). I am sure you will find this next lesson one of the most interesting in your entire course.

TEST QUESTIONS

Be sure to number your Answer Sheet 2FR-4.

Place your Student Number on every Answer Sheet.

Important Notice: *Send in your answers for this lesson immediately after you finish them.* Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. What is the approximate *range* of frequencies (the lowest and highest) which can be heard by the human ear?

2. What is the important purpose of a microphone?

3. When the voice coil of a dynamic microphone is moved in and out by sound waves, what is generated in the coil?

4. What name is given to the important electrode which *emits* electrons in a vacuum tube?

5. What name is given to the important electrode which *attracts* electrons in a vacuum tube?

6. Give the radio terms corresponding to the following abbreviations: (1) d.c.; (2) kc.; (3) mc.; (4) r.f.; (5) a.f.

7. Why are tuning circuits needed in a radio receiver?

8. What is the purpose of the detector in a receiver?

9. What part in a television system converts a scene into an electrical signal?

10. Is a separate transmitter employed for transmitting the sound portion of a television program?

HOW ELECTRICITY IS GENERATED FOR USE IN RADIO SYSTEMS

3FR-1

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

DO EVERYTHING WELL

In this lesson we settle down to an investigation of that all-important foundation of radio—a knowledge of electricity. You will learn what it is, how it is produced, and how it behaves under different conditions.

Naturally this lesson is going to be a little bit more technical than those already studied—but you expect this. Always remember that I am giving you information which you will need to become a success in radio—up-to-date data together with those fundamentals which will prepare you to tackle any radio job that may come your way.

Now roll up your sleeves—get to work—develop those hidden powers of concentration. Study hard, rest hard, play hard—do each little thing the best you possibly can—and you will build for yourself a firm foundation for success.

J. E. SMITH.

If you have built castles in the air, your work need not be lost; that is where they should be. Now put the foundations under them.—Thoreau.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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How Electricity is Generated for Use in Radio Systems

ELECTRICITY—A REVIEW

WHAT do I mean when I talk about *electricity?* In the light of modern scientific investigations I find it convenient to think of *electricity as the force associated with electrons and protons,* those two elemental particles (negatively and positively charged) which make up all matter. In the field of radio only movements of the simplest negatively charged particle, the electron, are generally of importance.

Although scientists say that electrons are continually moving about in *any body,* these electrons may be considered *ineffective,* as far as

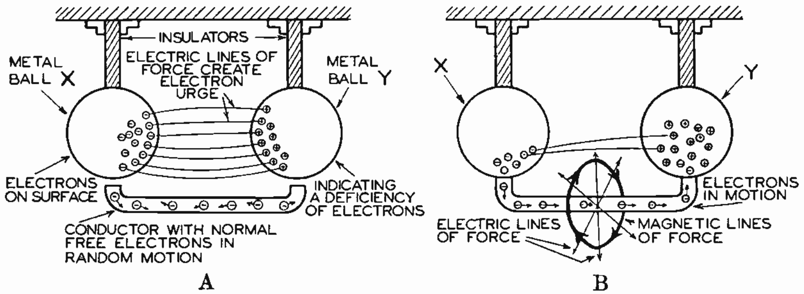


FIG. 1. Before electrons can become "tourists," they must have two things—a conducting path, which can be a wire, and a driving force which gives them an urge to "go places."

external effects are concerned, when there are just as many positive charges in the body as there are electrons (negative charges). Under this condition the body is *neutral.* When we say that a body is neutral, we mean that it is *neither positively charged nor negatively charged.*

Suppose that two metal balls are insulated from each other and from other objects in the manner shown in Fig. *1A,* and extra electrons are pumped out of one ball and into the other by some electrical device, giving to ball X a negative charge and to ball Y a positive charge. Naturally the extra electrons in ball X will want to get back to ball Y, which now has a shortage of electrons, but electrons cannot ordinarily travel through air. There is an urge to move, but no motion—electricity is at rest.

When these two charged balls are connected together by a wire, as in Fig. *1B*, an electrical path or conductor is provided, along which electrons will move from the negative to the positive ball. These electrons in motion produce *moving electric and magnetic lines of force,* effects which are of extreme importance in radio systems.

Bodies *X* and *Y* in Fig. *1* really represent an electron "pump," for they can send electrons through a wire; if ball *X* could be kept supplied with more negative charges than are on ball *Y*, electrons would flow continually through the wire, and we might call the combination of charged metal balls an *electron generator.* In the first case (Fig. *1A*), after the extra electrons were placed on ball *X*, the electricity was at rest but had the urge to move; in the second case (Fig. *1B*) the urge was changed into action, resulting in a flow of electrons.

CHARACTERISTICS OF AN ELECTRICAL GENERATOR

For the present let us consider an electrical generator as simply a box containing something inside which makes one terminal *negative* (gives it a continual surplus of electrons), and makes the other terminal *neutral* or *positive* (Fig. *2*). The electrons at the negative terminal have an urge to go places—to reach the positive terminal, this urge existing even after a path is provided between the terminals, if the negative terminal is receiving a continuous supply of electrons.

This *electron urge* at the generator terminals is called an *electromotive force,* a very appropriate term for *electron-motivating* force, and meaning *force which makes electricity move;* it is often abbreviated to *e.m.f.* Other names for this urge are *voltage* and *potential;* a more correct term, used by many, is *potential difference** between the two terminals. But all these names mean the same thing—that the electrical generator is capable of "forcing" electrons out of its negative terminal, through an external circuit, to its positive terminal.

HOW IS ELECTRICITY MEASURED?

What do I mean when I say that the voltage of an electrical generator is 22½ volts? Of course you know that this rating has something to do with the strength of the electron urge. But *how much* is

* To the scientist *potential* means available energy or work. The negative ball does work when it "pushes" electrons through the conductor, and the positive ball is working when it attracts or "pulls" electrons through the conductor. Suppose that ball *X* had a strong *negative* charge and ball *Y* a weak *negative* charge; ball *X* would push electrons through the conductor, but ball *Y* would push a few of them back; wouldn't the work done, or the potential difference, be the difference between the amount of work done by each? These two examples show that the potential difference between any two bodies depends upon the work which those bodies can do *together;* if the bodies have unlike charges, the potential difference will be the sum of the potentials of each.

a volt—a practical, every-day volt? To answer this I am going to "put the cart before the horse," and discuss electron *current* first.

Practical Unit of Electron Flow. To measure the electron flow through a wire, we send these electrons through a measuring device called an ammeter. *The standard practical unit of electron flow is called the ampere;* an ammeter tells how many amperes of electrons are moving. Actually, 6,300,000,000,000,000,000 (6.3 million million million) electrons must flow past a given point in the circuit each second to produce an electron flow or electron current of *one ampere.* When you consider that your automobile generator delivers from 10 to 20 amperes, you can realize just how small an electron is, and how inconvenient it would be to specify the flow of electricity in terms of the number of electrons moving past a point each second. This is why we use the *ampere* as the standard practical unit of electron flow.

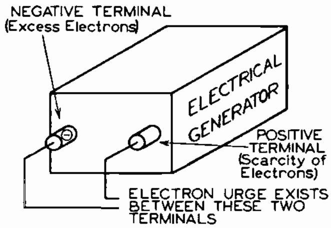


Fig. 2. Imagine an electrical generator to be like this, no matter what is inside.

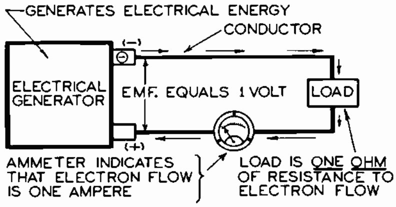


Fig. 3. This "picture" is a definition: One volt will send one standard practical unit of electron flow, called *one ampere,* through a resistance of one ohm.

Unit of Resistance. All conductors offer some resistance to the flow of electrons. In order to predict the electron current through a circuit under certain conditions it is necessary to have a practical unit which represents a definite amount of resistance to electron flow. Scientists have selected as their standard the resistance presented to electricity by a certain carefully constructed glass tube filled with mercury, and have called this unit *one ohm.*

Unit of E. M. F. From the first two units, ampere and ohm, comes the *volt,* a unit of electromotive force. I always like to give this *practical* definition of a volt: If we connect a conductor (an electron path) having a resistance of one ohm to the terminals of an electrical generator in the manner shown in Fig. *3,* and our current meter (ammeter) shows a reading of one ampere, the electrical generator has a voltage, an electron urge, an e.m.f., or a potential difference, whichever you prefer to call it, of *one volt.*

ELECTRON FLOW AND CURRENT

Observe carefully that in Fig. *3* electrons are flowing from the (—) to the (+) terminals of the generator. Isn't this just what you would expect, when you consider that the (—) terminal has an excess of free electrons, while the (+) terminal has only a normal or below normal number? Of course!

Many years ago, long before the existence of the electron and the proton was known, scientists asked: "In what direction does electricity flow through a wire?" These men already knew about electrical generators, electromotive force, volts, amperes and ohms—they knew that electricity was in some way a movement of two kinds of electric charges, one of which they called *positive*, the other *negative*. Their experiments indicated that electric lines of force were associated with these charges, and that movements of electric lines of force created magnetic lines of force. Now here is where these "old-timers" made their mistake—*they insisted that the electricity which moves in a conductor was a movement of positive charges.* All their laws of electricity were made with this in mind; for example, when a compass indicated the direction shown in Fig. *4A* for the magnetic field about a certain wire, they insisted electricity was flowing to the left through the wire, or that *current* flow was to the left.

Today scientists know that a flow of electricity through a wire is really a flow of negative charges—a flow of *electrons*, and that positive charges are flowing only in a few special cases.* But look at Fig. *4* again—what difference does it really make whether I say *current* flows through the wire to the left (Fig. *4A*) or electrons flow to the right (Fig. *4B*), when the observable effect, the magnetic field, is the same in each case?

If electron flow and current flow produce the same effects, why is it so important that you know the difference between the two terms? Radio is the reason! The radio engineer speaks in terms of electron flow because he can more easily determine the directions which *electrons* take inside a vacuum tube (often called an electron tube); he then uses these vacuum tubes as guide posts in tracing electron flow through other parts of his circuits. In other words, it is *more convenient* to

* In certain vacuum tubes containing gases at low pressure (neon signs or mercury vapor rectifiers are examples), and in chemical solutions used for electroplating purposes positive charges, consisting of atoms which have lost some of their free electrons, are also flowing. In these tubes and solutions electrons and positive charges will often be moving at the same time, in opposite directions; their magnetic fields, being in the same direction, add together. You will learn more about this in later lessons.

specify electron flow than current flow when dealing with radio apparatus containing vacuum tubes.

You will often encounter meters (electrical measuring instruments) and electrical equipment having only the (+) terminal marked, for the old meter connection rule was: *Current* (positive charges) must flow *into* the (+) terminal of the meter, and out of the (—) terminal, which naturally is the other terminal. This rule still holds true; use it whenever you like, provided you know the direction of current flow.

As I said before, Radiotricians almost always use the true direction of flow of electricity—that of electrons. You know that electron flow is opposite in direction to the old idea, current flow—this, then, is the new meter connection rule which you will use: *Electrons must flow out of the positive terminal and into the negative terminal of a meter.* On some meters the positive terminal is marked (+); on others it is marked PLUS, POSITIVE, or POS.

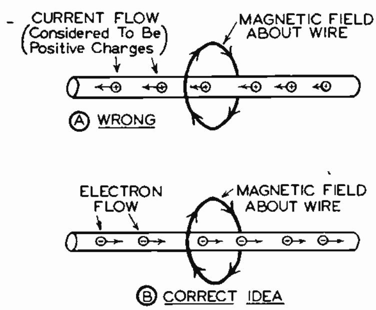


FIG. 4. Showing that moving positive and negative charges produce the same magnetic effect when they move in opposite directions. The old idea of current flow through a wire, illustrated at *A* above, is now known to be wrong.

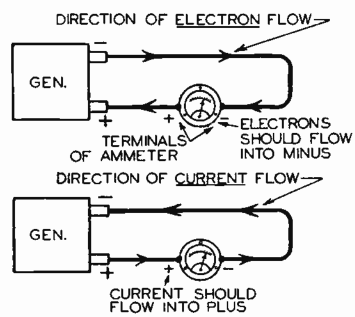


FIG. 5. Meters must be connected the same way regardless of whether you consider electron flow or current flow. On any direct current meter, one terminal is always marked (+); the other, whether marked or not, is (—).

I strongly advise you to memorize this rule now—for you will use it dozens of times a day in your work as a Radiotrician. And here is the nice part—once you know this short rule, and you remember that electron flow is always opposite in direction to the old idea of current flow, you will be able to connect *any* meter correctly.

Although Radiotricians prefer to deal with electron flow, it really doesn't matter whether you pick electron or current flow, *provided you choose one and stick to it for any one circuit.*

With all these facts in mind, I am going to set down a few simple rules which will always hold true.

1. The term *electron flow* means a flow of *electrons*, and nothing else.
2. The term *current,* used without specifying a direction, simply means *electricity in motion.* This is a general term and is commonly used when the direction of flow of electricity is not important.
3. The term *current,* used with a direction of flow, implies a flow of *positive electrical charges.* This term, even though incorrect, is used extensively by electrical engineers when they are speaking of a flow of electricity through a wire. Current flow (the old idea) is opposite in direction to electron flow.
4. In any circuit connected to the terminals of an electrical generator, electrons flow *from* the *negative* terminal of the generator through the wires and load *to the positive terminal* of the generator.
5. Meters should be connected so that electrons flow *out of the positive terminal* and into the negative terminal of the meter (Upper diagram in Fig. 5). (You know now that this is the same as saying *"current* should flow *into the positive* terminal of a meter," as is shown in the lower diagram in Fig. 5.)
6. Electrons always flow from cathode (or filament) to plate in a vacuum tube.

HOW ELECTROMOTIVE FORCES VARY

Now that I have cleared up the difference between electron flow and current flow, let me go back to electrical generators again. In Fig. *6* is a more general picture of a generator sending a current through some radio or electrical device, which I will simply call a "load."

I have assumed up to now that the e.m.f. of this generator was constant; actually there are many different types of generators, which can deliver to the negative terminal a supply of electrons in one of these three conditions:

1. Constant, with terminal *a* in Fig. *6* always having the same potential difference with respect to terminal *b;* that is, terminal *a* always having more electrons than terminal *b*, the difference being constant.
2. Continually increasing and decreasing in number, but with terminal *a* always having more electrons than terminal *b*.
3. Varying greatly in number but with terminal *a* sometimes having more, sometimes less electrons than terminal *b*.

The difference in the number of electrons at terminal *a,* as I have already shown, is caused by the e.m.f. of the generator. This e.m.f.

or generated voltage, existing between the generator terminals, is indicated as E* in Fig. *6*.

To get a better picture of just how E is changing with time for each type of generator, I will make use of simple diagrams which are called graphs.† To show what E is at any instant of time, I lay off on line OX in Fig. *7A* equal distances, each of which represents one unit of time, such as one second, on this horizontal or time axis. Next I mark off equal units of voltage on the line OY, working upward from O, and let the distance from O to any point on this *vertical* or voltage axis represent the e.m.f. of terminal b in Fig. *6* with respect to terminal a. Now I mark on the graph with a heavy dot the generator voltage at each unit of time, and draw a smooth straight or curved line through all of the dots.

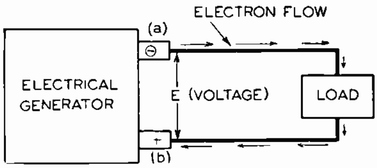


FIG. **6.** E is a commonly used symbol for e.m.f. or voltage difference; here it represents the potential of terminal b with respect to a. The positive terminal (b in this case) is said to be at a high potential.

When an engineer plots voltage against time in this way for a generator whose voltage is not varying, he obtains a horizontal line like that in Fig. *7A*. This represents *a continuous direct voltage;* sometimes it is called a *direct current voltage,* because it produces a constant current flowing in only one direction. This last phrase is commonly abbreviated to *D.C. voltage.*

Figure *7B* shows the kind of graph obtained when the voltage is varying continually to make terminal a and terminal b alternately positive. Note that the variation in voltage is gradual and harmonious, the pattern repeating itself regularly; this is an alternating voltage or an *alternating current voltage,* abbreviated *A.C. voltage,* and is the type of voltage supplied by the A.C. generator to most of the electri-

* V, the symbol for voltage, is often used in place of E, the symbol for e.m.f. Voltage, potential difference, or e.m.f is always measured between two points, or between one point and the ground. You must always have a reference point in mind when you say "this is the 90 volt terminal"; in radio this reference point is usually the grounded chassis or the cathode of a tube. When you specify which terminal of a generator is positive, you are giving the *polarity* of the generator.

† Graphs and charts are taken up in reference book 2X, "The Language of Radiotricians," which you now have. Refer to it.

cally lighted homes in this country. Each complete variation in voltage is called a cycle (a cycle of events), and the time required for one complete cycle or complete change is called a *period*. The *number* of *cycles* through which the voltage passes *in one second* is the *frequency*. This *A.C.* voltage varies according to a simple mathematical expression, a *sine* variation, and is therefore called a sine variation. Although not in any sense a wave, the close resemblance to one resulted in the term *sine wave* for the graph of an A.C. voltage which is given in Fig. *7B*.

When one terminal of a direct current generator (*b* in this example) is always positive but the voltage is varying in a simple manner such as the sine variation of Fig. *7B*, we obtain a voltage graph like that in Fig. *7C*, which is very common in radio and is a *pulsating D.C. voltage*. If you were to add the D.C. voltage shown in Fig. *7D* to the A.C. voltage shown in Fig. *7E*, you would obtain the pulsating current shown in Fig. *7C*. The voltage in Fig. *7C* may be easily separated into these two components by radio parts; for instance, you will soon learn that a condenser will pass the A.C. voltage but hold back the D.C. voltage.

Up to this time I have discussed only the nature of the generated voltage—but what happens to the current when the varying e.m.f. is forcing electrons through some device? That question is easy to answer—just remember that the generator voltage determines the number of electrons pumped out to a given terminal at any instant. When the voltage varies, the electron flow will vary correspondingly. The curves in Fig. 7 can therefore represent voltage, electron flow or current, depending upon whether you make the vertical axis represent volts or amperes.

Reversing the Polarity. When the voltage of a generator reverses its polarity, the direction of electron flow in the circuit *will reverse also*. This is entirely logical, for the generator or source pushes the electons in the opposite direction through the circuit when polarity is reversed.

SECRETS OF ENERGY

When an electrical generator pumps electrons through a connected electrical load, these electrons have to be pushed to get through the resistance of the load; in doing this the generator releases energy. The rate at which energy is being supplied to the load is called *power;* isn't an electrical generator, then, a device that will deliver power? When I say a man is powerful, I mean he can do more work in a given time than some other man; likewise, a generator delivering high power will do more work per second than a low power generator.

You are already familiar with the word "work"—energy is just a little broader term, including work, everything which is done by work and everything which can be changed into work. Energy exists in many forms, some more useful than others, and can be changed from one form to another, but this statement always holds true: *Energy can neither be created nor destroyed.*

Going back to an electrical generator, you know that it can deliver energy; therefore it must first be supplied with energy. I will now take up the different ways in which generators convert the supplied energy into the various forms of delivered electrical energy.

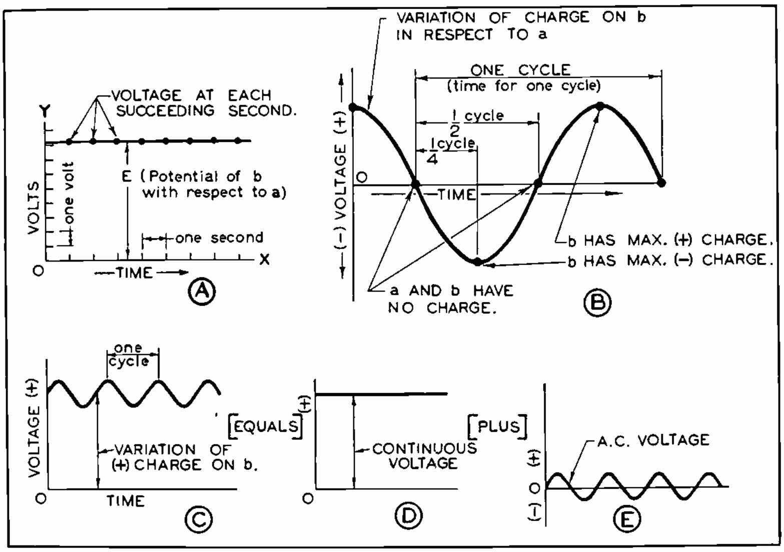


FIG. 7. Shown here are three basic voltage characteristics which generators can have: *A*, continuous; *B*, alternating; *C*, pulsating. Note that the third type (*C*) is made up of the first two types, a continuous voltage (*D*) and an A.C. voltage (*E*). In later lessons, you will learn more about these graph pictures of invisible electricity.

BATTERIES STORE CHEMICAL ENERGY

You already know what batteries are—know that they are used to ring doorbells, to operate flashlights, to start automobiles and to do hundreds of other jobs. In the radio field batteries are used extensively in laboratories, at the work-bench, and to supply power to radio equipment on farms, in autos, airplanes, ships and other locations where a socket power system is not practical.

A battery is a group of individual electric cells connected together to deliver more power than could a single cell. A *group* of cannon is called a battery, but you know that a *single* cannon is not called a battery; likewise a single electrical cell cannot be called an electrical battery. Keep this distinction between a battery and a cell clearly in mind.

There are two distinctly different types of electrical cells, *primary* cells and *secondary* cells; electricity is produced by chemical action in each. In a primary cell the material used in the construction is consumed, as electrical energy is delivered; when the supply of this material is exhausted the useful life of the cell is ended. The materials in a secondary cell simply change from one form to another as electrical energy is delivered; a secondary cell can be restored to its original condition by an electrical charging process, in which electricity from some source is pumped back into the cell, restoring the original condition of the material in the cell. A secondary cell can therefore be used over and over again by recharging, whereas the life of a primary cell, which cannot be recharged, is limited.

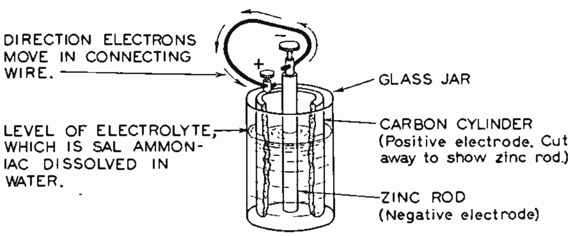


FIG. **8**. This diagram shows the construction of a Leclanché cell. The modern dry cell operates on much the same principle.

PRIMARY CELLS*

The Wet Cell. Let us consider first one of the simplest primary cells, the Leclanché wet cell, shown in Fig. *8*. The three necessary parts of this cell are the negative electrode (a zinc rod) and the positive electrode (a carbon cylinder or rod), immersed in a solution of sal-ammoniac and water.

To explain just how electrons are "pumped out" to the negative electrode I must first discuss molecules and atoms, particles of matter with which you are already familiar. I will shorten this explanation by using the language of chemists, a system of abbreviations which is quite easy to understand.

Sal-ammoniac is another name for ammonium chloride, a common chemical which chemists abbreviate as NH_4Cl; N represents one atom of nitrogen, H_4 represents four atoms of hydrogen and Cl represents one atom of chlorine. The chemist's abbreviation for zinc is Zn. The carbon electrode, though important, plays a rather inactive chemical part.

Some very interesting chemical reactions take place inside a Leclanché cell. First of all, the NH_4Cl molecules, being dissolved in water, are each broken

*You will find that some material in this lesson appears in a smaller type; this is advanced material, which I have included here because many students in the past sent me special letters asking for exactly this information. If you do not understand all of the statements now, review them after you have mastered more of the lessons in this Course.

into an ammonium ion NH_4, and a chlorine ion, Cl, the Cl taking the one free electron which previously held NH_4 and Cl together. Chemists indicate this fact as NH_4^+ and Cl^-, the NH_4^+ ion being positive and the Cl^- ion negative.

The zinc electrode has a peculiar attraction for these negatively charged chlorine ions; drifting through the electrolyte two by two, each pair eventually reaches the zinc, "bites off" one zinc atom and combines with it to make one molecule of zinc chloride ($ZnCl_2$). In order to combine in this way, two negative charges (two electrons) must be left on the zinc.

If the zinc (negative) terminal of the cell is now connected to the carbon terminal by a wire, electrons will flow through this wire to the carbon, where they will attract the positive NH_4^+ ions which have been left in the electrolyte. Arriving at the carbon, an NH_4^+ ion loses one hydrogen atom with a

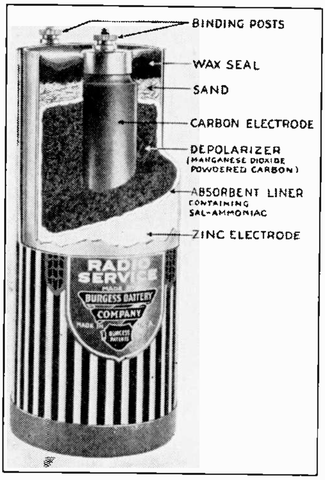


FIG. 9. Cut-away view showing construction of a dry cell.

FIG. 10. Cut-away view showing construction of a 45-volt B battery.

positive charge ($H+$), this hydrogen ion combining with one of the electrons on the carbon to make an atom of hydrogen gas. The remaining NH_3 molecule, known as ammonia, remains in solution.

Just one thing prevents this simple action from continuing over and over again—the hydrogen gas which is released forms little bubbles which adhere to the carbon. This gas being an insulator, the electrical action of the cell stops as soon as the carbon electrode is completely covered by the gas. Chemists and battery service men now say that the cell is *polarized*.

You can readily see that in order to get continuous action from a Leclanché cell the hydrogen gas must be removed as fast as it forms. Battery makers do this by mixing manganese dioxide (MnO_2) with the carbon of the positive electrode. The oxygen in this chemical combines with the hydrogen ion to make water, which stays in the solution. With polarization troubles eliminated, the cell will now continue to operate until the water weakens the solution, or until the zinc electrode is "eaten" away.

Although I do not expect you to master this chemical process, I do want you to have a general knowledge of the operation of a wet cell.

Remember that the chemical action of the electrolyte on the zinc electrode leaves free electrons which make that terminal more negative than the other. Thus there is a constant supply of electrons, making the cell an electrical generator—a source of e.m.f. The Leclanché wet cell will deliver about 1.5 volts when new, but its current capacity (its ability to deliver a large current) is limited by the rate at which the depolarizer can get rid of the hydrogen.

The Dry Cell. The modern dry cell, often called "electricity in package form," is really an improved Leclanché cell, and hence delivers the same voltage of 1.5 volts when new. The electrodes are carbon and zinc; the electrolyte is in paste form and is so protected by the zinc container that it cannot dry out, but the chemical

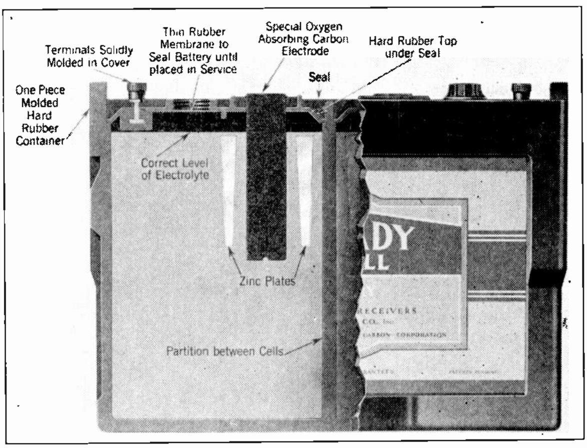


FIG. 11. Cut-away view of an air cell A battery, showing extreme simplicity of internal construction. When placed in service, rubber membranes placed at bottom of filler holes to seal battery are punched out and water added. The pieces of rubber falling inside the cells can do no harm. Two cells are in series, delivering about 2.4 volts.

reactions are exactly the same. The construction of a dry cell is shown in Fig. *9;* note that the chemicals are the same as those used in the Leclanché cell. A battery of thirty smaller sized dry cells, connected so that their voltages add together to deliver 45 volts for radio B supply use, is shown in Fig. *10.*

In a dry cell the zinc cup serves a double purpose—as electrode and as container for the other cell materials. A carbon electrode with a terminal screw at the top is centered inside the cup, and surrounded by a layer of manganese dioxide and powdered carbon. Between this and the zinc is an absorbent liner made from blotting paper, which holds the sal-ammoniac paste. The large quantity of manganese dioxide prevents premature polarization, lengthening the life of the cell. The cell material is held in place at the top by layers of sand and wax or pitch.

A new dry cell will generate 1.5 volts (1½ volts). The bell-ringing type, designated as No. 6, will deliver as much as 40 amperes. The life of a dry cell is ended when its voltage has dropped below one volt, for at that point the terminal voltage drops so fast with additional use that the cell is worthless.

The Air Cell. Designed especially for use with battery type radio receivers, the air cell battery is a modern wet unit of two cells built into a single container. The main chemical action is similar to that of the Leclanché cell but no depolarizer is used. The carbon electrodes are porous and absorb oxygen from the air by a process which the manufacturers call "breathing," to produce water and neutralize the troublesome hydrogen atoms. The air cell, shown in Fig. *11,* should really be called an air cell battery, for it has two separate cells connected in series. One cell will generate about 1.2 volts. The air cell has a rating of 600 ampere-hours;* the maximum current that can be obtained without unduly shortening the life of the battery is .75 ampere. With an average receiver which has been designed to use tubes requiring a 2 volt (.6 ampere) filament supply, an air cell will give about 1,000 hours of service, or 3 hours a day for nearly a year.

SECONDARY CELLS

The Lead Storage Cell. Most important of the secondary cells is the ordinary lead storage battery, used in automobiles and for many other purposes. You probably know that the automobile battery has three individual cells mounted in an acid-proof container; you know too that this battery can be recharged when it becomes discharged.

Whereas the cells studied up to this time had only one positive and one negative electrode, the storage cell usually has a large number of positive plates, all attached to one terminal, and a correspondingly large number of negative plates attached to the other terminal. These positive and negative groups of plates fit together alternately in the manner shown in Fig. *12.* Actually each plate is a lead grid, with spaces between the bars to hold the active material of the cell, which is in paste form. The operation of the cell depends upon the materials *held by* the plates, the lead plate structure itself being inactive.

* Since the life of a battery depends upon the current taken from it as well as upon the time of operation, batteries are always rated in ampere-hours. One ampere-hour is the quantity of electricity transferred in one hour by a current of one ampere; 600 ampere-hours means that the battery will deliver one ampere of current for 600 hours, five amperes for 120 hours, ten amperes for 60 hours, etc. This ampere-hour rating decreases, however, if the current drain is higher than normal.

The negative plates of a storage cell are filled with spongy lead (Pb) and the positive plates with lead dioxide (PbO_2) both of which are in paste form. As shown in Fig. *12,* a separator made from a sheet of porous wood or perforated hard rubber is placed between each pair of plates to prevent electrical contacts which would short-circuit the cell (unintentionally connect together adjacent plates). The plates are immersed in a solution of sulphuric acid (H_2SO_4) and pure water, this electrolyte passing readily through the separators.

The amount of sulphuric acid in the electrolyte gives an accurate indication of the state of charge of the cell. This acid content is actually measured when a hydrometer like that in Fig. *13* is used to test the specific gravity of the electrolyte. Specific gravity is simply the ratio of the weight of any liquid to the weight of an equal volume of pure water; for instance, if a cell gives a specific gravity reading of 1.250, the electrolyte in that cell weighs 1¼ times as much as would an equal volume of water.

When the electrolyte is sucked into the glass barrel of the hydrometer, a graduated float inside indicates the specific gravity directly. A fully charged cell should read 1.300, and a completely dead cell about 1.120.

As a storage battery discharges, both the spongy lead in the negative plates and the lead dioxide in the positive plates change to lead sulphate ($PbSO_4$), forcing electrons to the negative terminal of the cell during this process and diluting the electrolyte with water.

When the storage battery is recharged, the lead sulphate plates return to their original condition (Pb and PbO_2), and water leaves the electrolyte. This cycle of charge and recharge may be repeated over and over again until: *1.* the active material falls out of the plates; *2,* more and more lead sulphate stays on the plates, causing them to become "sulphated" (in this case the cell will not take a charge); *3,* the plates buckle to crush the insulation and cause an internal short circuit; or *4,* the sediment at the bottom, dropping continually from the plates, piles up high enough to short-circuit the plates. The water in the cell evaporates continually because of battery heat; more must be added to the cell from time to time to keep the level of the electrolyte above the plates. Always add pure water, either clear rain water or distilled water, for any minerals in the water can shorten the life of the cell.

The voltage of a fully charged lead storage cell is about 2.1 volts, this dropping to 1.9 volts when the cell is completely discharged. For automotive purposes three storage cells are usually connected in series (as shown in Fig. *12*) to deliver 6 volts. The ampere-hour capacity of a storage battery increases with the number and size of plates in a cell, the average battery having a rating of about 100 ampere-hours.

Many students ask me what goes on inside a storage battery during charge and discharge; for this reason I am including here in smaller type a simple explanation of the chemical action of this type of electrical generator. Let me again use the language of chemists. In water the sulphuric acid (H_2SO_4) separates into two hydrogen ions ($2H^+$) each with a positive charge, and one sulphate ion (SO_4^{--}) with two electrons. When an electron path is provided between the two battery terminals, the SO_4^{--} ion moves to the Pb plate, combining with the spongy lead to form $PbSO_4$ and liberating two electrons. The Pb plate becomes charged with electrons, and is therefore the *negative* terminal of the cell. At the same time the hydrogen ions ($2H^+$) move to the PbO_2 plate, attack it, and remove one negatively charged oxygen ion (O^{--}).

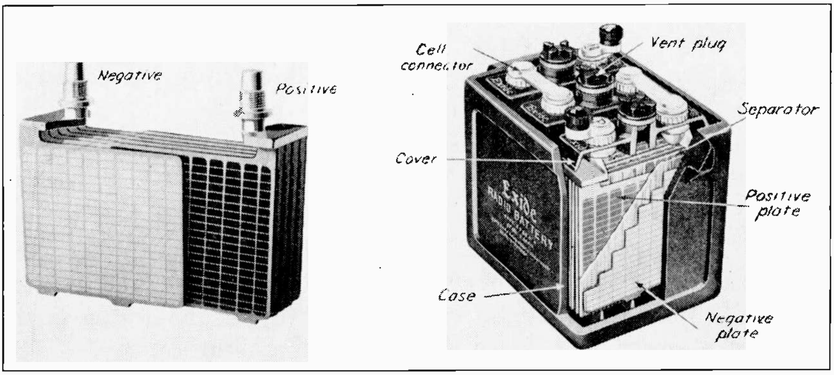


FIG. 12. (Left) Where a lead storage cell is to deliver a large electric current, the cell is made with many positive (PbO_2) and negative (Pb) plates as shown. Note that all plates having the same polarity are soldered to the same terminal in each cell. You can see the lead grid framework which holds the active chemicals in place. (Right) A modern three-cell lead storage battery, with one cell cut away to show the construction. Note the separator (insulating sheet) between each positive and negative plate.

This oxygen ion combines with the two hydrogen ions to form water ($2H^+ + O^{--} = H_2O$). This is why the weight of the electrolyte decreases, approaching that of water, when the cell is discharged. There is left at the positive plate PbO, which is very unstable (very active), and combines immediately with H_2SO_4 to produce lead sulphate and more water. This action continues until both groups of plates are changed to lead sulphate. The cell must now be recharged before it can be used again; this is done by connecting the terminals to a source of electrons, negative to negative and plus to plus. Only the water in the electrolyte enters into the charging reaction; each molecule of water (H_2O) breaks up into one hydrogen ion (H^+) and one hydroxyl ion (OH^-). The charging current forces the hydrogen ions (H^+) to attack the lead sulphate on the negative plate, converting it back into spongy lead, and adding sulphuric acid to the electrolyte. The hydroxyl ions (OH^-) attack the positive plate in much the same way, changing the lead sulphate here back into lead dioxide and producing more sulphuric acid. The water which was added to the solution during discharge is thus replaced by sulphuric acid during charge, increasing the specific gravity.

The Edison Cell. Before leaving the subject of secondary cells, I want to call your attention to the Edison cell, invented by Thomas Edison. In this cell one plate is iron, the other nickel oxide, and the solution is potassium hydroxide, all chemicals. This cell is not used in radio at the present time, and need not be covered in detail here.

Modern Radio Uses for Batteries. Batteries have many important advantages over other types of electrical generators; they are portable, supply electricity only when wanted, and deliver a steady, continuous D.C. voltage like that in Fig. *7A,* which is ideal for testing purposes away from or at the radio work-bench.

The auto radio receiver today depends upon the car storage battery for *all* of its power, whereas in the past separate B batteries were used to supply plate power to the vacuum tubes. The low battery voltage is here raised with a vibrator type power supply, a unit which you will study later in the Course.

Aircraft radio installations are very much like those in automobiles, an electrical generator driven by the plane engine being used to charge the storage battery.

All experimental radio work is invariably started with batteries, which can be connected to give any desired voltage and current capacity. With experimental work completed, the final step is the design of a power pack which will replace the batteries.

DYNAMO ELECTRIC GENERATORS

The majority of radio receivers today operate on power taken from a wall outlet. You know, of course, that behind this outlet is a complicated network of wires; eventually they all lead back to the central power station, where a steam turbine or a water wheel is driving a dynamo electric generator (a machine which takes in mechanical energy and delivers electrical energy).

Induced Voltage Principle for a Coil. Before I explain to you the basic principle of a generator, I want you to picture in your mind a cardboard tube, open at the ends, around which you have wound several turns of wire, forming a coil. Assume that you place this coil of wire in a magnetic field. Concentrate your attention only on those lines which pass through the coil and tube; the others do not count. Now for the important principle of induced voltage for a coil:

If the number of magnetic lines of force passing through a coil changes, an electromotive force will be generated in the coil.

These questions may come up in your mind: What kind of voltage will be produced? How can the voltage be increased, decreased, reversed, or stopped? Let me take up these questions one at a time.

1. *When will the voltage be constant?* When the number of magnetic lines of force passing through the coil changes the same amount in each interval of time, the e.m.f. generated in the coil will be constant. For instance, if 100 lines are originally passing through the coil and one second later there are 120, two seconds later 140, three seconds later 160, etc., the change would be 20 lines for each second, which is a constant change in the number of lines.

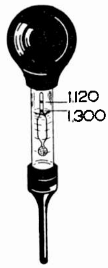


FIG. **13.** This hydrometer is used to test the condition of charge of a storage cell.

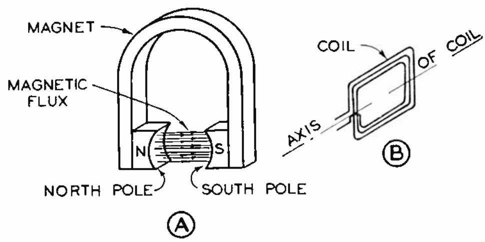


FIG. **14.** The essential parts of a dynamo electric generator, a magnetic field and a coil of wire, are pictured here. A voltage is generated when the coil is rotated between the magnet poles.

2. *When will the voltage increase?* If the change in the number of lines passing through the coil becomes more rapid, the number of lines increasing in greater and greater amounts each second, the voltage generated will increase. The number of lines passing through the coil in succeeding seconds might in this case be 100, 120, 150, 190, 240, etc. Notice that the change each second is 20, 30, 40, and 50 lines, an increasing change.
3. *When will the voltage decrease?* If the change in the number of lines going through the coil becomes less and less after each interval of time, the generated voltage will decrease. The number of lines through the coil might in this case be 100, 120, 135, 148, 155, 159, etc. Note that the change—the difference for succeeding seconds—becomes less and less: 20, 15, 13, 7, 4.
4. *When will the voltage reverse in direction?* If a voltage is being induced in a coil by a varying magnetic flux, a reversal in the direction in which the flux passes through the coil will reverse the polarity (direction) of the voltage at that instant. The generated voltage will also reverse in polarity when the

number of lines of flux passing through a coil stops increasing and begins to decrease in number (or vice versa), provided the direction of these lines through the coil does not change at that same instant.

5. *What if I add more turns of wire to the coil?* The voltage is proportional to the number of turns in the coil, other things being constant, so that increasing the number of turns increases the voltage. Decreasing the turns decreases the voltage.
6. *When will the voltage drop to zero?* The voltage is zero at any instant when there is no change in the number of lines passing through the coil. I want to emphasize here that there *must be a change* in the number of lines to produce a voltage; simply holding the coil in a magnetic field will not give a voltage.

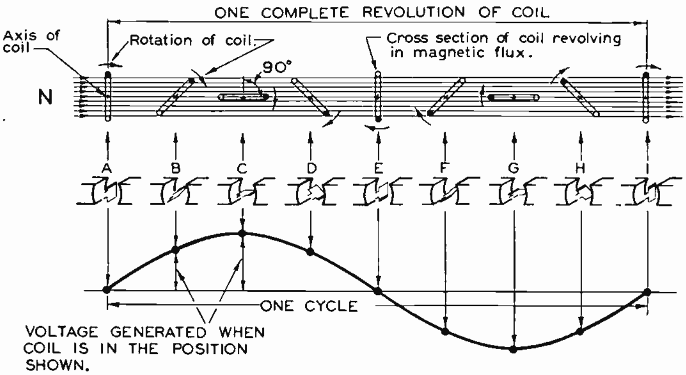


Fig. 15. When a coil of wire is rotated at constant speed in a uniform magnetic field, the voltage generated will vary in the manner shown here.

The Alternating Current Generator. Having covered the basic facts regarding induced voltages in coils, let us apply these facts to a simple dynamo electric generator having only the two essential parts pictured in Fig. *14*. The source of the magnetic flux (a common name for magnetic lines of force) is shown at *A* as a horse-shoe type permanent magnet, and the coil of wire is shown at *B*.

Now imagine that the coil of wire is placed between the N and S poles of the magnet in such a way that the magnetic flux passes through the coil in the manner shown at *A* in Fig. *15*. If the loop is turned a little on its axis, until it takes the position shown at *B*, there are clearly fewer lines of force now passing through the coil. At *C* there are no lines of force passing through the coil.

But it isn't the actual number of lines of force which is of importance; it is, as I pointed out before, the change in this magnetic flux passing through the coil which must be considered. A small amount of rotation of the coil at position *A* (Fig. *15*) causes very little change in the number of lines passing through or *linking* the coil; at position *C*, however, this same amount of rotation of the coil gives a large change in the number of *linking lines* (lines passing through the coil). The e.m.f. generated will then be greatest at position *C*, least at position *A*, and will vary gradually from zero to a maximum as the coil turns at uniform speed through 90 degrees, to give the first part of the voltage characteristic curve in Fig. *15*. As the coil passes through position *C*, two things occur: *1*. The number of lines of flux through the coil decreases to zero at *C*, then increases again as the coil rotates beyond *C*; 2. The direction in which the flux passes through the coil is reversed as the coil passes through position *C*. Each change by itself would cause a reversal in the polarity of the generated voltage, but when both occur simultaneously they offset each other and the polarity remains the same. Turning the coil another 90 degrees to position *E* brings the voltage down to zero again, for at *E* the coil sides are moving almost parallel to the magnetic lines of force, and there is practically no change in the flux linkages (lines of flux passing through or "linking" the coil). As the coil passes through position *E*, the lines of flux through the coil increase in number to a maximum value and then decrease, without changing their direction through the coil; this reverses the polarity of the generated voltage. As the coil successively takes positions *F* to *I* the process repeats itself, with voltage increasing to a maximum negative value at *G*, then gradually returning to zero at position *I*. One complete revolution of the coil gives the complete voltage curve in Fig. *15*, which you will recognize as a sine variation. If the coil is given 60 complete revolutions per second, 60 of these cycles will be produced each second, and you will have 60-cycle electric power.

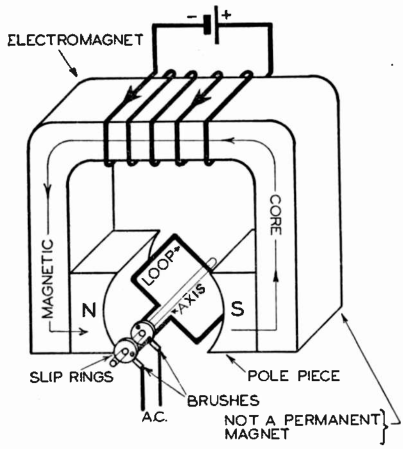


FIG. **16.** An A.C. generator in its simplest form has one coil of wire revolving in a magnetic field. The great A.C. dynamos used in power plants are simply more perfectly developed models of this elementary A.C. generator.

This generated A.C. voltage exists across the ends of the moving coil of wire; to collect it you need only attach the ends of the coil to two rings known as slip rings, which are mounted on but insulated from the shaft. Blocks of carbon, called brushes, slide against these rings and thus allow the electrons to flow to an outside device.

You now know how a simple A.C. dynamo works; a practical A.C. dynamo is more in the form shown in Fig. *16*. Note that an electromagnet supplies the magnetic flux; the power taken from the battery by the electromagnet coil is very small in comparison with the power delivered by the dynamo.

Direct Current Generators. In a generator the direction of electron flow in a coil always reverses at the instant when the plane of the coil is at *right angles* to the magnetic lines of force, for when the coil passes through this position the number of lines of flux through the coil increases to a maximum value and then begins decreasing. Positions *A, E* and *I* in Fig. *15* show the coil in this midway position. If the brush connections of an A.C. generator were reversed each time the coil reached this midpoint, wouldn't the generator output current always flow in the same direction? Certainly it would.

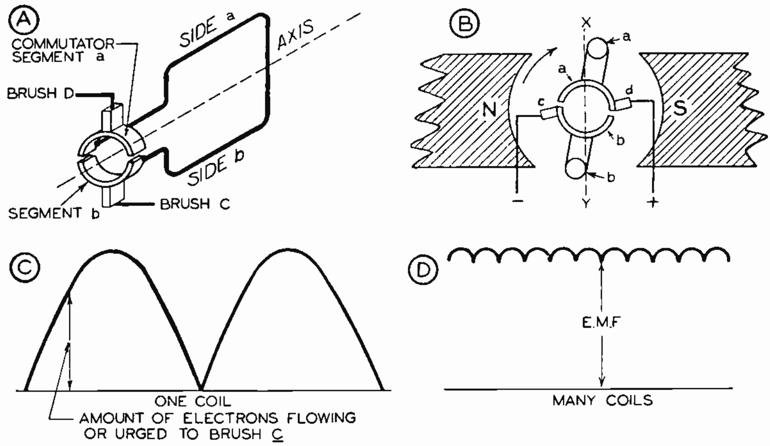


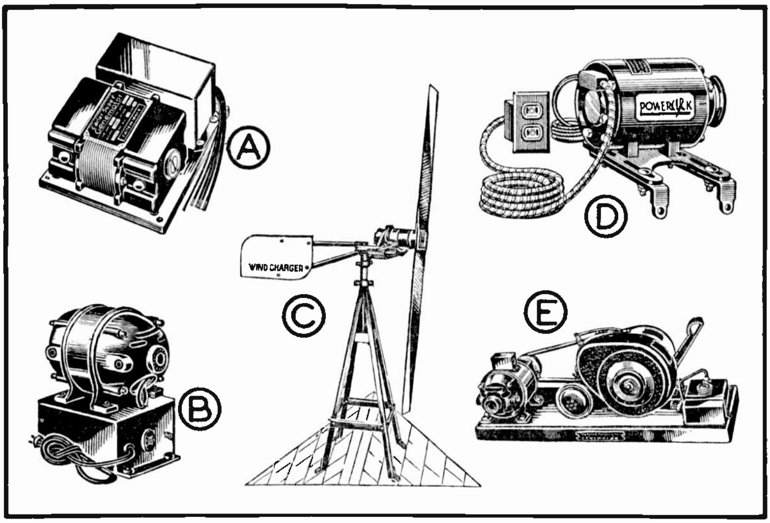
FIG. 17. The underlying principles of the D.C. generator are shown here. *A D.C. generator has a commutator, while an A.C. generator has slip rings;* this is the important difference in the construction of these two types of generators.

In a D.C. generator this reversal of coil connections is accomplished automatically by a device known as a *commutator.* I will first explain to you the operation of the simplest type, having only two commutator segments; this is shown in Fig. *17A.* Each coil lead is connected to one part of a two-segment commutator mounted on the coil shaft. Two brushes, *c* and *d,* mounted on opposite sides of the generator shaft rub against the commutator, contacting first one segment, then the other as the coil is turned. The coil is midway between the N and S poles (Fig. *17B*) when the brushes "exchange" segments. The voltage characteristic of this generator will be that in Fig. *17C,* indicating that the polarity of the terminals does not change. This is a pulsating D.C. voltage.

By using a number of coils of wire, each connected to a pair of segments on opposite sides of the commutator, each coil generates its own voltage and these individual voltages add together to give the voltage characteristic shown in Fig. *17D,* a D.C. voltage with a small A.C.

ripple. For each coil added, two more segments must be placed on the commutator. The A.C. ripple voltage must be removed or smoothed out by filters before this D.C. generator can be used to operate a D.C. radio receiver.

Commercial D.C. generators use electromagnets, of course, to produce the necessary magnetic field; part of the direct current output of the generator is used to feed the electromagnet coils. There is always enough magnetism in the core of the generator to start current flow in the rotating coils, deliver a direct current to the electromagnet coils (called field coils), and progressively build up the magnetic field strength to its normal value.



A—A combination motor and generator, commonly referred to as a dynamotor, and used extensively in automobiles to convert 6-volt car battery power to the high D.C. voltage required by auto radio receivers and public address amplifiers.

B—A dynamotor which is commonly used in districts having only D. C. power, to convert 110 volts or 32 volts D.C. to 110 volts A.C., allowing the use of standard A.C. receivers and amplifiers.

C—A wind-driven generator used extensively in farm areas to charge the 2- or 6-volt storage battery which furnishes all the power required by the farm radio receiver.

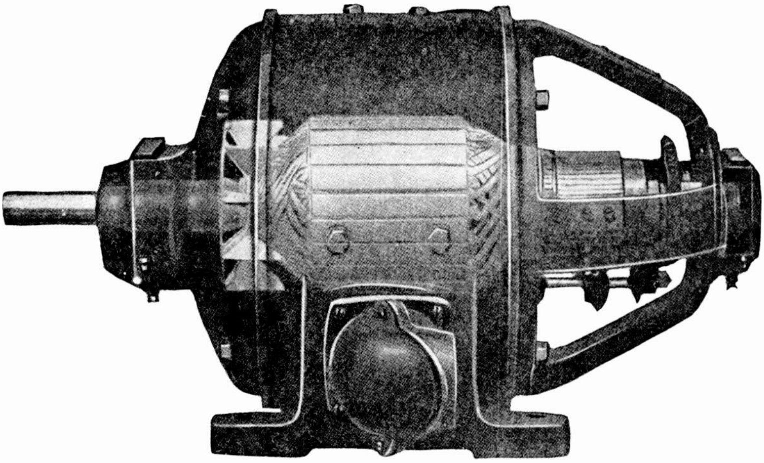
D—An A.C. generator which is belt-driven by the engine of an automobile or truck and which is used to furnish 110 volts A.C. for standard public address amplifiers.

E—A widely used means of obtaining A.C. and D.C. power for operating electrical and radio equipment in localities where suitable power is not otherwise available. A small gasoline engine drives a combination A.C.-D.C. generator which is nothing more than a mechanically driven dynamotor.

Radio Uses for Dynamo Electric Generators. In order to use any electric power intelligently you must know first how it is produced. A.C. power is used far more than D.C. in this country, because A.C. of one voltage can be changed to A.C. of a higher or lower voltage by means of a transformer without excessive losses, and because A.C. power can easily be converted into D.C. by means of rectifiers (radio units which you will study later).

On board ship, in certain industrial sections of large cities, and in farm power plants you will encounter direct current. Your auto generator is a direct current generator, used to recharge the storage battery. D.C. generators driven by wind propellers are now popular for use on farms, where they keep the radio battery charged or, in the larger units, supply D.C. power for the entire farm.

In districts where only D.C. socket power is available and an A.C. receiver is to be used, a D.C. motor operating from the power line is used to drive an A.C. generator which produces the desired A.C.



The frame is shown transparent in this photograph of a modern D. C. generator to show you the armature and the arrangement of the various parts.

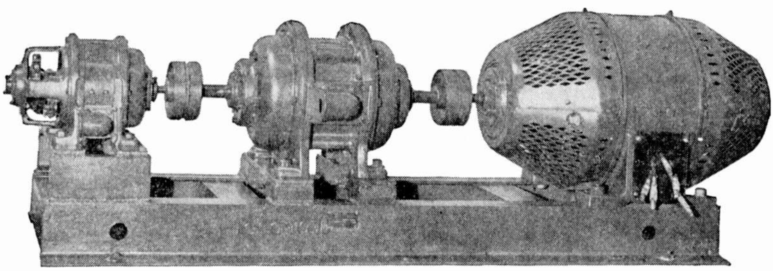
voltage. In the smaller sizes these motor-generator sets, as they are called, are built as a single unit, with slip rings at one end connected to one set of coils and a commutator at the other end connected to its set of coils, both groups of coils turning in the same magnetic field. A unit of this type is called a rotary converter or a dynamotor.

Thus you can see how A.C. and D.C. voltages are produced by dynamos and how the voltages are changed from one value to another. Remember that A.C. and D.C. generators are much the same except for this important difference: In a D.C. generator a commutator replaces the slip rings used on A.C. generators, this commutator changing the generated alternating e.m.f. to a pulsating direct e.m.f.

From a practical point of view, the Radio-Trician wants to know which terminal is (+) and which is (—). This problem does not exist in A. C. generators because each terminal, as you know, is alternately (+) and (—); but in a D.C. generator a D.C. voltmeter connected to the generator terminals will give the desired information. Connect the meter so it reads properly up-scale; the (+) terminal of the voltmeter will now be connected to the (+) terminal of the generator.

OTHER TYPES OF ELECTRICAL GENERATORS

Although batteries and dynamo electric generators are the most economical sources of electrical energy, there are a number of other ways of obtaining electrical energy. The friction generator, the piezoelectric crystal, the thermoelectric generator and the photoelectric generator are the four which I consider most important.



Courtesy General Electric Co.

In this motor-generator set the A.C. motor in the center is driving a double generator (right) and an exciter generator (left).

I have prepared the chart on page 25 to give you on a single page a complete review of all types of electrical generators which you may encounter in your radio work. The first four: *1*, dry cell and battery; *2*, air cell battery; *3*, storage battery; and *4*, dynamo electric generator, you are already familiar with; these devices generate electrical power at a low cost per watt.* The cheapest power is, of course, that produced by the dynamo electric generator, the cost of electrical power here depending upon the expense of operating the driving unit. In the illustration on the chart a small gasoline engine is shown driving a generator which may be either an A.C. (alternating current) or D.C. (direct current) type. This particular installation is used extensively

* Power is measured in watts; when an electrical generator having an e.m.f. of one volt sends a current of one ampere through a resistor load, the power delivered to that load is one watt. *Volts* times *amperes* equals *watts*.

on farm homes; another common use is in supplying power to transmitters and P.A. systems.

The last column on the chart, "Unique and Graphical Characteristics," gives voltage characteristic curves and technical data for a representative unit in each type of generator; this reference data will mean more to you as you become more familiar with radio work.

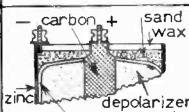
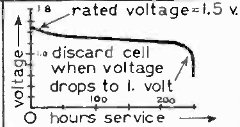
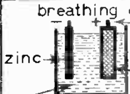
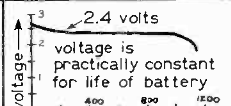
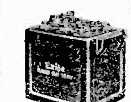
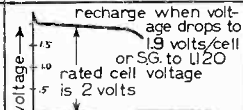
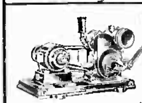
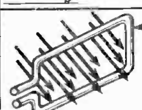
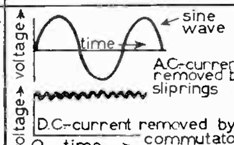
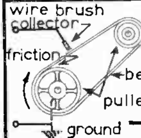
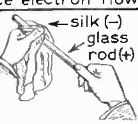
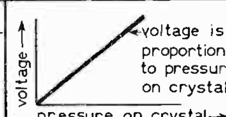
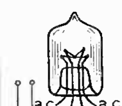
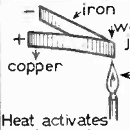
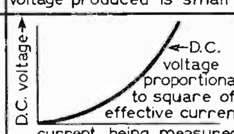
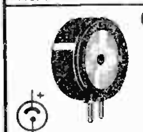
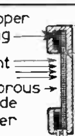
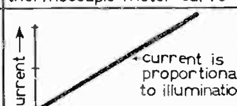
Generator Type No. 5. In radio, queer as it may seem, the *friction generator* is more of a nuisance than a useful source of electrical power. This oddity will be evident to you as soon as I explain how the friction generator operates.

When any two insulating materials are rubbed together, one will take on free electrons, while the other will lose free electrons. When separated, these materials will be electrified or charged, one positively and the other negatively. Materials which can be electrified are arranged in a definite order in this list: Fur, wool or flannel, ivory, glass, silk, metals (insulated), hard rubber, celluloid. Select any two of these materials, rub them together, and the one coming last in the list will be negatively charged. For instance, if glass is rubbed with fur the glass will take on electrons and become negatively charged, while the fur will be positively charged. When silk is rubbed with glass, the silk will be negatively (—) and the glass positively (+) charged.

Why do electrons move in this way when two insulating materials are rubbed together? I like to look at it this way: Every material has a certain number of electrons, each whirling around in its own atomic orbit. When two different objects are rubbed together the friction between them produces heat; you know that heat has an exciting effect on any material, setting electrons into violent motion and releasing some of them from the atoms. Naturally there will be more of these "free" electrons at the surfaces, where the heat is greatest; that material which can hold the greatest number of these free electrons on its surface will be negatively charged.

A leather belt rolling on a metal or wood pulley is a simple form of friction generator, yet one which is encountered in every factory having rotating machinery. The friction between the belt and pulley causes each to become charged. The pulley is usually connected to the ground through the shaft and frame of the motor, making the ground one terminal of this electrical generator. The charge on the belt will jump from the belt, in the form of a spark, to that grounded metal object which is closest to the moving belt. A Radio-Trician removes the charge from the belt by mounting a grounded wire brush near the moving belt in the manner shown in part *5* of the chart.

ELECTRICAL GENERATORS

Appearance & Symbol	PRINCIPLE of Operation	How Primary Energy is Converted	Unique & Graphical Characteristics
①  DRY CELL & Battery	 Primary Cell	CHEMICAL TO ELECTRICAL Sal ammoniac "eats away" the zinc electrode, leaving free electrons. Manganese dioxide, surrounding the positive electrode, chemically prevents polarization, lengthening the life of the cell.	 (No.6 dry cell; load=.5 amp.)
②  AIR CELL Battery	 Primary Cell	CHEMICAL TO ELECTRICAL Same as dry cell, except that electrolyte is in liquid form. Oxygen, "breathed" through the porous carbon, prevents polarization	 2 cells in series; load=.5 amp.
③  Lead Storage Battery	 Sec. Cell	ELECTRICAL TO CHEMICAL Electrons pumped into cell change chemicals on electrodes, storing energy in chemical form. CHEMICAL TO ELECTRICAL Chemical action reverses; electrons fed to (–) terminal.	 (normal current drain)
④  A.C. D.C. Dynamo Elect. Gen.	 Changes in magnetic flux through a coil induce electron flow	MECHANICAL TO ELECTRICAL Mechanical energy, used to rotate coils of wire in a magnetic field, is converted into electrical energy which may be either A.C. or D.C. of various voltages.	
⑤  Friction Generator	 Friction between two materials	MECHANICAL TO ELECTRICAL Mechanical energy used in producing friction between two insulating materials provides heat which liberates free electrons, giving electrical energy.	 a D.C. voltage with high frequency variations
⑥  microphone osc. crystal Piezo-electric Gen.	 rubber form holds three corners rigid	MECHANICAL TO ELECTRICAL Mechanical pressure on crystal distorts orbits of electrons inside, making one face of crystal (+), the other face (–).	 voltage produced is small
⑦  Thermoelectric Gen.	 Heat activates electrons in metal	HEAT TO ELECTRICAL Heat at junction of two dissimilar metals causes electrons to flow to or from the cold ends, producing an e.m.f. In meters heat is produced by the current being measured.	 thermocouple meter curve
⑧  Photovoltaic Cell	 Photo-electric effect	LIGHT TO ELECTRICAL Light falling on cuprous oxide layer causes electrons to come to surface and move to copper collecting ring.	 photronic cell characteristics

Other examples of friction generators are the tires of an automobile slipping on a wet pavement, an aerial wire rubbing against dry tree branches, or dust driven against a car by a high wind. Here is how radio enters into the picture—these charges on an object become stronger and stronger and eventually discharge, causing a current to flow; radio receivers pick up radio effects of this current (an interference signal), amplify it many times, and send it out of the loudspeaker as an annoying noise.

Radio technicians have a very effective cure for bothersome friction generators—they simply short-circuit (or ground permanently) the bodies which are continually becoming charged through friction, or else separate or insulate the rubbing parts.

Generator Type No. 6. It is well known that when a crystal of quartz, Rochelle salts or tourmaline is squeezed in a certain way, the faces of the crystal will become oppositely charged, and an e.m.f. will thus be generated. This manner of obtaining electrical energy directly from mechanical energy is known as the *piezo-electric* effect. In the piezo-electric or crystal microphone, sound waves bend a thin crystal disk, thus charging opposite faces (+) and (—) and generating an e.m.f. which varies with the strength of the sound. In the piezo-electric phonograph pick-up the crystal converts vibrations of the phonograph needle into a varying e.m.f. Even though the charge produced is quite small, it is easily amplified by radio tubes.

How does a crystal become charged? I have seen many long mathematical proofs answering this question, but the following explanation satisfies my curiosity. A crystal, first of all, is a material in which atoms are lined up in a definite geometric pattern, with electrons revolving around the nucleus of each atom in an orderly manner, the nucleus being in the exact center of the atom. Twisting or compressing the crystal changes the paths of the ever-revolving electrons, making them crowd more to one face of the crystal than to the other; that face then acts as if it had a surplus of free electrons, or was negatively charged. The opposite face, of course, has a deficiency of electrons and is positively charged, for the number of electrons in the crystal must always remain constant.

Just as mechanical pressure on a crystal generates electricity, so does the shape of the crystal change when one face is charged (—), the other (+). This is the principle of the crystal loudspeaker; output signals of the receiver, fed to opposite faces of a flat crystal, cause the crystal to vibrate and produce sound waves.

Generator Type No. 7. If you should take a strip of metal and hold one end in the flame of a blow-torch for a few minutes, the free electrons in the heated end would be set into violent motion.

If two strips of metal are joined together at one end, perhaps by welding, and this joint is heated, the electrons in each strip will have an urge to "go places." When two different metals such as the copper and iron in sketch 7 of the chart are together, a difference in potential exists at the two cold ends, one becoming negative and the other positive, for heat has a different effect on each metal. Thus a *thermoelectric generator* is formed, with the cold end of the iron as the (—) terminal and the cold end of the copper as the (+) terminal.

Lead, the only known metal in which the electrons are not greatly excited by heat, is used as a reference point in the following list of metals: Bismuth (+90); constantan* (+19.3); nickel (+15.5); German silver (+10.7); lead (O); platinum (—.9); copper (—1.4); zinc (—2.8); iron (—17.5). When any two of these metals are joined together and heated, the cold end of the one appearing first in the list will be (+). You can easily calculate the approximate voltage produced by this simple electrical generator if you know the difference in temperature between the junction and the ends. For each change of one degree centigrade (the centigrade temperature scale is discussed in your dictionary), the voltage in microvolts (millionths of a volt) will be the *difference* between the numbers given after the metals; if one metal has a (+) number, the other a (—) number, *add* the numbers. For example, when iron and copper are together the voltage per degree change in temperature will be 17.5 — 1.4, or 16.1 microvolts, this being the difference between the potentials or electron urges of each strip. For iron and constantan, a very common combination for temperature measuring work, this voltage will be the sum of the voltages for each metal, because one is (+), the other (—); the result will then be 19.3 + 17.5, or 36.8 microvolts per degree C, and constantan will be (+). Although the above voltage values change slightly as the metals become hotter, the general relation between the metals is interesting.

Combinations of metals used in this way are known as thermoelectric generators or more often as thermocouples. In radio the thermoelectric generator is widely used for measuring purposes. The current to be measured, which can be either radio frequency, 60 cycle A.C., or direct current, is sent through a resistance wire which has welded to its center the junction of a thermocouple. The heat produced by current passing through the resistance wire raises the temperature of the thermocouple junction, producing across the cold ends of the thermocouple a voltage which is easily measured by an ordinary direct current voltmeter. This type of thermocouple is very reliable and is usually mounted in a small vacuum tube in the manner shown on the chart.

Generator Type No. 8. Although there are many so called photoelectric cells (devices which are electrically affected by the presence

* An alloy made up of 60% copper and 40% nickel.

of light), only a few of these are true electrical generators. A dry type, simply a copper disk on which is a thin layer of cuprous oxide, is shown in part *8* of the chart. A copper ring makes contact with the surface of the cuprous oxide, this ring and the copper disk being connected to the terminals of the cell. Sometimes the cuprous oxide layer is protected by a transparent material such as ordinary glass, clear celluloid, or quartz glass.

The action of a photoelectric cell of this type, also known as a *photovoltaic* cell or a photronic cell, is surprisingly simple. When the light from the sun or any other source strikes the oxide layer, electrons are forced to the surface of the layer and flow over this surface to the copper ring. The ring becomes negatively charged; the copper disk is consequently positively charged because it has lost electrons. Now a current, which is proportional to the amount of light, flows through a load when the two terminals of the cell are connected together by the load.

Although scientists are ever hopeful of using photovoltaic cells in this way to obtain electrical power from the sun, the power output of one cell is so small in proportion to the cost of the cell that the project is not as yet economically practical. In electronic control, a field closely allied to radio, the photovoltaic cell finds hundreds of uses. It has a distinct advantage over other types of photoelectric cells in that it can generate its own power. The photovoltaic cell is used to measure illumination, to match colors, to detect moving objects such as persons, automobiles, or even airplanes, to safeguard life and property, and to provide almost magical light beam control over all types of equipment.

LOOKING FORWARD

In this lesson we have made a rapid inspection and study of the important types of electrical generators; some of these you will study again later, when a more detailed knowledge of the many different models of generators becomes necessary. I have mentioned briefly some methods of converting A.C. to D.C. and vice versa; so important is this changing of one type of electrical power to another that I will discuss it time and again in future lessons.

Having explained to you how electrical generators deliver electrical energy, I will in the next lesson show exactly how these generators are used in simple radio circuits. Gradually we will come to practical radio receivers and transmitters.

TEST QUESTIONS

Be sure to number your Answer Sheet 3FR-1.

Place your Student Number on every Answer Sheet.

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. What is meant by a neutral body?

2. What is the standard practical unit of electron flow called?

3. If the voltage of the generator in Fig. 6 reverses its polarity, will the direction of electron flow in the circuit reverse?

4. Name the two distinctly different types of electrical cells.

5. What type of cell can be used over and over again by recharging it?

6. What voltage will a new dry cell generate?

7. State the important principle of induced voltage for a coil.

8. What is the important difference in the construction of A.C. and D.C. generators?

9. What happens when crystals of quartz, Rochelle salts or tourmaline are squeezed?

10. What happens when light from the sun or any other source strikes the oxide layer of a photovoltaic cell?

ESSENTIALS OF RADIO CIRCUITS AND THE METERS USED TO TEST THEM

4FR-1

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

ONE THING AT A TIME

I want to tell you about student B——, an ambitious young man who some time ago sent my chief instructor this letter:

"DEAR CHIEF: I have now completed my twelfth lesson in your Course, but still cannot repair radio receivers. What is the trouble?"

Looking up the record of this student and going through all past correspondence with him, I found that while he was studying lessons dealing with fundamentals and simple radio circuits he was sending in to the Institute one letter after another, asking for information on transmitters, television apparatus, public address amplifiers—in fact, about everything except those simple circuits he was supposed to be studying. His record for every one of the twelve lessons was like that—his mind way ahead of his work—his head high up in the clouds most of the time.

I knew then what the trouble was, and you probably do too by now—he was trying to jump up to the top floor of his success skyscraper while he was still working on the foundation for the basement.

How could he expect to repair complicated eight- and ten-tube radio receivers when he did not understand the simple one tube radio circuits?—how could he hope to do the hardest jobs in radio after studying for only a few weeks? Why, if radio were that easy, each person would be repairing his own radio, and there would be no business for trained service men!

Learning is a building process, with each completed lesson counting as another brick in your structure of success. Omitting or rushing hurriedly through any one lesson weakens your whole structure of learning and leaves you dangling in the air above weak and crumbling foundations.

Keep your feet solidly on the ground; concentrate on one lesson at a time until you understand that thoroughly. Save those advanced questions for a while—put them in a "questions" file, go through them after completing each group of five lessons, and I wager you won't have a single question left to ask me when you receive that coveted *Radiotrician & Teletrician* diploma. If you have questions on the lessons you are studying—send them in, of course. I'll be more than glad to help you.

Doing today's work well today makes tomorrow's work more easy.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

JD5M241 Printed in U.S.A.

Essentials of Radio Circuits and the Meters Used to Test Them

TALKING ABOUT CIRCUITS

IN describing the features of a modern receiver to a technically inclined person, a radio serviceman will say: "That set has the latest superheterodyne *circuit.*" Asked what the knobs on the panel are for, he will reply: "This one throws on the power supply *circuit;* that knob adjusts the tuning condensers in the signal *circuit;* the other knob is a part of the volume control *circuit.*" Should you be curious about what is below the chassis he would go on describing filament *circuits,* plate *circuits,* grid *circuits* and supply *circuits,* all of which are a part of the superheterodyne *circuit.*

Receivers, transmitters, public address systems and photoelectric controls are all alike, in the sense that each one is a complex circuit made up of many simple circuits. In order to understand and read the circuit diagram of a large radio receiver, you must first be able to understand the simple circuits which are grouped together to make the whole radio device. In this lesson I am going to give you a good start towards understanding real radio circuits.

HOW TO IDENTIFY A CIRCUIT

Loudspeakers, vacuum tubes and all other radio and television devices must be supplied with electrical or signal power. This power will naturally come from some source—from one of the many types of electrical generators which you have studied, or from any device which can supply the signal.

In an electrical circuit, the part which supplies power is called the *source,* and the part which absorbs this power is called the *load.*

Since electrical power must be transferred from the source to the load in an electrical circuit, a path or connection of some sort must be supplied. We can call this path either a connector, a conductor, or more generally, a *transmission system.* Whenever I have an electrical arrangement containing these three essential parts—*a source, a load* and *a transmission system,* I know that I have a complete *electrical circuit.*

An example of the simplest possible circuit you can have, containing a simple source (*S*), a simple load (*L*) and a very simple transmission system (*T*), is pictured in Fig. *1A.* Electrons flow out of the negative terminal of the dry cell and through one wire of the transmission system to the filament of the vacuum tube. Passing through the filament, electrons return to the (+) terminal of the dry cell by way of the other transmission line, which you can call a *wire*, a *connector*, a *conductor*, or a *lead* (pronounced leed, not led), as you prefer. There is here a complete path with no stopping points for the electrons—a path you might picture in your mind as a circular racetrack for electrons—a complete circuit. As the filament, a very thin high-resistance wire, takes power from the transmission system to produce heat, it is here the *load*.

In Fig. *1B* is a more general example of a circuit. Here we have the aerial and ground system (*S*) feeding a radio signal into the re-

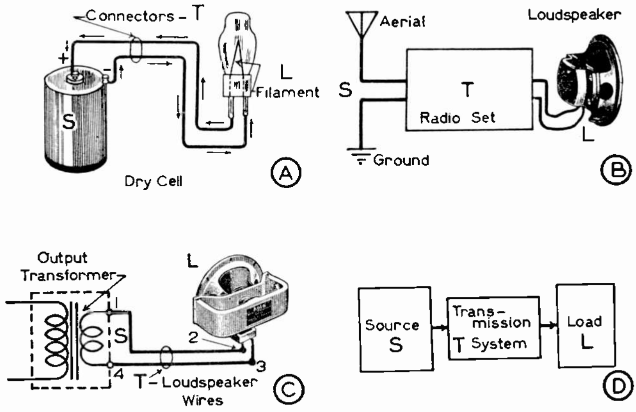


Fig. 1. Although there are thousands of different kinds of circuits, each circuit must consist of three basic parts: a source *S*, a transmission system *T*, and a load *L*.

ceiver (*T*), and the loudspeaker (*L*) taking an audio signal from the receiver to produce sound waves. Remembering my definition of a circuit as any arrangement of a source, a transmission system and a load, you will agree that in Fig. *1B* there are all three, and consequently a complete circuit.

Any one circuit can contain any number of other circuits. To convince you of this statement I have drawn Fig. *1C*, showing just one part of the circuit of Fig. *1B*. Here the output transformer of the receiver is feeding audio power through the loudspeaker wires to the loudspeaker. Points *1* and *4* are therefore the terminals of the source, and points *2* and *3* the terminals of the load. The two wires, *1-2* and *3-4*, are here the transmission system; since the source is supplying an A.C. voltage of an audio (sound) frequency, the electrons will at one instant flow over the path *1→2→3→4→1*, and will reverse their direction the next instant, taking the complete but reversed path *1→4→3→2→1*.

Simply keep in mind the picture given in Fig. *1D*, which shows that a circuit is made up of a source, a load and some means of connecting the two together, and you will have no trouble in identifying a complete circuit. If you have these three things but they are not connected together at the time, the circuit is said to be *incomplete* or *open.*

MORE ABOUT SIMPLE CIRCUITS

Suppose that you are driving an automobile on a hard level pavement, with the gas throttle at a fixed position; you know that when you "step on the gas" the speed of the car increases. If you reduce the gas flow, the car slows down; if you push down steadily on the brake pedal while the gas throttle is fixed, the car travels slower, because now the forward force of the engine is being opposed by the frictional "drag" of the brakes. If, with the gas throttle fixed, you turn on to a muddy

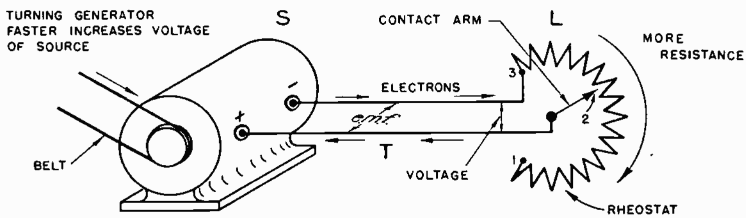


Fig. 2. If you want to send more electrons through this simple circuit, you will either have to turn the generator faster or reduce the resistance of the load.

road, the car will again slow down—this time because the mud presents more resistance to the car wheels than did the pavement.

A radio circuit behaves very much like an automobile. The voltage of the source is the strong forward force; the resistance of the electrical load, slowing down the flow of electrons, is the drag. Isn't this just what you would expect, that electron flow depends upon the voltage or "forward force" of the source and the resistance of the load? If the resistance of the load is *reduced*, the opposition to current flow is *reduced*, and more electrons can flow. If the resistance is kept the same but the voltage of the source is *increased*, the "forward force" will be able to push more electrons through the resistance, and current flow will be greater. If you think of the source voltage as the automobile throttle, the resistance as the brakes, and the electron flow as corresponding to the speed of the car, you can tell immediately what will happen to the electron flow when some change is made in a simple circuit.

Variable Source. In Fig. *2* is a simple circuit where both the source and the load can be varied. The faster the generator is turned, the higher is the voltage which it delivers to the load. This load is a variable resistor, a device whose resistance can be changed (varied) from zero to a maximum value by changing the position of the contact arm. If I set this resistor at its maximum value (at end *1*) and turn the generator at a certain speed, a certain number of electrons will flow. Assuming for the sake of simplicity that the resistance of the transmission system (the wires in this circuit) is very low, then wouldn't more electrons flow through the resistor if the generator speed were increased? Certainly. All energy which is delivered by the generator must be taken by the load (energy cannot be destroyed), and the resistor gives off this energy as heat. You know how the resistor elements in an electric stove give off heat when the stove switch is turned on—well, a radio resistor will get just as hot if the source can push enough electrons through it.

Variable Load. Now imagine that the generator in Fig. *2* is being turned at a constant speed, and that the resistance of the load is reduced by moving the resistor arm from point *1* to point *2*. Electron flow is increased, as you would expect. If the resistor is turned to position *3*, the only resistance left in the circuit is that of the transmission lines (which is usually very low), and a very large current will flow. (To be strictly correct, the generator itself has some resistance, but let us assume that the electrical generator being discussed has very little or no resistance.)

PROTECTING CIRCUITS WITH FUSES

Fuses. Too much current is far worse than too little, for current flowing through a resistance produces heat, and excess heat melts wires or destroys devices in the circuit. Fuses, little devices which are constructed like those in Fig. *3*, are cheap insurance against electrical "overloads." A wire or ribbon made from an alloy of lead and tin (often called soft lead) is connected between the two terminals of the fuse; the fuse is connected into a circuit in such a way that all current passing through the load must also pass through the fuse wire. If the current becomes too large, the soft lead in the fuse melts, or as it is commonly expressed, *the fuse "blows," opening the circuit* and stopping the flow of electrons. Fuses are made in many sizes, and are rated in amperes; for instance, a 15 ampere fuse is designed to melt when the current through it exceeds 15 amperes.

By choosing a fuse which will melt before damage can be done to any other part in a circuit, valuable meters and instruments are protected against overload. Fuses used in the power supply of an ordinary radio receiver will "burn out" or melt at 3 amperes, a value of current which is slightly higher than that required for normal operation of the set. Fuses in the switch box near the electrical meter in your home may have ratings such as 15 or 25 amperes, depending upon the amount of electrical apparatus and the size of wire used in the home.

SUPPLYING THE LOAD PROPERLY

A radio receiver rated to operate at 110 volts would soon burn out if connected by mistake to a 220 volt line (if there were no fuses). A vacuum tube filament would not be heated enough to drive off electrons if the voltage were too low. A loudspeaker fed with too high an A.F. voltage would blast (distort); with too low a voltage the volume would be too low. Thus you can see that every load must be fed with its *correct voltage;* when it gets the correct voltage the correct amount of current will flow, and the device will operate properly. The source, therefore, must be able to deliver this voltage and handle the maximum current taken by the load. What can we do when the source does not meet the demands of the load?

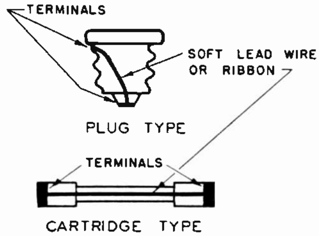


Fig. 3. The screw plug type fuse shown above is used in home wiring circuits; the cartridge type fuse has many uses, in automobiles, in radios and even in great power plants. When the current flowing through a fuse becomes too large, the fuse "blows" or melts, opening the circuit.

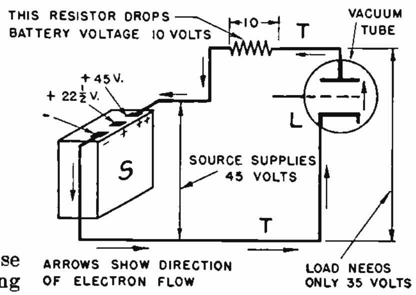


Fig. 4. A problem in subtraction: This B battery gives 45 volts, but the load wants only 35 volts. A resistor settles the problem by "wasting" the unwanted 10 volts.

First I will consider the case where the source can supply all the current which is required, but at the wrong voltage. You can now forget about A.C. power, for as I have already explained, transformers can be used to step up or step down the voltage of an A.C. source.

Voltage-dropping Resistors. If the D.C. supply voltage is greater than is necessary, such as occurs very commonly in radio, part of the voltage of the source can be wasted or dropped by a resistor connected as in Fig. 4. The resistor is here said to be in series with the load, which in this case is a radio tube * requiring 35 volts for the correct electron flow. The B † battery to be used delivers 45 volts and this voltage, applied directly to the tube, would cause too much current to flow.

* For the present consider a vacuum tube as a resistance which must be connected into a circuit in such a way that electrons flow *from the cathode to the plate* inside the tube.

† Batteries which are used to heat the filament of a tube are called *A batteries;* those used to supply plate voltage to a vacuum tube (charge the plate +) are called *B batteries;* those used to charge the grid of a tube (provide a grid bias voltage) are called *C batteries.*

The resistor must therefore be of such an electrical size that it will hold back some of the electrons, limiting the electron flow through the complete series circuit to the correct value by reducing the voltage 10 volts. *A series resistor is very commonly used to reduce the voltage of a D.C. source which is supplying current to a load;* this resistor may be placed in any convenient part of the circuit.

When a Higher Voltage Is Required. On the other hand, what can I do when a tube requires 135 volts? B batteries are usually made to furnish only 45 volts; can I connect a number of batteries together in some way to get 135 volts? Get into your automobile again, and we'll find the answer. Suppose the car gets stuck on the muddy road, and one horse can't pull it out—you would of course get two, three and more horses, hitching them to the car in such a way that their individual forces, adding together, would be strong enough to pull the car out.

Likewise if one battery furnished 45 volts, two batteries connected so that their electron urges add would produce 90 volts, and three would

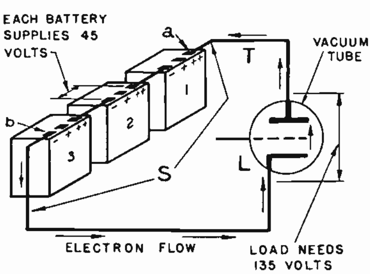


Fig. 5. A problem in addition: One battery gives only 45 volts, but the load demands 135 volts. Three batteries connected in series as shown will add their voltages to meet the demand of the load and solve the problem.

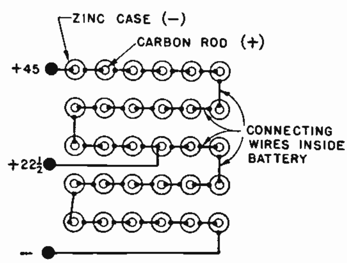


Fig. 6. A 45 volt B battery contains 30 separate dry cells, connected in series as shown here. Batteries or cells should always be connected *in series* when you want the greatest voltage.

give three times 45 volts or 135 volts. The method of connecting batteries together in succession or *in series* to get a higher voltage is shown in Fig. *5*. Isn't it obvious that all three batteries are acting on the same electron flow, each battery giving these electrons an urge or push of 45 volts? Electrons flow into *a*, through the batteries and out of *b*.

B Battery Connections. Discussing B batteries brings us to the method by which a battery delivers 45 volts. As you know, B batteries are made up of a number of small dry cells, each about the size of a flashlight cell, and each capable of delivering 1.5 volts. If thirty such cells are connected in series as shown in Fig. *6* so that their voltages add, they will give 30 x 1.5 or 45 volts. A 22½ volt tap is obtained by making connections to the positive terminal of the 15th cell in the group. Remember, the center terminal in a dry cell is (+) and the zinc case (—).

Another example of a series connection, a practical radio problem which you will encounter in battery receivers and in radio testing equipment, is given in Fig. 7. The load (the filaments of the tubes in this radio set) requires a 2 volt source, and when connected to it draws ½ ampere of current. Suppose that you have on hand a quantity of No. 6 dry cells, each of which can supply a voltage of 1.5 volts and handle a current of ½ ampere. Here, then, is the problem—one cell gives too low a voltage for your purpose, and two cells in series give 3 volts, which is too much. Three volts would send too great a current through a 2-volt tube, burning out its filament. The solution to this problem is simple—use two cells in series, and connect into the circuit a series resistor which will drop 1 volt of the source voltage. A series resistor used in this manner is often called a "current limiting resistor," because it limits the load current to a safe value. You will find these resistors in every radio circuit where the available D.C. voltage is too high.

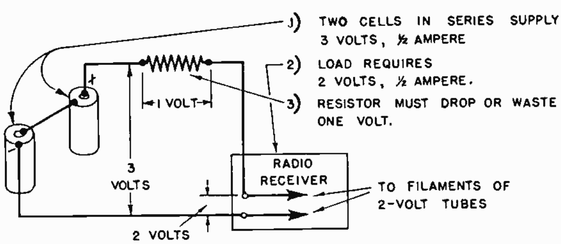


Fig. 7. A three-volt battery and a resistor hooked up like this can be used to supply exactly two volts for the filaments of tubes in a radio receiver. The resistor limits the filament current to the correct value by using up or dropping one volt of the source voltage. The same current flows through all parts of a series circuit like this, and consequently the resistor will have the same effect regardless of where it is located in the circuit. It may be in the positive lead from the battery (as shown), in the negative battery lead, or in the lead which connects the two dry cells.

When a Higher Current Is Required. You know now how the voltage of a D.C. source can be increased or decreased; suppose, however, that after the batteries are connected to give the correct voltage, they cannot economically or safely deliver the needed current. What is to be done?

Figures *8A*, *8B*, and *8C* will help you to understand the solution to this problem. Suppose that the load shown in Fig. *8A* is a powerful modern battery receiver having a built-in current-limiting resistor, so that a 3-volt battery capable of delivering 1 ampere of current to the tube filaments is required. Two dry cells in series will provide the correct voltage, but what about the current? A No. 6 dry cell, the largest made, is not designed to deliver currents as large as 1 ampere efficiently for long periods of time; the cell will last *more than twice* as long when supplying ½ ampere as when supplying 1 ampere.

In Fig. *8A* I assumed that the source *A* was two dry cells in series, supplying a current of 1 ampere; in Fig. *8B* another source *B*, exactly the same as *A*, is also connected to the load. What does source *B* do? Naturally it takes over half the job of supplying current to the load, and delivers ½ ampere of current. Source *A*, relieved of half of its work, now has to supply only ½ ampere, which is a more ideal current drain for the dry cells used. The actual and more practical connection of these two sources, each source consisting of two dry cells in series, is given in Fig. *8C*. Two dry cells in each group are connected in *series* to give the required 3 volts, and the two groups are connected in *parallel* to give the required 1 ampere without overloading any one cell; this arrangement of cells is therefore known as a series-parallel connection.

Tracing Electron Flow in Series Connections. You can always identify series connections of electrical sources by the fact that the same electron flow passes through each of the interconnected sources. In Fig. *5*, for instance, battery #**1* pushes electrons to its negative terminal and on to batteries #*2* and #*3*, each of which gives the electrons an equally strong push; each battery contributes its electron urge to the flow of electrons, and consequently the voltages of the individual batteries add together in this series circuit. Every electrical generator connected into a series circuit must be able to handle the maximum current which will pass through the entire circuit. Cells or batteries connected together in series can be considered as a single battery whose voltage is equal to the sum of the individual battery voltages. For example, if you were to connect together in series five batteries having voltages of 45, 9, 2, 6, and 3 volts respectively, the total voltage would be 65 volts, and the group of batteries would for all electrical purposes be equal to a single 65 volt battery or D.C. generator.

Tracing Electron Flow in Parallel Connections. You have seen that the tracing of electron flow through series connections of generators amounts to no more than tracing electrons through a single large battery made up of a number of smaller batteries and individual cells connected one to the other in a single line. In parallel connections of electrical generators the situation is slightly different. With two sources connected in parallel and having the polarity indicated in Fig. *8B*, you know immediately that electrons will flow out of the negative terminal of each source. Starting at these points, trace the electron flows to the point where they meet to go through the load. Since source *A* and source *B* are each supplying ½ ampere, the total current supplied to the load will be 1 ampere. Just as many electrons must return to a source as leave it; therefore the electron flow divides equally after leaving the load, half returning to source *A* and the other half to source *B*.

Figure *8B* shows the electrons taking two separate paths between the sources and the load, but I could just as well connect the negative terminals of *A* and *B* together, as is done in Fig. *8C*, and have the electrons from both sources flow through the same wire. Electrons flow out of the (—) terminal of each battery in the same manner as in Fig. *8B*, move

* # Represents Number.

to the junction with the single load wire, pass through this wire to the load, then return through the load and the other wire to the (+) junction, where electron flow divides equally to return to the (+) terminals.

When batteries are connected in parallel, as in Fig. *8C*, each must have the same e.m.f., for otherwise the battery having the higher voltage would do the most work and would even push electrons back into the lower voltage source.

So far I have considered all electrical generators as being perfect, *but no generators, and therefore no batteries, are perfect.* A battery has internal resistance, and hence we must consider it as a voltage source acting in series with this resistance between the battery terminals. As a dry cell battery ages, the ohmic value of this internal resistance goes up,

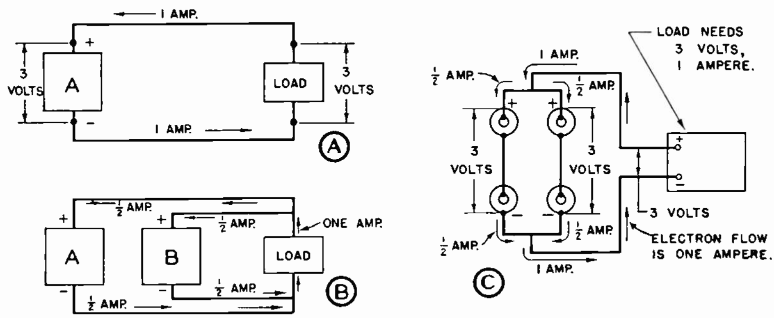


Fig. 8A. The box marked *A* represents a battery which is built to deliver only ½ ampere; this battery won't last long in this "greedy" circuit, which takes 1 ampere!

Fig. 8B. Help has arrived! *B*, another battery just like *A*, takes over half the work.

Fig. 8C. A "share-the-work" connection, which is exactly the same electrically as that in *Fig. 8B*, is shown here; two batteries connected in parallel feed one load.

while the internal voltage source value remains essentially the same. Under no-current conditions, the terminal voltage of a battery is the same as the internal source voltage. When current is drawn from a battery, however, the terminal voltage is lowered by an amount equal to the voltage drop produced across the internal resistance by this current flow.

When batteries with different internal resistances are connected in parallel to a load, the battery currents will automatically adjust themselves to values which make the internal voltage drops of all batteries the same; the terminal voltages will then also be the same. This means that the battery having the lowest internal resistance must supply the most current to the load in order to produce its required internal voltage drop.

Parallel and Series-Parallel Connections of Generators. The ten battery connections given in Fig. *9* are really a review of material you have already covered. You will recognize those in Figs. *9A, 9B* and *9C* as simple series connections, with the voltages of the cells adding to make up the e.m.f. of the group. Figures *9D, 9E* and *9F* are likewise familiar, being parallel connections in which the voltage of a group is the voltage of each individual cell in the group. Batteries should be connected together *in series* when you want to get *the greatest possible voltage;* batteries should be connected together in parallel to get the greatest possible current.

Figures *G, H* and *I* show how cells are first connected in series to give greater voltage, and then series groups of the same voltage are connected together in parallel to provide greater current output. The voltage of the combination in any case cannot exceed that of one series group; as many cells as desired can be connected in series, and as many groups can be connected in parallel as are required to supply the required current, as long as each group has the same voltage.

Many dry cells are often connected together and placed in a wood or metal box having two terminals. One example of this is the common 6-volt "Hot-Shot" ignition battery. When four dry cells are connected in series-parallel as at *G* to form one of these combination batteries, and you connect two of these groups in series to deliver 6 volts, the connections inside and outside the groups will be as in Fig. *9J*. Note that connections *I* and *J* give the same voltage and current, even though the connections are slightly different. If you remember to treat groups of cells or batteries as the equivalent of a single battery, you cannot go wrong.

LOADS IN SERIES AND PARALLEL

Just as batteries can be connected together in many different combinations to supply the correct voltage and current to a single load, so can loads be grouped together in series or in parallel to match the voltage and current available from a common source. Actually this grouping of loads, such as the connecting of thousands of light bulbs and appliances to a single power plant generator, is the only economical and practical procedure to take. Large electrical generators generate electricity at a very low cost per unit of electrical energy.

In radio, too, loads are grouped together. Good radio sets have anywhere from five to ten or even more tubes, each of which must be supplied, among other things, with plate voltage and filament voltage. Instead of using separate power supplies for each tube, we use one common source for filaments, and another for the other electrodes.

A Four-Tube Radio Circuit. You are already familiar with the case where one vacuum tube filament (a short length of resistance wire) is to be heated (Fig. *1A*), so I will start with a four tube circuit like that in Fig. *10A,* in which the filaments of all tubes are alike. Here the tube filaments, drawn in the usual symbolic form, are connected together in series and the group is connected to the common source *S,* which I am showing as simply a box with a (+) and a (—) terminal. Electrons flow out of the (—) terminal, through the filaments of tubes *#1*, *#2*, *#3* and *#4* in succession, and finally return to the (+) terminal of the source. The same current passes through each filament, since no electrons can leave the wire or take "short-cuts" in a series circuit.

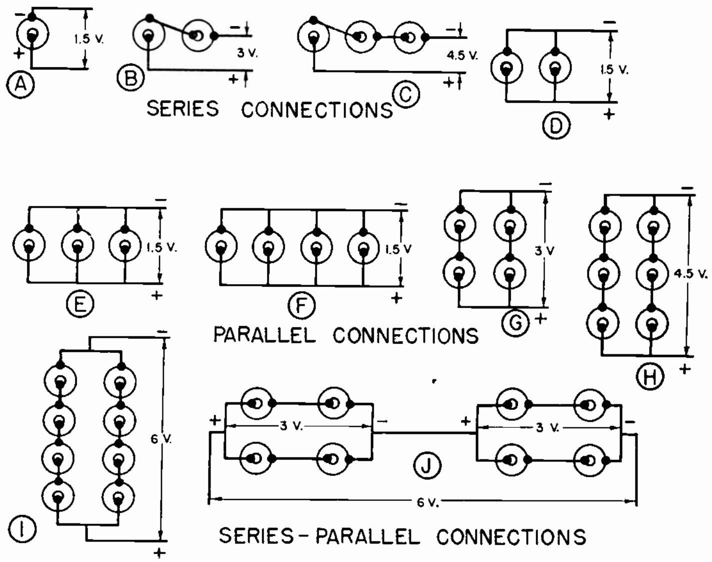


Fig. 9. Here are just a few of the many ways of connecting cells and batteries to obtain different voltages and currents. Series connections give maximum voltage; parallel connections give maximum current; series-parallel connections provide a compromise between maximum voltage and maximum current.

If the rated voltage of each filament is 2.5 volts (meaning that each tube requires this voltage to send normal current through the filament), then all four filaments together will require four times 2.5 volts, or 10 volts. The source must therefore supply 10 volts; if it has a higher voltage the surplus will have to be dropped or wasted by a resistor connected in series with the tubes, just as was done in Fig. *4*.

In 110-volt D.C. radio receivers and in universal 110-volt A.C.-D.C. receivers, the filaments of the tubes are usually connected together *in series*, as shown in Fig. *10A*.

Filaments in Parallel. What could be done if the only source available for heating these four filaments had a voltage of 2.5 volts? This is only the voltage required by one tube filament, but if these tubes are connected in parallel so each gets the same voltage, as in Fig. *10B*, everything will work out all right. Assuming that each tube takes a current of 1 ampere, the electron flow out of the (—) terminal of the source must be 4 amperes. Tube *#1* will take 1 ampere of this, leaving 3 amperes to flow on to tube *#2;* 1 ampere less will flow to tube *#3*, and exactly 1 ampere will flow to tube *#4*.

In Fig. *10B* we show the filaments of vacuum tubes connected in parallel as used in A.C. sets. Tubes connected in series should all have the same filament current rating, but can have any voltage rating. Tubes connected in parallel can on the other hand have any current rating as long as the voltage rating is the same for each tube. Of course, you could supply any tube or electrical device with more or less voltage or current than the rated value, but the performance of the device would in general be quite unsatisfactory.

Unlike Tubes in Series. Suppose that a number of tubes are to be connected in series, but one requires *less* filament current than the others—what can be done? Why not provide a shortcut around this one tube for the unwanted current? The manner of doing this is shown in Fig. *10C*, where tube *#2* has a lower filament current rating; resistor R is connected across (in parallel with) this tube, making part of the total current go through the tube and part through the resistor. By selecting the correct value of resistance for R, tube *#2* will get its proper amount of current. Incidentally, I have shown in this circuit (Fig. *10C*) tubes having a cathode and a plate. The cathode encloses the filament in an actual tube and emits electrons when heated by the filament, and the plate P receives the electrons sent out (emitted) by the cathode. There is no electrical connection between the cathode K and the filament; this is one method of separating the common supply voltage from the other circuits of the tube, assuring independent operation of each tube. The filament resistor connection shown in Fig. *10C* is quite common in universal and 110-volt D.C. receivers.

Here is another practical radio example. Assume that you have a 6 tube radio receiver in which four filaments require 2.5 volts and two require 5 volts. Figure *10D* shows one way of making the connections to a single 5 volt source, while Fig. *10E* shows how this situation is met in an actual radio receiver. In the latter case two sources, which would be separate secondary windings on the same power transformer, are used.

Connecting Tube Plate Circuits in Parallel. The plates of several vacuum tubes can be connected to a single (common) source. Consider the plate (P) and cathode (K), terminals of the vacuum tubes in Fig. *10F* to be the load terminals, and you will see that here the plate circuits of the three tubes are connected in parallel. I am neglecting the filament circuit source in this case, since it is entirely independent of the cathode. The condensers marked C prevent the common plate supply from interfering with the operation of each tube. Radio or audio frequency signals in the plate-cathode circuit take the path through C to the cathode instead of going through the source and getting mixed up with signals which belong to other tubes. But this is all away ahead of this lesson—just remember that many radio tubes can be operated from a common source, and forget about methods of separating signals from supply voltages until later lessons.

While I have by no means covered all possible connections of loads to a common source, I have given enough to show that you can connect

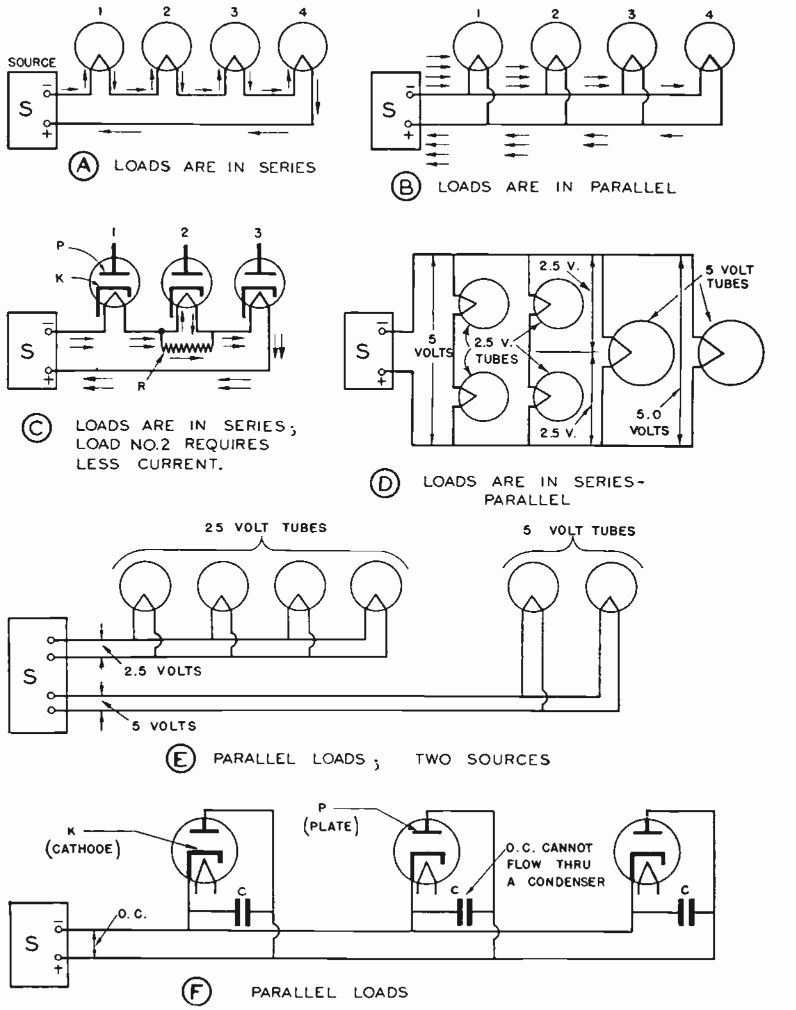


Fig. 10. These examples of practical load connections are in many radio receivers.

any number of loads together in any possible manner if the connections are such that each load gets rated voltage and current, and the source is capable of supplying the current required. Keep in mind these facts: All connections are either series, parallel, or a combination of the two, and groups of loads connected together can be considered as a single load as far as the source is concerned.

PRACTICAL CONNECTIONS

Before going on, I want to point out that the actual wire connections in a radio circuit may appear quite different from those which I have shown here. A simple circuit like that in Fig. *1A* rarely confuses anyone, for the polarity is always marked on the source and oftentimes on the load as well. In radio work, connections are always made to tube sockets instead of to the tube prongs; tubes are so designed that they can be plugged into the socket in only one way.

Figure *11A* shows how a single source would be connected to a single load. The (—) terminal of the load (if marked) is connected to the (—) terminal of the source; the (+) terminals of the load and source are likewise connected together.

When three vacuum tube filaments are to be connected in parallel to a common source, the schematic circuit diagram would be like that in Fig. *11B*, because this is the simplest and neatest way of showing the correct connections. To actually show *how* the connections would be made, you would have to make sketches like those in Fig. *11C* or *11D*, which show the position of every wire. The latter circuit is more practical since it requires the least amount of wire and has the least number of connections. In making connections like those in Fig. *11D* the Radio-Trician would use only two lengths of wire, one going from *1* to *4*, and the other from *5* to *8*, and he would scrape insulation from the wires to make contact to terminals *2*, *3*, *6*, and *7* respectively. Study these circuits carefully and you will see that Figs. *11B*, *11C* and *11D* are the same electrically.

Two of the many other possible practical connections for these three tubes are shown in Figs. *11E* and *11F*; these differ from the first connections only in the positions of the parts. Circuits *C*, *D*, *E* and *F* all correspond to the original diagram in *B*, for in each terminals *1*, *2*, *3* and *4* are connected together; the order in which the connections are made, or the amount of wire used, does not ordinarily matter. Remember that schematic * circuit diagrams like those in Fig. *10* and in Fig. *11B* only show the electrical connections—not the actual layout or wiring. Practical connections are nearly always made at the terminals of either the source or load instead of from wire to wire.

A RADIO VACUUM TUBE CIRCUIT

You have in your mind a "picture" of the operation of a complete radio system containing a transmitter and a receiver, and you have just learned about simple circuits; now I will show you how to identify and trace the circuits in an amplifier stage such as might be found in any radio set. You are now getting into real circuit diagrams, for it

* Pronounced "skeematic." This word comes from "scheme"—a plan.

is perfectly possible that the circuit diagram in Fig. *12A*, which will be studied next, is like that for one of the stages in your own radio receiver. Since many of the symbols used are unfamiliar to you, I have shown in Fig. *13* pictures of the radio parts which are considered.

This amplifier stage is designed to build up the strength of a weak audio frequency signal; that is, if a 1 volt signal is fed into the amplifier, the strength of the signal delivered by the amplifier might be 5,

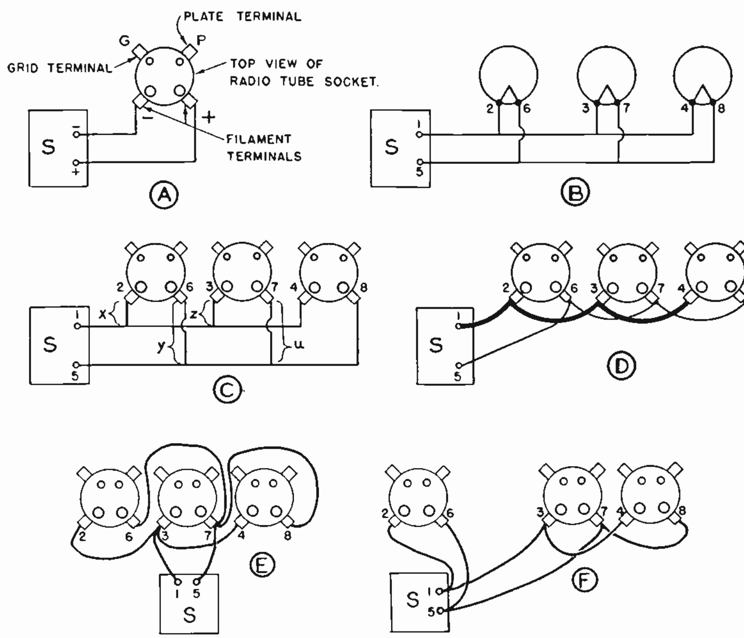


Fig. 11. A wiring diagram like that shown at *B* only tells which terminals of a circuit should be connected together; it does *not* show the actual *location* of the *terminals* or *wires*. Sketches *C, D, E* and *F* show just a few of the many possible correct connections for the three tubes shown at *B*. Keep leads *x, y, z,* and *u* in *C* as short as possible or eliminate them entirely as is done at *D*.

10 or 50 volts, depending upon how much amplification the amplifier was designed to produce. It is the radio tube, the heart of any radio circuit, which "does the trick," but naturally it requires operating power from some source other than from the input signal. The filament of the tube must be heated, so it will in turn heat the cathode and make it emit electrons; the plate must be given a continuous positive charge so it will attract electrons continuously, and the grid must be given a negative charge with respect to the cathode, if the tube is to operate in the best possible manner. Reasons for these things will come later—now I will show you how the power is supplied to each of these three parts of the tube—the filament, plate, and grid.

Power Supply Circuits. I am considering an A.C. operated amplifier stage, as you have undoubtedly guessed from a glance at the power line plug (P_g) and transformer T_2, both shown in Fig. *12A*. When you insert this plug into an outlet in the wall of your home, it takes power from the dynamo electric generator which is operating in the central power station. Forget about this power station, however, and simply consider the wall outlet in your home as the electrical source of power. It supplies alternating current power to the power transformer which is marked T_2 on the diagram, this transformer having one primary winding marked P and two secondary windings marked S_1 and S_2. In this way we secure two power sources from one, for in a transformer power is transferred from one winding to others by the magnetic field which passes through the iron core linking all of the windings (coils). Just remember, for the present, that a transformer transfers power from one winding to another.

The secondary winding S_1 furnishes an A.C. voltage to the filament of the tube. Trace through this filament circuit; starting at F_1, electrons flow to the tube terminal F_2, through the filament, out at F_3 and through the return lead to the secondary winding terminal F_4. As the source is A.C., the direction of electron flow will change in the next alternation of the supply voltage. There is a source, a load, and two connecting wires; thus we have a complete filament circuit, as shown in Fig. *12C*.

With the filament power supply taken care of, I will consider the plate supply circuit next. The source here is the transformer winding S_2, which I have shown as feeding into a box representing a rectifier; this is a device which changes A.C. power to D.C. power in a manner which will be covered later in the Course. You could call S_2 the source, the rectifier a load, and thus say that you had a complete circuit including these two parts and the connecting wires, as shown in Fig. *12D*, but I want you to concentrate your attention on the output terminals of the box, which are labeled R_1, R_2, R_3 and R_4. This is the D.C. source which supplies power to the plate-cathode load and to the grid-cathode load. I will next trace through these circuits with you.

Plate Circuit. Vacuum tubes are guide-posts which point out the direction of electron flow in a circuit, for a radio tube *electrons always flow from the cathode to the plate inside the tube.* I will make use of this fact here by starting to trace the *plate circuit* electron current at G_3, the cathode terminal of the tube (Fig. *12E*). Electrons flow from the cathode to P_1, the plate; from there they go to P_2, and through the primary winding of the output transformer T_1 to terminal P_3. Remember that we are tracing a direct current circuit, and that direct current cannot pass through a condenser; we can therefore neglect condenser

C_P for the present time, and say that electrons next flow to terminal R_1, the positive terminal of the rectifier. Considering this rectifier as the source, electrons will flow out of terminal R_2, the negative terminal of the source, and back to G_3, the starting point.

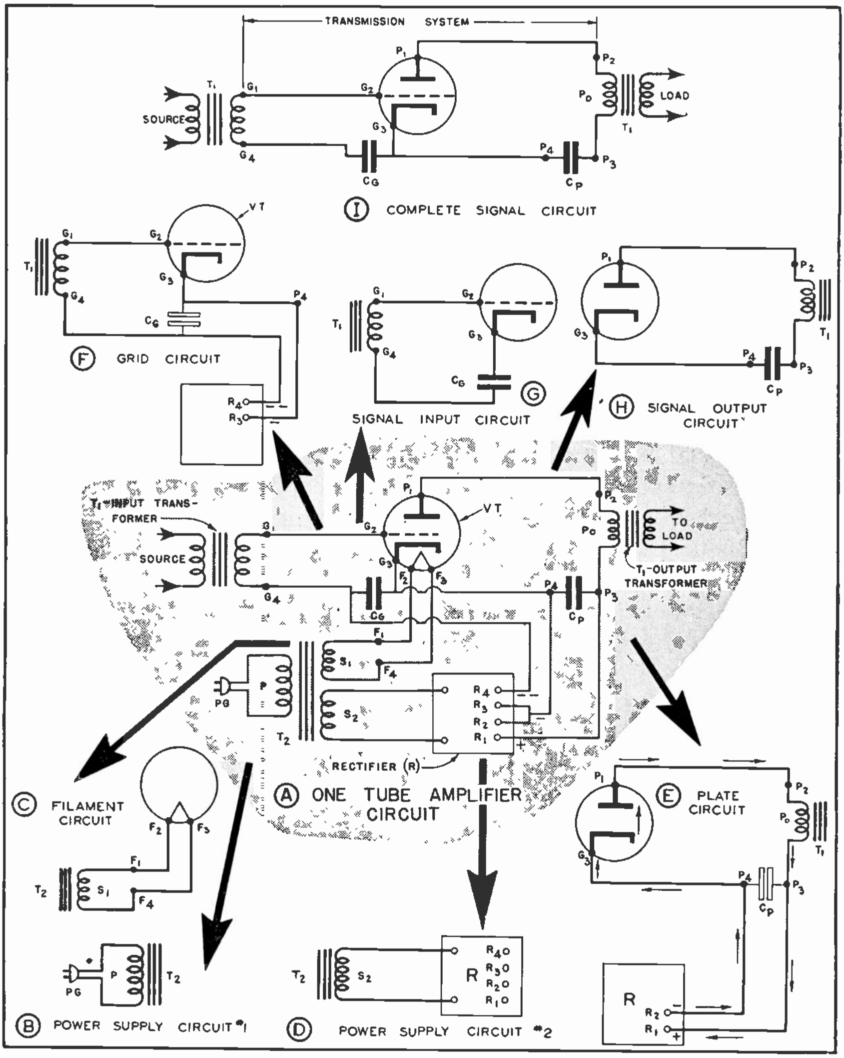


Fig. 12. Circuit tracing is easy when you learn to recognize the many little guide-posts. *A* is a typical A.C. operated, one-stage amplifier; around it are the eight separate circuits in it. The double minus sign (— —) means R_4 is more negative than R_3, or, stated in another way, R_3 is positive with respect to R_4. It is the difference in potential between any two points in a circuit which causes electrons to flow. More details of tube circuits will come in later lessons in the Course.

The output transformer winding T_1 has nothing to do with the power supply circuit, but, as you will see later, is used for another purpose, that of feeding the amplified radio signal to the next stage. This transformer simply reduces the plate voltage of the tube a small amount, because the transformer winding has some ohmic resistance.

Grid Circuit. The grid circuit is just as easy to trace; follow it through on Fig. *12A* first, then check your circuit against that in Fig. *12F*, remembering that condensers are "Detour—Road Blocked" signs to direct current.

Signal Circuits. The signal input circuit is easily identified if you remember the definition of "circuit" as a combination of a source, a load, and a transmission system. Signals coming from the source are transferred by magnetic induction to the secondary winding of the input transformer T_1. Terminals G_1 and G_4 (Fig. *12G*) are then the source terminals of this signal input circuit. When dealing with audio frequency or radio frequency signals, which are of course alternating current, the direction of electron flow is unimportant; it is enough to say that the signal at terminals G_1 and G_4 is fed to the load terminals of this circuit, G_2 and G_3. Condenser C_G here allows the A.C. signal to pass, completing the grid signal or signal input circuit.

In the signal output circuit the terminals G_3 and P_1 of the tube serve as the source, and terminals P_2 and P_3 of the output transformer T_1 are the load terminals. Condenser C_P here acts as a "short-cut," allowing signals to get to the load without going through the rectifier. The complete plate signal circuit is shown in Fig. *12H*.

The circuits in G and H can be combined to form the single complete signal circuit shown at I; here the vacuum tube acts as a special type of transmission system, strengthening or amplifying the signal.

Although these eight circuits are woven together to form one complete amplifier circuit, each can be studied separately, as you have seen. You should realize by now that a device which is the load for one circuit may be the power supply for another.

A radio receiver is really an assembly of many circuits like this, each feeding a radio or audio frequency signal to the next stage, and each stage contributing its share of work to the building up or the changing of the radio signal, until the final powerful output signal is fed to the loudspeaker. Each stage has its own supply circuits, all of which may take power from a common source such as a rectifier. In reading any radio circuit diagram, large or small, first trace the supply circuits, then trace the signal circuits, just as I did for this one tube amplifier stage. *Remember that electrons flow from the cathode to the plate inside a vacuum tube.*

Obviously you will have to learn a lot more about radio before you can understand the operation of complete radio circuits, but you have made a good start here by learning how to separate one large circuit into its many smaller circuits.

What a Radiotrician Usually Measures. Most radio troubles occur because some part of the circuit is receiving the wrong voltage, because the current through some part is not what it should be, or because one circuit is open or shorted, cutting off the power. Radio servicing actually "boils down" to the checking of the supply circuits for each tube, checking the common source of power, and making sure that the signal circuits are working properly. The signal circuit can be checked with special testing equipment which will be discussed later. In any event, the Radiotrician has to measure only three things when checking radio supply and signal circuits, to tell when a part or circuit is operating correctly: *1. Voltage; 2. Current; 3. Resistance.**

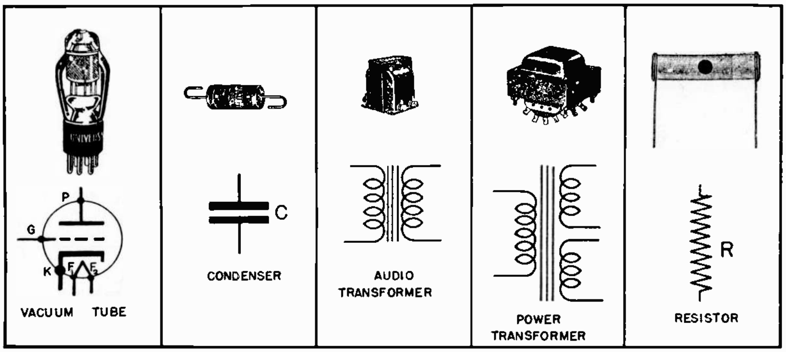


Fig. 13. In your radio work you will encounter these five parts and their symbols many times; learn to know them.

Voltage is, as you already know, the generated e.m.f. or that amount of it which is dropped in any part of the circuit when current flows through that part. A voltage will exist across any two points or terminals of a device having resistance if a current is passing through that device.

The volt is the unit commonly used when measuring voltages; volts are measured with a voltmeter. Just as length is measured in miles, feet, or inches, depending upon which is most convenient, so is voltage measured in volts, millivolts or microvolts, the latter two being smaller units. One volt is equal to 1,000 millivolts or 1,000,000 microvolts.

Current, whether considered as a flow of electrons or positive charges, is measured in *amperes.* To measure the current flowing in any circuit,

* Condensers and coils also have *reactance,* which is a lot like resistance except that it comes into effect only when the current is changing (as in A.C. circuits). Reactance and resistance are both measured in the same unit—the ohm. More about reactance comes later in the Course.

all you have to do is break the circuit at some point and connect an ammeter (a current measuring instrument) to the two wires provided by the break. In radio work currents are usually a good deal less than one ampere; for convenience two smaller units, the milliampere and the microampere, are used. One ampere is equal to 1,000 milliamperes or 1,000,000 microamperes.

ELECTRICAL MEASURING UNITS

Voltage	Abbreviation	Current	Abbreviation	Resistance	Abbreviation
Volt	v.	Ampere	amp. (or a.)	Ohm	Ω or ω
Millivolt	mv.	Milliampere	ma.	Kilo ohm	MΩ or Mω
Microvolt	μv.	Microampere	μa.	Megohm	meg.
Kilovolt	kv.				

Changing from One Unit to Another. It is easy to change from one unit to another if you remember what the prefixes used before the basic unit mean. (These prefixes come from old Greek words.)

Milli means one thousandth of
Micro means one millionth of
Kilo means thousands of
Meg means millions of

A glance at the following reference table will show you how to convert one unit to the other simply by moving the decimal point. No arithmetic is needed.

Values are Now In	In Order to Change To	Move the Decimal Point in Original Value	Example
a.	ma.	3 places to right	.027a. = 27. ma.
a.	μa.	6 places to right	.000350a. = 350. μa.
ma.	a.	3 places to left	462.ma. = .462 a.
ma.	μa.	3 places to right	.01 ma. = 10. μa.
μa.	a.	6 places to left	1875. μa. = .001875 a.
μa.	ma.	3 places to left	19.7 μa. = .0197 ma.
v.	mv.	3 places to right	.05 v. = 50. mv.
v.	μv.	6 places to right	.007 v. = 7000 μv.
mv.	v.	3 places to left	775 mv. = .775 v.
mv.	μv.	3 places to right	935 mv. = 935,000 μv.
μv.	v.	6 places to left	39 μv. = .000039 v.
μv.	mv.	3 places to left	1450 μv. = 1.45 mv.
ω	Mω	3 places to left	250,000 ω = 250 Mω
ω	meg.	6 places to left	5,500,000 ω = 5.5 meg.
Mω	ω	3 places to right	50 Mω = 50,000 ω
meg.	ω	6 places to right	7 meg. = 7,000,000 ω

Resistance is another term with which you are already familiar; the smallest convenient unit in which it is measured is the ohm. You can determine the resistance of any device by comparing it with a resistor whose size you already know, using a special testing circuit, or you can use a battery of known voltage, measure the current it will send through your device, and make a single calculation to give the resistance in ohms. A larger unit of resistance, the megohm, is used when the smaller unit is inconvenient; 1 megohm is equal to 1,000,000 ohms.

To help you convert volts, amperes and ohms from higher to lower units, I have prepared a chart of electrical measuring units. Study it now, learn the abbreviations, and refer to this data whenever necessary. Now let me describe the important radio measuring meters.

THE D.C. MILLIAMMETER, MOST POPULAR OF METERS

A milliammeter is an ammeter which measures current in terms of thousandths of an ampere. A D.C. milliammeter responds only to electrons which flow in the same direction all of the time; if this current is varying the meter will measure the average value. For instance, if you should connect a D. C. milliammeter to measure a current which was changing regularly from 3 to 5 ma., the meter would give a reading of 4 ma., the average value.

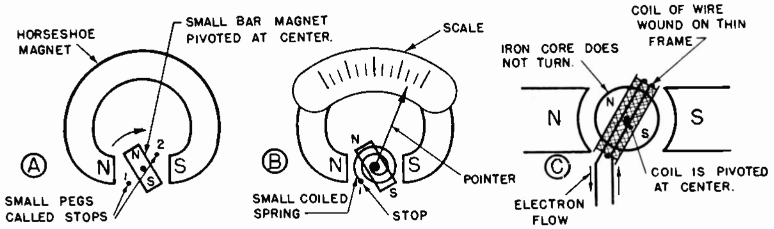


Fig. 14. Explaining the operation of a direct current milliammeter.

One of the easiest ways of measuring current is to measure the strength of the magnetic effect produced by the current. To show you how this is done, I will describe the underlying principles of a typical D.C. ammeter.

How It Works. First let me explain the principle by discussing an arrangement like that in Fig. *14A.* A small permanent magnet, bar-shaped, is pivoted so it can turn freely between the poles of a large horseshoe-shaped permanent magnet. Little metal pegs called *stops* prevent the bar magnet from turning too far in either direction. Remembering that like magnetic poles repel, can you tell which way the bar magnet will turn if in the position shown in Fig. *14A*? Naturally it will turn clockwise until its *N* pole bangs up against stop No. *2,* for like poles repel.

Now suppose that I removed stop No. *2* and attached a small coil spring between stop No. *1* and the bar magnet in such way that the spring opposed the magnetic turning forces. Now the bar magnet will turn until the magnetic force acting on it is balanced by the back twist of the spring. If I should attach to the bar magnet a pointer which is moving over a graduated scale, as in Fig. *14B,* the pointer would indicate the strength of the magnetic field of the bar magnet.

In order to determine the strength of a certain current, all you have to do is change the current into a magnet. This, as you know, is easily done by winding wire in the form of a coil and sending the current through the coil. Replace the bar magnet used in the previous arrangement with this coil, attach a spring as before to oppose the twist, put on a needle pointer and a calibrated scale, mount the entire unit in a glass-topped box, and you have a real D.C. milliammeter. The meter coil is mounted as shown in Fig. *14C* and current passed through in such a direction as to give the indicated polarity to the coil. The inside appearance of a commercial D.C. milliammeter is shown in Fig. *15*. The needle of a standard milliammeter will move to the maximum value on the scale when 1 ma. is flowing; more sensitive laboratory instruments give full-scale deflection for currents as small as 1 microampere.

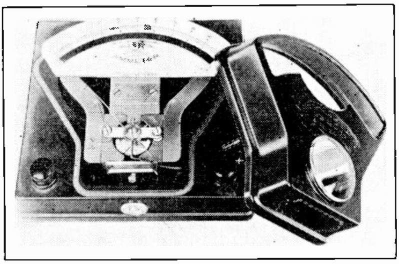


Fig. 15. This is what you would see if you looked inside a laboratory model D.C. milliammeter. Radio meters for D.C. use have very much the same construction.

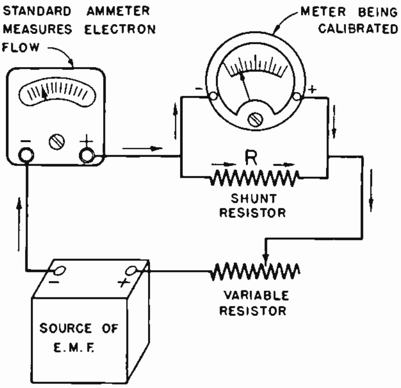


Fig. 16. This is one way of calibrating an ammeter.

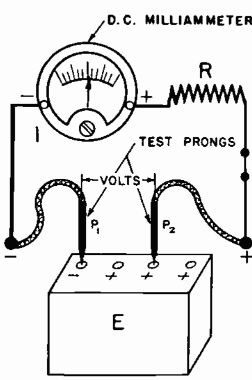
I am going to leave the question of calibrating meters for a later lesson in the Course, when you will study meters in greater detail; now I will simply give a few hints as to the procedure sometimes followed.

Calibration. You can always compare one milliammeter with another by connecting the two in series, as shown in Fig. *16*. You know that the same current must flow through both meters, they being in a series circuit, so select for comparison a standard meter which you know to be accurate. Place across the meter being calibrated a resistor *R* which will "sidetrack" some of the current. Now send enough current through both meters (by adjusting either the battery voltage or a separate resistor placed in series with the battery) to make the standard meter read that value which you want the meter being tested to indicate at its full-scale mark, then adjust the resistor *R* until this meter under test does read full-scale. That's all there is to this method of calibrating a meter; the resistor R is quite small in size, and is mounted permanently inside the meter case.

D.C. meters need to be calibrated at only one point on the scale, for once calibrated, the meter will read exactly ½ or ¼ scale when ½ or ¼ of rated current is passed through. Some meters are adjusted for full-scale deflection during calibration by adjusting the strength of the permanent magnet; on these, no shunt resistor is needed.

Increasing the Current Range With Shunts. The *range* of an ammeter is a rating indicating the current values which can be measured by that meter. For instance, on a 0 to 1.0 milliammeter you could measure any current between zero and the full-scale reading of 1 milliampere.

But suppose that I want to measure larger currents—what can I do? The answer is simple—provide a "short-cut"—a *shunt resistor* like R in Fig. *16*, for all current over 1 ma. If a 0-1 ma. meter is registering a current of 1 ma. (full-scale reading) and I connect in parallel with the meter a shunt resistor which will make the meter read only $\frac{1}{10}$th scale, I know only $\frac{1}{10}$th of the former current, or .1 ma., is now flowing



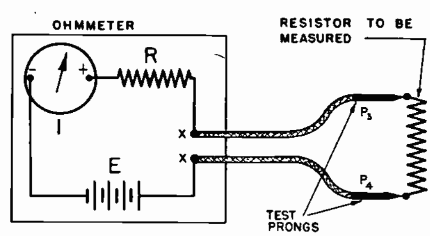


Fig. 17 (Left). Here a simple series resistor converts a D.C. milliammeter into a D.C. voltmeter.

Fig. 18 (Above). A milliammeter, used here as an ohmmeter, measures the ohmic value of a resistor.

through the meter. The remainder, .9 ma., must therefore be passing through the shunt resistor. Now I will have to pass 10 ma. through the combination of meter and shunt to get full-scale deflection—and thus I have a 0-10 ma. range meter.

Thus, you can increase the current range of a milliammeter *by using a shunt resistor*. When several different current ranges are needed, a shunt is provided for each range; when a particular range is desired, the shunt for that range is connected across the milliammeter terminals.

Using a Milliammeter as a Voltmeter. Most things are simple if you look at them correctly. Consider the circuit shown in Fig. *17*—a simple circuit containing a source E, an electrical resistance R, and a milliammeter *I*, all connected in series. The meter pointer, as I have drawn it, is about at the half-scale mark. By what two ways can I make the meter pointer move "up-scale"—to the right? Of course, you know the answer! Either increase the voltage of the battery, so it can push more electrons through *R*, or decrease the resistance (in ohms) of *R* to allow the original battery to push more electrons through. Here is how I can use this simple circuit to convert a milliammeter into a voltmeter.

Replace the battery *E* with another battery or D.C. source having the highest voltage which you desire to measure. Resistance *R* should be very large, to prevent the new battery from sending too much current through the meter. Now slowly reduce the value of *R* until enough current flows through the circuit to make the meter read exactly full-scale. If the battery voltage is 100 volts you now have a 0 to 100-volt voltmeter, with which you can measure any D.C. voltages up to this value. The resistance must always be used with this meter when measuring voltages; simply touch the test prongs P_1 and P_2 to the terminals of the source whose voltage you are measuring, being certain that the (+) prong of the meter is on the (+) prong of the battery. If the meter scale has 100 divisions, each division will represent 1 volt.

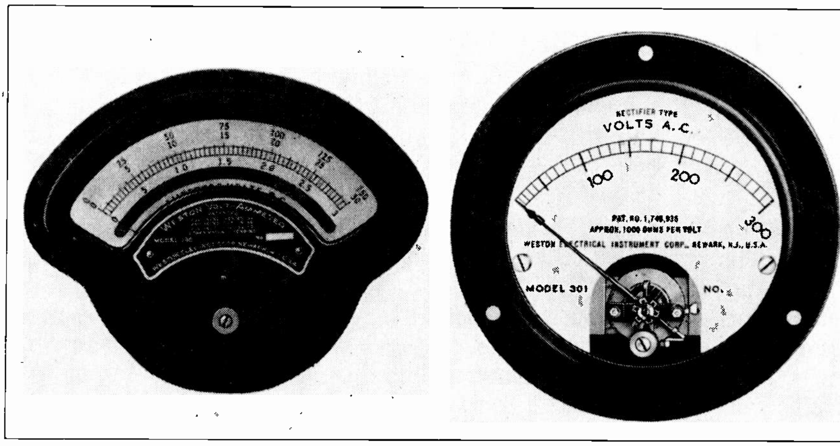
In the same way you can make other ranges of voltmeters, simply by connecting different sizes of resistors in series with the milliammeter. If you originally had a 0-1 ma. meter, resistor *R* would have to be 10,000 ohms to measure 0 to 10 volts; 100,000 ohms to measure 0 to 100 volts; 1,000,000 ohms to measure 0 to 1,000 volts. In other words, there is 1,000 ohms in the resistor *R* for each volt of the desired full-scale reading, and we say that the sensitivity of the voltmeter is 1,000 ohms per volt. High voltmeter sensitivity, obtained by using a very low range milliammeter (one capable of giving full-scale readings for a current of .5 ma. or less) is desirable in radio work, for then the value of *R* can be higher, the voltmeter will operate on smaller currents, and conditions in the circuit being tested will not change too much when the meter is connected.

Using a Milliammeter as an Ohmmeter. Returning to Fig. *17*, assume that resistor *R* is of the correct value to make the meter read full scale with a given battery in the circuit. If I break the circuit at *X* and connect to the two terminals a pair of flexible leads having at one end pointed connectors called probes or test prongs, I have the ohmmeter shown in Fig. *18*. When the test prongs P_3 and P_4 are connected to the ends of a resistor or other device, the meter will read full-scale when the device has a very low resistance, zero when the device has a very high resistance, and at intermediate points for other values of resistance. You can calibrate the meter scale to read in ohms by noting the meter reading for different sizes of standard resistors whose value you know, and marking these values right on the scale of the meter. Another way, which I will describe later in the Course, involves the use of simple arithmetic to compute the resistance values needed to give different meter readings.

Ohmmeters which are designed to measure resistances of 1 megohm and higher require sensitive milliammeters (operating on ¼ ma. or less) and high voltage batteries.

An ohmmeter must never be used in a circuit in which current is already flowing, for the extra voltage in the circuit being measured would send extra current through the ohmmeter, and probably ruin the meter.

An ammeter is always connected so that electrons flow *out of* its positive (+) terminal. If an ammeter pointer bangs against the stop which is to the left of the 0 mark on the scale, connections are wrong; simply reverse the connections to the meter. An ammeter must always be connected *in series with the load;* it will be burned out or seriously damaged if connected across a voltage source or drop.



The combination D.C. voltmeter and D.C. ammeter (left) and the rectifier type A.C. voltmeter (right) are typical examples of modern radio meters designed for panel mounting. A.C. meters are always calibrated to read r.m.s. values.

The positive terminal of a voltmeter should be connected to the positive terminal of the source or device whose voltage you are measuring; if the meter pointer moves in the wrong direction, indicating improper connections, simply reverse the connections to the voltmeter.

Let me repeat: Electrons flow out of the *negative* terminal of the source, but out of the *positive* (+) terminal of any devices connected to the source.

A.C. METERS

Alternating current is equally as easy to measure as D.C. But what can be measured, you ask, if the voltage or current is continually varying in value and in polarity? Actually the Radiotrician does not measure the A.C. voltage or A.C. current at any one instant for ordinary work; he is interested only in the *effect* of this varying voltage.

If two identical resistors are each placed in separate and identical glass containers, each of which has the same amount of water, and you send A.C. current through one resistor, D.C. through the other, the currents will be equal as far as their *effect* on the water is concerned, if they both take the same amount of time to make the water boil. If the D.C. current is 1 ampere, then the A.C. current—the effective value of A.C. current—is 1 ampere, too. If the e.m.f. which forces D. C. current through one of the resistors is 1 volt, then the effective value of the A.C. voltage which sent A.C. current through the other resistor is 1 volt.

R.M.S. Values. Effective values of A.C. voltage or current are also called r.m.s. values, r.m.s. being the abbreviation for "root mean square," a mathematical procedure which is necessary to compare the effective value with the peak value. Actually the effective value is about $\frac{7}{10}$ths of the peak (maximum or highest) A.C. value for simple sine values. Remember that effective and r.m.s. values are the same, and that they refer to the *equivalent D.C. heating effect* of an A.C. current or voltage.

Calibration of A.C. Meters. Regardless of how A.C. voltmeters or ammeters work, their scales *are always calibrated to read in r.m.s.* values (not in peak A.C. values). Most A.C. meters have non-uniform scales, with each division a different length and most of the readings bunched at one end of the scale. This means that the scale of an A.C. meter must be checked at many points during calibration.

The ranges of most A.C. voltmeters can be extended by using *series* resistors, and is done for D.C. voltmeters. Likewise A.C. milliammeters can be made to read higher currents by connecting resistors *in parallel* with the meter. An arrangement very similar to the D.C. ohmmeter circuit (Fig. *18*) is used to measure A.C. ohms (impedance), except that an A.C. voltage is used.

Rectifier Type A.C. Milliammeters. Most of the A.C. milliammeters used in radio work do not measure A.C. at all; instead they use a device called a rectifier or converter to change the A.C. into D.C., which can then be measured by an ordinary D.C. milliammeter. The meter scale must, of course, be changed to read r.m.s. values.

A rectifier is a device which allows electrons to pass through it in only one direction. The commonest of all rectifiers, employing copper and cuprous oxide elements, is shown in Fig. *19A*. This unit, often called a copper-oxide rectifier, is simply a surface of copper on which is a thin layer of cuprous oxide. Contact is made to the oxide layer with a square sheet of lead or soft copper, and the two pieces, with the cuprous oxide layer between, are bolted rigidly together. Electrons pass freely from the lead to the cuprous oxide, but very few can get through in the opposite direction. The symbols commonly used in radio circuits for a copper-oxide rectifier are shown in Fig. *19B*. The curves in Fig. *19C* illustrate how this rectifier allows current to pass in one direction only.

In a practical hook-up, four rectifier elements bolted together like those in Fig. *19D,* and connected to a D.C. meter in the manner shown in Fig. *19E,* are used. With this arrangement of rectifier units the A.C. current is automatically reversed each time it drops to zero, providing what is known as full-wave rectification. Now all of the A.C.

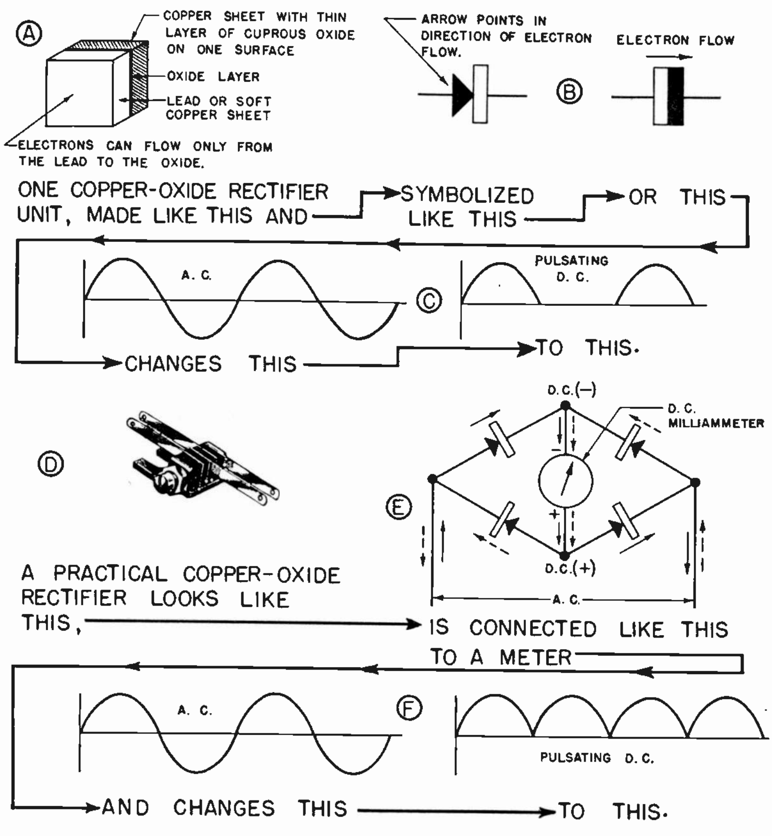


Fig. 19. This chart tells you all about the copper-oxide rectifier, a tiny little STOP-AND-GO device which allows electrons to travel only in one direction. Follow the heavy-arrowed lines from top to bottom.

current, rectified into a pulsating D.C. current, flows through the D.C. meter, making it give a greater deflection. The manner in which the current is rectified is shown in Fig. *19F.* Copper-oxide rectifier milliammeters may be used for power line frequencies and audio frequencies, but not for radio frequency currents. With series resistors they can be used to measure A.C. voltages as well.

Thermocouple Type Milliammeter. The copper-oxide rectifier cannot be used to measure high frequencies simply because it then acts as a small condenser, allowing the R.F. currents to pass through in both directions. For this reason another type of meter, the thermocouple milliammeter, is commonly used for making measurements in radio frequency circuits.

In this instrument, as you already know, a portion of the A.C. current is changed into heat which raises the temperature of the thermocouple junction, producing a D.C. voltage which sends current through a D.C. milliammeter (Fig. *20*). To calibrate a thermocouple milliammeter, it is only necessary to send known values of current through the instrument and make corresponding marks on the scale.

Another measuring instrument which changes A.C. to D.C. is the vacuum tube voltmeter; here an ordinary radio tube serves as the rectifier. This instrument will be studied later in the Course.

Conclusion. Remember that all A.C. voltmeters and ammeters, regardless of how they work, are calibrated so their scales read *r.m.s. values*.

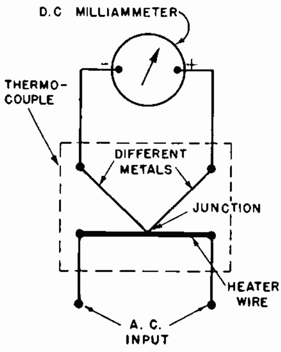
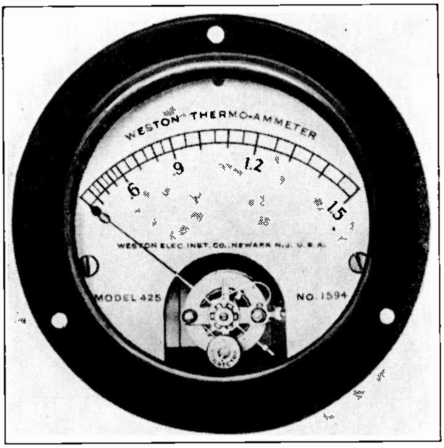


Fig. 20. **A thermocouple milliammeter is simply an ordinary D.C. milliammeter connected to a thermocouple in the manner shown in this diagram.**



This thermo-ammeter will measure any A.C. or D.C. current up to 1.5 amperes.

LESSONS TO COME

Now that you have studied the different types of simple and more involved circuits which are encountered in radio and know how to measure currents, voltages and resistances, you are ready to learn more about the individual parts—the resistors, coils, condensers, tubes, and transformers—which are used in radio circuits. In the following lessons you will find much interesting information on these devices—how they work, what they look like, where they are used, and what they do to different voltages and currents when used in circuits. I will take up resistors first.

TEST QUESTIONS

Be sure to number your Answer Sheet 4FR–1.

Place your Student Number on every Answer Sheet.

SPECIAL NOTICE

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

1. What name is given to that part of an electrical circuit which supplies power to the load?
2. What three essential parts are necessary in a complete electrical circuit?
3. What happens to a fuse or circuit when the current becomes too large?
4. What electrical device is commonly used to reduce the voltage of a D.C. source which is supplying current to a load?
5. How would you connect batteries to get the greatest possible voltage?
6. How are the filaments of tubes usually connected together in 110 volt D.C. radio receivers and in universal 110-volt A.C.-D.C. receivers.
7. In what direction do electrons flow inside a vacuum tube?
8. Which three things does a Radiotrician have to measure when checking radio supply and signal circuits?
9. How can you increase the current range of a milliammeter?
10. In which of the following values are A.C. voltmeter and ammeter scales always calibrated to read: *1*, r.m.s. values; *2*, peak values.

HOW RESISTORS ARE USED IN RADIO TO CONTROL CURRENT

5FR-2

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

HEADWORK ELIMINATES GUESSWORK

You've heard that old saying "Look before you leap"—well, this applies just as much to Radio as to anything else. Some people think they are just naturally born lucky; give them a problem and they'll guess at the solution once, twice, a dozen times, until finally, by the law of averages, they guess correctly. You've seen the type—cocky, energetic, handy with tools, but woefully short on good old common sense. Why, they'd tear down a whole radio receiver part by part rather than sit still and think for just one minute!

To you, a future Radio-Trician, time is money; that's why you can't afford to gamble with guesses. In this Course you will be given methodical procedures for solving common radio problems—speedy checking methods which eliminate one by one the possible causes of trouble, until finally there is only one cause, the correct one, left; after using this method, which I call "defect isolation", a few times, you will be able to locate troubles in a few minutes.

But a radio device, you know, consists of many individual circuits; defects in any one of these may make the entire device inoperative. This is why, when working with modern highly-complicated receivers, a methodical defect-isolation procedure may take considerable time. Gradually, however, as you get ahead with your studies, as you learn *why* this or that thing works, what happens in a circuit when a part fails, and gain actual radio experience, you will discover that extensive isolation procedures become less necessary. You will find that you have only to listen to an effect (a squeal, rasping noise, or other indication that a set is not working satisfactorily) to tell what is wrong and even give the location of the defect. Your ears will have become trained to recognize the "earmarks" of each defective part in a circuit—you will be using the best of all servicing procedures, direct "effect-to-cause" reasoning.

Many men like to figure out some of their problems mathematically, to know *why* certain things are so, while others want only *results*. For those practical men who are not interested in mathematical explanations I have included in this Course many valuable shortcuts; the Easy Calculating Charts in this Lesson are an example. For the others, who want complete information, I have included the formulas on which these shortcuts are based. I leave the choice up to you.

Learning to save time today means extra dollars for you tomorrow.

J. E. SMITH.

WASHINGTON, D. C.
1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

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How Resistors Are Used in Radio to Control Current

MORE ABOUT CIRCUITS

THE simplest possible circuit, as you know, has three basic parts—a source, a load and a transmission system. If the transmission system consists of wires which have very little resistance, then the load must take everything the source has to offer, whether it wants to or not. But some loads are particular, demanding exactly a certain voltage and a certain current—and here is where the transmission system enters the picture.

A transmission system can bring about a balance between a source and a load in two different ways. In the first, devices are inserted in the transmission system to hold back a part of the voltage of the source, thus reducing the load voltage; in the second, vacuum tube amplifiers and vacuum tube systems, which can make up either a part or all of the transmission system, may be used to raise the voltage or alter the characteristics of the source.*

From this you can see that the transmission system plays a very important part in most radio circuits. I will first take up the uses for the three basic electrical devices which are used in transmission systems to oppose current flow: *resistors, coils* and *condensers.* Although each of these three devices offers an opposition to electron flow which can be measured in ohms, each has a different action in a radio circuit. In this lesson I will consider only resistors in detail.

Remember that when a resistor opposes the flow of electrons, it absorbs electrical energy and changes this *electrical* energy into *heat* energy. You can for convenience consider any load which absorbs energy as a resistor. Coils and condensers act differently from resistors, however; although they oppose the flow of current, they store up rather than convert or waste electrical energy. That is why we say that coils and condensers offer an *apparent* or *effective resistance* (measurable in ohms) to the flow of A.C. power in a circuit.

The Three Forms of Electrical Opposition. Figure *1* tells you at a glance how resistors, coils and condensers control the flow of electrons in the simple series circuit shown above the chart. This circuit contains a source which may deliver or generate either D.C. or A.C. power, and a load; either a resistor, a coil or a condenser may be connected to terminals *A* and *B*, in series with the load. If terminals *A* and *B*

*Impedance matching, another use for transmission systems, will be taken up later in the Course. You will learn that in order to obtain the greatest amount of power from a source the impedance or resistance of the load must match (be equal to) the impedance or resistance of the source.

were connected by a wire, the current *I* which would flow in the circuit would be constant in value and would depend entirely upon the effective opposition of the load (assuming the source voltage is constant). Now I want to tell you only what happens to the current if either *R*, *L* or *C* is inserted in the circuit and either D.C. or A.C. is being generated by the source; further along in the Course I will give you the reasons.

Resistors. What happens when a resistor is connected in series with the load? The first row of facts in Fig. *1* contains the answer. First there is a picture of a typical resistor; next its symbol is shown together with the letter R_1 (the number following the letter distinguishes one resistor from another when they are in the same circuit). The next two columns tell you that a resistor will control the flow of A.C. as well as D.C. You are already familiar with the next fact, that the *higher* the value in ohms of a resistor, the *greater* will be its opposition to electron flow. Lastly, this chart tells you that the frequency of the current has no effect upon the performance of a resistor—that the opposition of a resistor to current flow is the same for all frequencies.

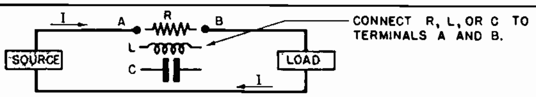
Coils. The behavior of coils is given in the second row of the chart in Fig. *1*. Coils are made in many different forms; that shown on the chart is called an *R.F. choke coil.* Since coils are generally wound with copper wire, they have a low resistance and are not of much use in controlling D.C., even though they allow this current to pass. With A.C., things are quite different, as you can see from the chart; a coil offers an opposition to A.C. current, this opposition increasing as the frequency of the current increases. Certain coils will stop practically all the R.F. current when connected into radio frequency circuits, without appreciably affecting the flow of direct current. Isn't it clear, then, that frequency must be considered when you measure the opposition of a coil?

The characteristics of a coil are combined in one word, *inductance,* a term which depends entirely upon the number of turns in a coil, upon the size and shape of the coil, and upon the material inside the coil (which may be either iron, air or some other substance). Increasing the length of the coil, the diameter of the coil, or adding some more turns of wire, increases the opposition of the coil to A.C. Electricity flowing through a coil creates a magnetic field; a coil thus *stores energy in magnetic form.*

Condensers. While coils store energy in magnetic form, condensers are devices which actually store *electrons.* The appearance of a typical radio condenser, the symbol, and the letter C_1 which is used to represent a condenser are given in the third row of the chart in Fig. *1*. Referring again to the simple circuit in Fig. *1*, a condenser will completely block or stop the flow of current when the source is D.C. This is what happens: Electrons flow for an instant after the battery is connected, these electrons giving opposite charges to the two condenser terminals. When the condenser is fully charged, electrons on that condenser terminal which is nearest to the negative terminal of the generator repel any additional electrons which the generator tries to push out, stopping the flow entirely. If the battery connections were now reversed, those electrons stored in the condenser would momentarily aid the battery in pushing electrons through the circuit, this flow of electrons stopping as soon as the condenser plates became charged again with the opposite polarity. A condenser acts something like your auto storage battery, storing electrons while being charged and emptying them out when discharging through a load.

When the source is alternating current the condenser plates are continually being charged and discharged. Electrons flow through the

THE CIRCUIT :



APPEARANCE	SYMBOL	DOES IT CONTROL D.C CURRENT ?	DOES IT CONTROL A.C. CURRENT ?	WHAT HAPPENS WHEN THE ELECTRICAL SIZE IS INCREASED ?	WHAT HAPPENS WHEN FREQUENCY OF A.C. IS INCREASED ?
 RESIS -TOR	R_1	YES	YES	OPPOSITION INCREASES	NO CHANGE IN OPPOSITION
 COIL	L_1	NO (CURRENT PASSES)	YES	OPPOSITION INCREASES	OPPOSITION INCREASES
 CONDENSER	C_1	NO (NO CURRENT PASSES)	YES	OPPOSITION DECREASES	OPPOSITION DECREASES

Fig. 1. **This chart tells you how a resistor, a coil, and a condenser will control the flow of electrons in the simple circuit given above. (Because a condenser completely blocks the flow of direct current, some engineers say that it does control direct current to this extent.)**

load during each reversal of the current, and energy is being absorbed by the load. Just as you would expect, current flows more easily through a condenser circuit when the frequency is increased, for then the condenser plates can discharge more often and be ready for another charge. The opposition of a condenser to the flow of current is therefore dependent not only upon the frequency but also upon the construction of the condenser. The larger the condenser, the more electricity it can store and the more current it will pass in an A.C. circuit; in other words, increasing the size of a condenser decreases its opposition to A.C.

Although the above discussion gives you only a brief idea of the characteristics of resistors, inductances and condensers, it will help you in understanding the detailed discussion of resistors which I am going to give next. You will learn more about the other two devices in future lessons.

HOW RESISTORS ARE MADE

Before taking up the behavior of resistors in different circuits I want to show you just how resistors are made and what they look like.

You have already learned that any material which contains free electrons is a conductor of electricity. Different materials have different numbers of free electrons, so naturally some conduct electricity better than others. A very poor conductor makes a good resistor, because it resists or opposes the flow of electrons.

How would you compare the electrical resistance of different materials? There are many ways, but the simplest that I know of would be to take a storage battery (because it supplies a constant voltage), connect it to exactly the same size samples of each material in turn, and measure the current which would flow through each. The following table, prepared by testing samples of the same size in this very way, gives the "relative resistance" of some of the materials which are often used in radio work.

TABLE OF RELATIVE RESISTANCES

Silver	.95	**Iron (soft)**	6.5
Copper	*1.00*	**Steel (hard)**	27.3
Aluminum	1.64	***Advance**	28.3
Tungsten	3.20	***Constantan**	28.5
Zinc	3.50	***Superior**	50.0
Brass	4.07	****Mercury**	56.0
Nickel	4.53	***Nichrome**	57.8
Platinum	5.80	***Nichrome II**	63.5
Tin	6.00	**Carbon**	450.0

* A special alloy or combination of metals which can be ordered under this trade name.
** Of course you would have to place the mercury in a glass tube.
Note: All values given here are approximate, since the resistance of a material varies with its purity and hardness.

Every value in this table is given with reference to the resistance of copper, for this metal is the best commercial and practical conductor of electricity. Brass, for instance, has 4.07 times the resistance of copper, so that if a certain brass wire allowed a definite amount of current to flow in a circuit, a copper wire of the same size would allow 4.07 times as much current to flow. Likewise, copper wire would allow 57.8 times as much current to flow as would Nichrome. These figures also mean that if a copper wire of a certain diameter and length had a resistance of 1 ohm, a Nichrome wire of exactly the same diameter and length would have *57.8 times* this resistance, or 57.8 ohms. The resistance of a Nichrome wire is thus *higher than* the resistance of a copper wire having exactly the same length and diameter.

If you were looking for good conductors, naturally you would choose either silver (which is quite expensive), copper, or perhaps aluminum, which is so much lighter in weight that it is often used in preference to copper for power transmission lines. If you wanted to build a good resistor you would choose Nichrome wire or perhaps carbon. But resistors should have a number of other important characteristics; you would want to know how heat affected the resistance of the material, how expensive, how heavy and how strong mechanically was the wire or material, and lastly you would ask whether the material could be economically manufactured in the desired shape and size. Carbon, for example, is quite brittle; it is next to impossible to make a carbon wire which will not break under ordinary use.

Certain liquids are very good resistance materials, although they are very rarely used in radio work. Your work will be mostly with metal and carbon resistors.

Metals are as a rule drawn (squeezed) into round or ribbon-shaped wire. The thinner the wire and the greater the length, the higher will be its resistance in ohms. Wire like Advance, Superior or Nichrome, having a high relative resistance, is generally referred to as *resistance wire.*

When resistance wire is wound on a convenient size of insulating form in order to concentrate the wire in a small space, we have what is called a wire-wound resistor. Where a resistor is not expected to become hot, the wire is simply covered with cotton or silk insulation to prevent one turn from touching the next; where the resistor is expected to develop heat, the wire used is covered with an enamel and baked to form a hard finish, or the wire is wound so that adjacent turns cannot touch. Baked enamel is a very good insulating material and at the same time is capable of withstanding a great deal of heat.

As you can see from the table of "relative resistances," carbon has a higher resistance for a given shape and size than any metal, and thus makes an ideal resistance material. Carbon in itself is too brittle for resistor use, and must be given "backbone" or strength. The first carbon resistors of high value were made by dipping strips of paper into a solution containing graphite (a form of carbon which is very finely powdered). When the liquid evaporated, leaving the carbon, the paper was placed in a protective glass tube and contact made to each end of the carbon strip to form a resistor. Lower resistances could be obtained by dipping the paper strips more than once, or by adding more powdered carbon to the solution. Even today some forms of these "coated resistors" are made in this way, except that a spray gun is used to apply a carbon solution over glass or porcelain rods rather than onto paper. A more recent coated resistor, known as the metallized resistor, is made by a secret process which involves placing metals in a liquid solution and then coating the backbone of the resistor, usually a glass rod or tube, with the liquid. Heating evaporates the liquid, leaving a thin, high-resistance coating on the glass.

Many of the disadvantages of carbon as a resistance material are overcome by mixing powdered carbon in varying proportions with the clay material from which porcelain is made. The mixture is squeezed into rods of varying diameter and length, then baked to form very hard and strong units which are called either "plastic carbon" or "ceramic carbon" resistors. Some ceramic processed resistors are no doubt being made today by mixing very small particles of metal with a plastic binder and then baking.

Resistors are continually being made better and better. Their life is being increased, and new manufacturing processes are being developed which turn out resistors by the thousands, all having very nearly uniform resistances. Whereas a few years ago only wire-wound resistors were used for accurate work, today you will find the new metallized resistors even in meter assemblies and in other apparatus requiring precision resistors. The ohmic value of a good metallized resistor remains quite constant over a long period of time, once the resistor has been *aged* (stored for a time so it will assume a fixed ohmic value).

INTRODUCING YOU TO PRACTICAL RADIO RESISTORS

You can classify resistors into three groups according to their *construction: 1, wire-wound* type; *2, coated* (or metallized) *insulator* type;

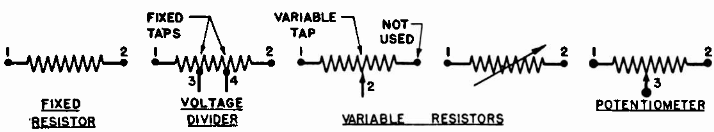


FIG. 2. These symbols are commonly used in radio circuit diagrams to represent resistors having four different kinds of electrical characteristics. Use either variable resistor symbol.

3, ceramic binder type. Resistors can also be classified according to their *electrical* characteristics: *a,* fixed resistors, which have a fixed *ohmic value* (value in ohms); *b,* voltage dividers, which are fixed in value but with intermediate taps or connections; *c,* variable resistors, called rheostats, which are variable in ohmic value; *d,* variable voltage dividers, called potentiometers, which are fixed in total value but have one or more variable taps or connections. Common symbols for four basic types of resistors (classified electrically) are shown in Fig. *2*.

Resistors in each of these different groups are shown in Fig. *3*. The simplest wire-wound fixed resistors, illustrated at *A* and *B,* are usually made of Nichrome or a similar wire wound on an insulating strip such as bakelite. These simple resistors are made with a wide variety of terminals in order to simplify their connection into various radio circuits. Sometimes resistors like that at *B* are wrapped in heavy fiber paper and covered with a piece of sheet steel, to give the appearance of the resistor at *C*. These resistors are called "canned" or "armored" resistors because they are placed in a metal "can" for protection.*

* Some are sold under the trade name "Candohm."

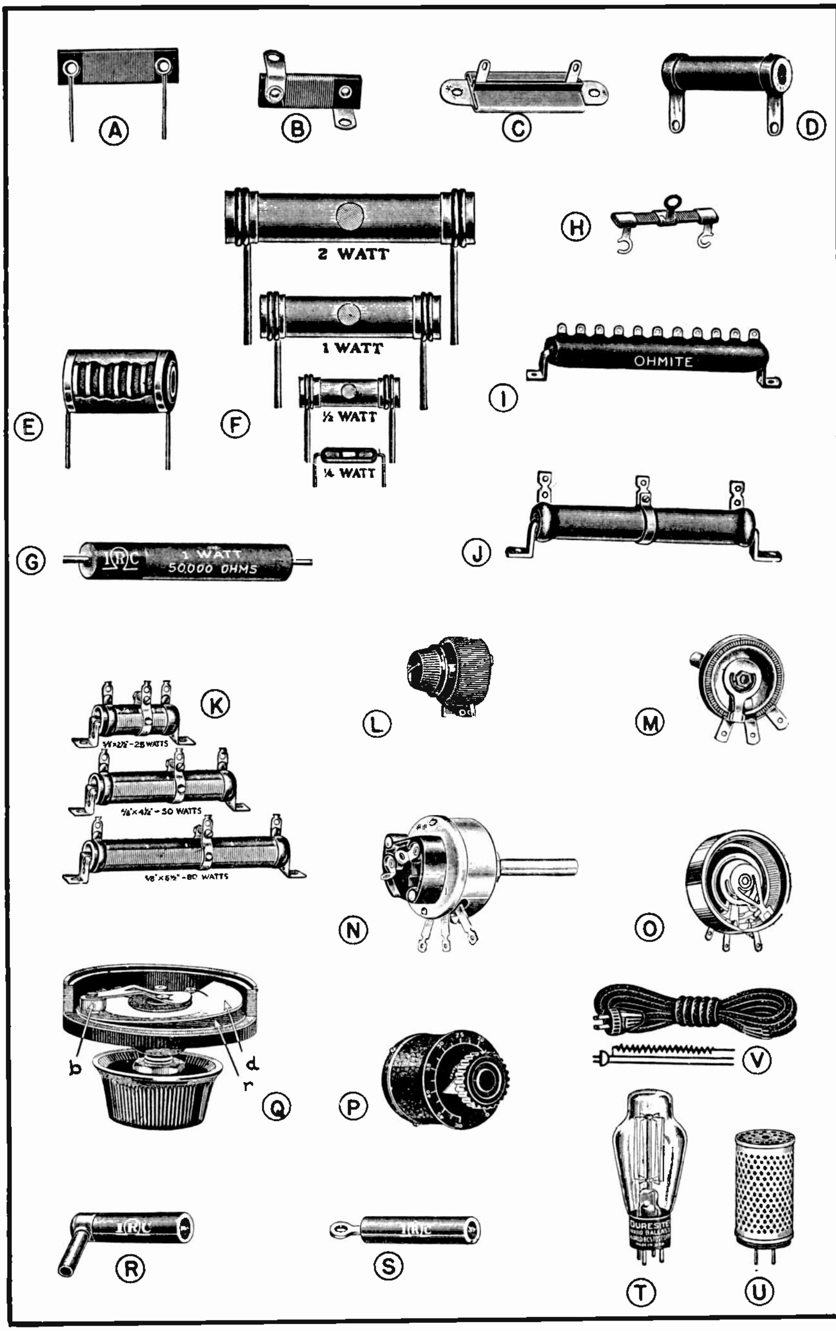


FIG. 3. Typical radio resistors, rheostats, voltage dividers, and potentiometers are illustrated here.

Another common type of fixed resistor, used where a good deal of power must be wasted, is shown at *D*. Here resistance wire is wound on a porcelain tube, terminal strips are squeezed over each end of the wire, and the entire unit except for the terminal strips is dipped in a porcelain enamel and then baked in an oven. These units are called vitreous enamel resistors.

At *E* you see a cut-away view of a "precision" (accurately rated) fixed resistor of the type which is used only in the most expensive electrical testing instruments. It is made by winding silk or cotton covered resistance wire in the grooves of a porcelain spool, connecting the ends to the wire terminals, and then covering the entire resistor with a protective fiber material.

Examples of ceramic carbon resistors are shown at *F*. A resistor of this type is simply a gray rod having copper plated ends, to which a copper wire has been soldered. The whole unit is then coated with enamel of various colors, each color representing a code which tells at a glance the ohmic value of the resistor. These resistors are made in hundreds of different sizes and ohmic values; the larger the dimensions of the resistor for a given ohmic value, the more power it can waste without overheating (becoming excessively hot). Heat may change the value of the resistor, crack the enamel, or even crack the unit itself. Thus all resistors at *F* may have the same ohmic value, but the smallest can handle only ¼ watt * of power without getting too hot, as compared to 2 watts for the largest unit. Obviously a larger resistor will have more surface area to radiate the heat generated in the resistor, and can therefore handle more electric power before becoming too hot.

Resistor *G*, of the metallic coated type, is in appearance very much like resistor *F*; it is made by coating a glass rod about 1/16 inch in diameter with a very, very thin layer of metal. Soft wires called "pigtails" are wound around each end of the metallized rod, and the entire resistor unit is molded into a cylindrical bakelite case, with the two connecting wires sticking out of the ends.

So far I have shown you examples only of the fixed type of resistor. Although resistor *H* is fixed in value it has a third terminal at the center of the winding. Called a "center tapped" resistor, it is used occasionally in the filament circuits of A.C. tubes. Resistor *I*, another type of tapped unit, is a power voltage divider which is used in radio power packs. On resistor *H* the resistance wire is exposed, but in *I* it is covered with vitreous enamel.

An adjustable voltage divider resistor, simply a fixed resistor with a movable or adjustable intermediate tap, is shown at *J*; units of this type are also available with two or more movable contacts. Three

* The meaning of this term is given later in this lesson.

sizes of voltage dividers (similar to *J*) are shown at *K*, each having a different wattage rating; enamel was not applied over a narrow strip on each, in order that the sliding terminal could make contact with the resistance wire. Most power resistors are of the vitreous enamel type, or are at least coated with a heat-resisting and moisture-repelling enamel.

In making a variable resistor unit like that shown at *L* (a rheostat), bare resistance wire is wound over a flexible insulating form. When the winding is completed the form is bent into the shape of a ring and mounted in such a way that a sliding contact can move over the edges of the turns. The sliding contact and one end of the resistance wire form the terminals of the rheostat; as the sliding contact is moved away from the terminal end of the wire, the resistance between the terminals increases.

A potentiometer like that at *M* is simply a rheostat having terminals at each end of the resistance wire as well as a variable terminal. Other examples of potentiometers, each of which has three terminals, are shown at *N* and *O*. Of course, any potentiometer can be used as a rheostat by making connections to the variable terminal and to only one of the end terminals.

The unit at *N* is a combination switch and potentiometer, both operated from a common shaft. Turning the potentiometer knob away from the starting end of the resistor operates the on-off switch. Many modern radio receivers use units like this as a combination tone or volume control and receiver power switch. Perhaps your own receiver is controlled in this way.

Imagine unit *I* bent into the shape of a ring, with each tap connected to a brass contact and a moving contact arm arranged to slide over all the contacts. When the entire unit is mounted in a neat housing you have item *P*, a variable resistance control which is used extensively in public address and broadcasting systems. Turning the knob of this potentiometer changes the resistance between one end and the movable contact by definite amounts (in steps).

The variable resistance units which have been studied so far have all been of the wire-wound type. Often a shallow groove cut into a round disc of bakelite is filled with a mixture of carbon and a binder, or a ring of insulating material is covered with a layer of carbon to form the resistance unit of the potentiometer. An example of the latter type is shown at *Q*; one surface of a washer-shaped disc of paper is sprayed with a liquid containing carbon. A small segment is then cut out of the disc and connections are made to the two remaining ends. A carbon (graphite) button sliding over the coated surface is sometimes used as the variable contact, but a more common arrangement is that at *Q*, where a thin metal disc *d*, connected to the variable terminal, makes contact with the resistance element *r* only at a point directly under the rotating button *b*.

Fixed resistors of the type shown at *R* and *S* are connected in series with the spark plug and distributor cables of automobile ignition systems, to prevent interference with auto radio reception. These resistors differ from those shown at *F* and *G* only in that they have special terminals which permit easy mounting on the spark plugs and the distributor.

Resistors like those at *T* and *U*, often called "ballast tubes" or "ballast resistors," are placed in series with the power supply input leads of some radio receivers to prevent excessive line voltage from damaging the set and its tubes. These resistors use wire made from either iron or nickel, metals which increase in resistance very rapidly when heated.* When the line voltage rises above a certain value, the increased current heats the ballast resistor, rapidly increases its resistance, and thus reduces the voltage applied to the radio set. Resistor *T* is sealed inside a glass tube filled with an inert (inactive) gas, while resistor *U* is mounted inside an air-cooled metal case.

Recently a new type of ballast resistor, mounted in a metal housing which can be plugged into an octal tube base, has been developed. This closely resembles an all-metal type tube.

At *V* is a *line cord resistor*, a device having three purposes: *1*, to bring the power supply source to the receiver; *2*, to furnish full line voltage to the tubes of the receiver; *3*, to furnish a reduced line voltage for the filaments of tubes in the receiver. The two ordinary stranded copper wires in the cord are just like those in any extension cord, and bring the line voltage to the receiver; alongside these is the resistance unit, made of flexible resistance wire wound around asbestos (heat-resisting) cord. This resistance wire gives off considerable heat when the set is in operation, explaining why the extension cords of some universal A.C.-D.C. sets are quite warm.† A simplified diagram of this line cord resistor, sometimes known as "cordohm", appears alongside the sketch at *V*.

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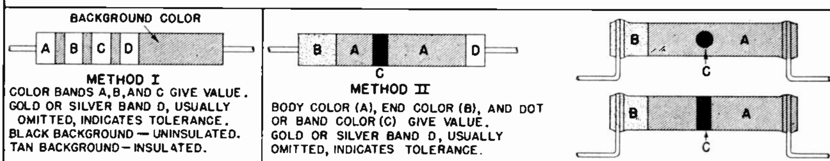
* Practically all metals increase in resistance when heated, primarily because the free electrons in the metals are "excited" by the heat and move faster, getting more in the way of those electrons which make up a flow of current. Thus heat hinders the flow of current through a metal by increasing the "opposition" or resistance. The need for resistors which are unaffected by heat led to the development of Constantan, an alloy (mixture of metals) whose resistance changes very, very little with temperature. The resistance of carbon and of electrolytes (fluids which conduct electricity, like the acid in a storage battery) *decreases*, however, as the temperature rises. When a material having a resistance of one ohm is heated (or cooled) one degree, the *change* in ohmic value is known as the *temperature coefficient* of *resistance*. Most of the commercial resistor wires have low temperature coefficients; that is, they are little affected by changes in temperature.

† Here is a service tip; these resistors, often referred to by the trade name "Cordohm," should never be cut or shortened, for obviously this would reduce their resistance. Do not coil the cord and jam it inside the radio cabinet; free circulation of air is necessary to keep the cord at a safe temperature.

RMA STANDARD COLOR CODE

With resistors being manufactured today in so many different sizes and shapes, the marking of the ohmic value on each resistor becomes a very important matter. To solve this marking problem, the Radio Manufacturers Association (RMA) developed the standard color code given in Fig. 4. Printed markings may fade or rub off, and paper labels may come off, but colors are essentially permanent. The code is now being used on almost all new ceramic and metallized resistors, so it is a good idea to practice identifying resistors with it whenever you have the opportunity. Not all colored resistors follow this code, however, so measure the value when in doubt about color markings.

RMA COLOR CODE FOR RESISTORS



Color	Figure
BLACK	0
BROWN	1
RED	2
ORANGE	3
YELLOW	4
GREEN	5
BLUE	6
VIOLET	7
GRAY	8
WHITE	9

COLOR A GIVES FIRST FIGURE OF RESISTOR VALUE.

COLOR B GIVES SECOND FIGURE OF RESISTOR VALUE.

COLOR C GIVES NUMBER OF CIPHERS FOLLOWING THE FIRST TWO FIGURES.

COLOR D: GOLD BAND INDICATES ± 5% TOLERANCE.
SILVER BAND INDICATES ± 10% TOLERANCE.
NO BAND INDICATES STANDARD ± 20% TOLERANCE.

FIG. 4. The two methods being used for marking resistors according to the standard R.M.A. Color Code are given here, and examples of each method are given below.

EXAMPLES — METHOD I

BAND A	BAND B	BAND C	BAND D	BACK-GROUND	RESISTOR
Violet (7)	Green (5)	Black ( )	Gold	Tan	75 ohms ±* 5%, insulated
Brown (1)	Black (0)	Brown (0)	Silver	Black	100 ohms ± 10%, uninsulated
Red (2)	Green (5)	Brown (0)	None	Tan	250 ohms ± 20%, insulated
Red (2)	Red (2)	Red (00)	None	Black	2,200 ohms ± 20%, uninsulated
Orange (3)	Black (0)	Red (00)	Gold	Black	3,000 ohms ± 5%, uninsulated
Brown (1)	Green (5)	Orange (000)	None	Black	15,000 ohms ± 20%, uninsulated
Orange (3)	Black (0)	Yellow (0000)	Gold	Tan	300,000 ohms ± 5%, insulated
Red (2)	Green (5)	Green (00000)	None	Tan	2,500,000 ohms ± 20%, insulated

Note: With Method I, Band A is never black (a resistor value cannot start with zero); when you encounter a resistor with a black band at the left end, it is either an uninsulated Method I resistor which you are trying to read backward, or it is a Method II resistor with the black band serving as end color B.

EXAMPLES — METHOD II

BODY (A)	END (B)	DOT OR BAND (C)	RESISTOR
Violet (7)	Green (5)	Black ( )	75 ohms
Brown (1)	Black (0)	Brown (0)	100 ohms
Red (2)	Green (5)	Brown (0)	250 ohms
Red (2)	Red (2)	Red (00)	2,200 ohms
Orange (3)	Black (0)	Red (00)	3,000 ohms
Brown (1)	Green (5)	Orange (000)	15,000 ohms
Orange (3)	Black (0)	Yellow (0000)	300,000 ohms
Red (2)	Green (5)	Green (00000)	2,500,000 ohms

When a color band is missing in uninsulated (black background) resistors marked according to Method I, assume that the color of the missing band is black.

When end color B, or dot or band C, is missing in a resistor marked by Method II, the missing marking is the same as body color A; thus, an all-red color-coded resistor would be 2,200 ohms.

Note that with Method I markings the color bands are all equal in width, while with Method II markings on resistors having leads coming straight out from the ends, the color bands are of different widths; this serves as a clue for telling which method of marking is employed.

* The symbol ± indicates the amount plus or minus the resistor may deviate from its rated value.

OHM'S LAW TELLS YOU "HOW MUCH"

You know that resistors in a circuit can control the amount of current which a given voltage can force through the circuit, or in other words, reduce the voltage which is applied to the load; now I will take up the question of "how much?"—the question of how much change there will be in voltage and current values when different resistors are used in a circuit. I will show you how to find out "how much" by two different methods, one which uses simple arithmetic (such as addition, division and multiplication), and another which does not require arithmetic.

In the year 1827 Dr. Ohm, a German scientist, made this short but then astonishing statement: "The current flowing through a resistor is proportional to the voltage applied to that resistor." These words, as true today as they were over a century ago, made Dr. Ohm famous; the electrical unit of resistance, the *ohm,* was named after him.

Dr. Ohm meant that if 10 volts applied to a load or resistor caused 1 ampere to flow, 20 volts (twice the voltage) would send 2 amperes (twice the current) through that load; 30 volts would send 3 amperes; 5 volts (half the voltage) would send ½ ampere (half the current), etc.—and if you change the load resistance an entirely new set of similar conditions will exist.

Finding Current: A more practical manner of stating Ohm's Law is:

(1) To find the current flowing through a load, divide the applied voltage by the resistance of the load.

If you keep in mind the circuit shown in Fig. *5A*, containing simply a source, a resistance load *R*, and the connecting wires, you can simplify Ohm's law to the following form, which can be used to find out what the current through the load is when the load resistance and the voltage across the load are known:

$$\textbf{(2)}\quad \textbf{Current} = \frac{\textbf{Voltage}}{\textbf{Resistance}}$$

The value of current you obtain will be in amperes if the voltage is in volts and the resistance is in ohms. The sign "=" means "is equal to"; the line "——" means that you should divide the value above this line by the value below the line. To save time, the second expression [marked (*2*)] is often abbreviated to this:

$$\textbf{(3)}\quad I = \frac{E}{R}$$

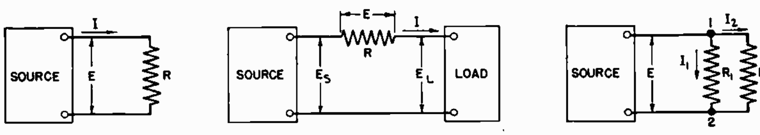
Where: *I* represents current in amperes.
E represents voltage or e.m.f. in volts.
R represents resistance in ohms.

Actual values substituted for *I*, *E* and *R* in this simple formula give you the answer to "how much." *Although you do not have to be able to compute values with this formula in order to be a successful service man, it is important that you know the practical meaning of Ohm's*

Law—know, for example, that when a resistor is connected across the terminals of a storage battery, a certain value of current will flow, and this current will *decrease* in value when the resistor is replaced with one having a *higher ohmic value.*

Finding Voltage Drop. In practical radio circuits you will find many uses for Ohm's Law. You already know how to find the current when the voltage and resistance are known; now I will take up a second application of the law—a practical case where the current and resistance are known and you want to find the *voltage.* Resistor R in Fig. *5B* is connected into the transmission system of a simple series circuit. As I have pointed out before, the voltage at the load (E_L) will be the source voltage (E_S) minus the voltage (E) which is "wasted" or "dropped" in the resistor R. Suppose that you know the voltage of the source, the ohmic value of resistor R, and the current (I) which the source is supplying—how much is the voltage drop (E) across R?

Again Ohm's Law gives the answer—E is equal to I multiplied by R,



A. When E and R are known, Ohm's Law will give you I, current flowing in the circuit.

B. When I and R are known, Ohm's Law will give you E, the voltage drop across the resistor R in this simple circuit.

C. When E, I_1 and I_2 in this circuit are known, Ohm's Law will give you the values of R_1 and R_2.

FIG. 5. These circuits illustrate the three different applications of Ohm's Law.

the voltage E being in volts, the current I (which passes through the resistor) being in amperes, and the resistance of R being in ohms. It is customary to use the letter V for a voltage drop or loss, and the letter E where a generated e.m.f. is indicated. Both mean voltage, however, so you can use either, as you prefer.

In arithmetic you could not multiply apples by oranges; radio arithmetic is quite different in this respect, however, for here you *are* allowed to multiply or divide unlike units, such as volts, amperes and ohms.

Finding Resistance. The circuit in Fig. *5C* illustrates a third application of Ohm's Law, in which the *voltage* of the source is known, the *current* drawn by each load device is known, and you want to find the *ohmic values* of R_1 *and* R_2, resistors which are connected in parallel. Assuming that the leads (the wires) have negligible resistance, it should be clear that both resistors will receive the same voltage, E, which is the source voltage. You know the voltage across each resistor and the current through each; Ohm's Law gives the missing values of resistance: $R_1 = E \div I_1$ and $R_2 = E \div I_2$. (The symbol "$\div$" means the same as it did in arithmetic, "divided by".)

No matter how simple or how complicated a circuit may be, the relations between the voltage, the current and the resistance of any part or of the entire circuit will always be given by Ohm's Law. This applies whether the current flow is A.C. or D.C., provided that in the case of A.C. you consider *effective* voltage, *effective* current and *effective* resistance. When any two of these factors are known, the third one can be computed by one of the following forms of Ohm's Law, each of which I have already discussed:

$$(A)\quad \mathrm{I} = \frac{\mathrm{E}}{\mathrm{R}} \qquad (B)\quad R = \frac{\mathrm{E}}{\mathrm{I}} \qquad (C)\quad \mathrm{E} = \mathrm{I} \times \mathrm{R}$$

Although eventually you will have memorized all three forms of Ohm's Law, all you really have to remember is the first formula (*A*). From it you can easily get the other two by placing the formula in a square like that shown in Fig. *6A*. You can move any letter *diagonally*

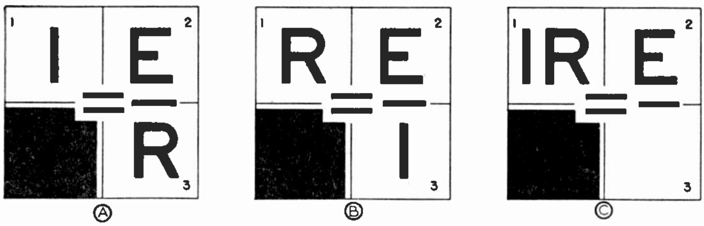


FIG. 6. Here is an easy way of remembering the three forms of Ohm's Law. Letters can be moved diagonally only, as in checkers. Take your choice—remember all three formulas or remember the first one and the method of obtaining the others.

to any other square just as you would play checkers, until the value you want to find is in an *upper square* (either to the right or the left of the "=" sign) with nothing in the square below it. For instance, if you want to find *R* simply move *R* up to square No. *1* and move *I* down to square No. *3*, as in Fig. *6B*. To find *E*, move *R* diagonally upward to square No. *1*. *I* and *R* are now in square No. *1*, as in Fig. *6C*, and should therefore be multiplied together to get *E*. The lower left square is never used. Try this scheme yourself a few times for practice; isn't it much easier to remember only one equation instead of three?

TWO PRACTICAL RADIO EXAMPLES

They say that an example is worth many words of explanation, so let me show you now two examples of how Ohm's Law can be used to solve actual radio problems. Figure *7A* shows a radio circuit in which the resistor *R* plays an important part (determines the potential at which the grid is charged (with respect to the cathode), in a manner which will be taken up later in the Course). Now suppose that resistor *R* burned out and that it had no markings which would tell you its ohmic value. What could you do? Let us suppose that you have manufacturers' information or a tube characteristics chart which tells you the voltage across terminals *1* and *2* (the grid bias voltage of the tube) and the current which should flow through the resistor *R* (the plate current of the tube). Ohm's Law makes this problem easy; you know *E* and *I*—to find *R* simply divide *E* by *I*, and replace the burned-out resistor with a new one of the correct ohmic value. For example, if the required voltage were 6 volts and the required current 4 milliamperes (.004 ampere), you would divide 6 by .004 to get the answer, which is 1,500 ohms.

You can solve this same problem in another way without arithmetic. Remove the damaged resistor *R*, connect in its place a variable resistor or rheostat, and place the tube in operation by closing the power supply switch. Since you are dealing only with D.C. in this circuit, connect a D.C. voltmeter across terminals *1* and *2* and vary the rheostat until the voltmeter reads the correct voltage (6 volts in this example). Now

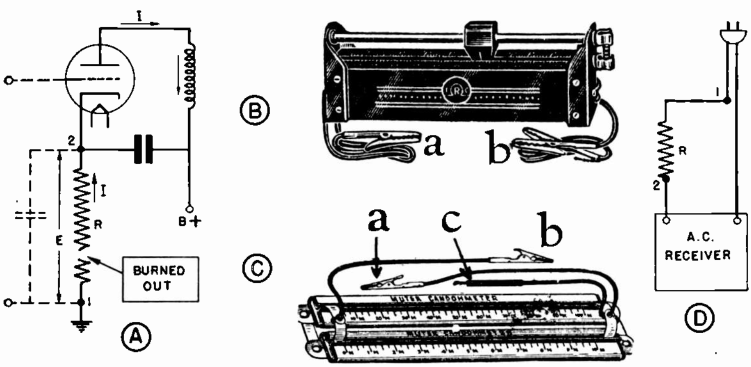


FIG. 7. A—Practical radio problem: resistor R burns out and the circuit diagram available for the set does not give its value. How would you determine the correct value of resistor to use? B—Slide type of resistance indicator. C—Test prong type of resistance indicator. D—Ohm's Law comes in handy when you want to test the power transformer of a receiver. By measuring the voltage across resistor R, you can determine how much current the power transformer is drawing, and thus check its performance.

remove the rheostat and measure its resistance with an ohmmeter to determine the resistance setting which gave you the correct voltage. Connecting into the circuit a resistor having the value indicated by the ohmmeter completes the job. In this second method you must have two meters in addition to a variable resistor and more time will be required than if you used Ohm's Law.

A simpler and more practical method of solving this problem without arithmetic requires only a voltmeter and a resistance indicator like that shown in Fig. *7B* or *7C*. Connect the resistance indicator in place of the burned-out resistor *R*, using the two test clips, *a* and *b*, and connect the voltmeter to measure the voltage across this indicator by connecting the meter to terminals *1* and *2* in Fig. *7A*. Now adjust the slider in the case of the indicator shown in Fig. *7B*, or the ball-point test prong (*c* in Fig. *7C*) until the correct voltage reading is obtained. The indicator now tells you the value of resistance required.

My second example likewise deals with trouble in a radio receiver. Suppose the set is not working properly, and you suspect that some of the turns in the power transformer are shorted (insulation scraped or burned off the wire, allowing turns to touch or cross). You can check this transformer very easily by measuring the current drawn when all the tubes are removed. On good transformers this current should be less than .2 ampere.

Unfortunately, very few service men have a 0-1 ampere A.C. ammeter, which would be the size required to measure this A.C. current. This would be no drawback, however, to a practical man who thoroughly understood Ohm's Law and had the A.C. voltmeter which should be a part of a Radio-Trician's test equipment. Figure *7D* shows how to measure this small A.C. current. First insert a resistor, *R*, having a low ohmic value which you know, in series with the power line, then measure the voltage across this resistor by connecting an A.C. voltmeter across it (to terminals *1* and *2*). Dividing the measured voltage by the known resistance, you obtain the current which is flowing in the circuit without even using an ammeter. For example, if the resistor value is 4 ohms and the measured A.C. voltage is 2 volts, then 2 divided by 4 is equal to .5 or ½ ampere. This being more current than the transformer would ordinarily draw under no-load conditions, it is clear that the transformer is defective.

CIRCUIT TRACING HINTS

You already know that you can simplify the tracing and analyzing of any complicated radio circuit by dividing it into a number of simple series circuits, in each of which the parts are arranged in one continuous path. In doing this, there are two very important facts which you must observe. They are:

***1.* The current flowing *to* any terminal (any junction or connection of wires) must equal the current flowing *away from* that terminal.**

***2.* When tracing any complete circuit (a complete path for electrons) the sum of the voltages which are trying to force electrons through the circuit must equal the sum of the voltage drops which exist in a circuit because of the opposition which the parts present to the flow of electrons.**

Both of these rules are quite logical; No. 1 is often called *Kirchhoff's Current Law* and No. 2 is called *Kirchhoff's Voltage Law,* after the scientist who first stated them.

Examples will help to fix these ideas in your mind. First take the simple vacuum tube filament circuit shown in Fig. *8A*, where a 6-volt battery is supplying a current of 1 ampere, the resistor R_1 being in series with the load to reduce the voltage applied to the tube filament. If you measured the voltage between terminals *1* and *2* and then between terminals *3* and *4*, and added these together, you would *always* find that these two voltages would add up to equal the voltage supplied by the battery. The voltage which pushes electrons through the circuit must naturally be equal to the sum of the voltage drops across each resistor through which the electrons flow. There are no terminals here where the current can divide, so the same current must flow through each part and you have a simple series circuit. The circuit current is 1 ampere and the source voltage is 6 volts; Ohm's Law says that resistance is equal to voltage divided by current, so the ohmic value of R_1 is $1 \div 1$ or 1 ohm. Likewise the value of R_2 is $5 \div 1$ or 5 ohms.

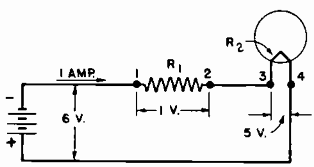


FIG. 8A. You can "bet your last cent" that 5 + 1 equals 6 in this series circuit.

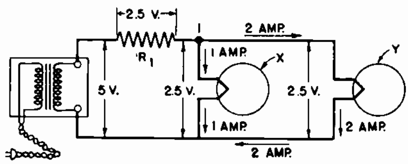


FIG. 8B. What should be the value (in ohms) of R1 if it is to waste 2.5 volts in this circuit?

Another practical example is shown in Fig. *8B*. Here a step-down transformer feeds A.C. current to the filaments of two radio tubes through a resistor R_1. Each tube requires only 2½ volts, but the supply voltage is 5 volts. What resistance should R_1 have in order to reduce the supply voltage to the correct value for the tubes, which are connected in parallel? Before you can answer this question you must first determine what current is passing through the resistor. This much you know: The current flowing through resistor R_1 up to point *1* in the circuit must be equal to the sum of the current flowing through tube X and the current flowing through tube Y. The current each tube requires can be found on the charts supplied by tube manufacturers. Suppose you find that tube X needs 1 ampere and tube Y needs 2 amperes; the current through resistor R_1 will then be $2 + 1$ or 3 amperes. Ohm's Law says $R = V \div I$, so R_1 will then be equal to 2.5 (the voltage it is required to waste) divided by 3 (the current which will flow through it). By simple arithmetic you obtain .83 ohm as the value of resistor R_1.*

I now want to show you the importance of Kirchhoff's Laws in testing a radio receiver. In Fig. *8C* I have shown the plate supply circuits of three vacuum tubes, let us say of a simple public address amplifier. The plates of all tubes are connected to a common 270 volt D.C. source. The voltage across any part and the current in any circuit can be

* Be sure to read the chapter "Sensible Calculations" in reference to text 2X; it will help you in making calculations like this.

measured with the proper meters; if the circuit is operating as it should the measured values of current and voltage should agree with those indicated by Kirchhoff's Laws for a correctly operating circuit. For instance, if the voltage across tube M, as measured between points P_M and K_M with a D.C. voltmeter, is 180 volts, you know immediately from Kirchhoff's Voltage Law that the voltage across the plate load resistor R_M must be 90 volts, for 90 + 180 is equal to 270 volts, the source voltage. The same condition will hold true for tube N, for it has the same characteristics. The voltage across tube O (between points K_O and P_O) is 250 volts, however, making the voltage across R_O 20 volts, for 250 + 20 equals 270.

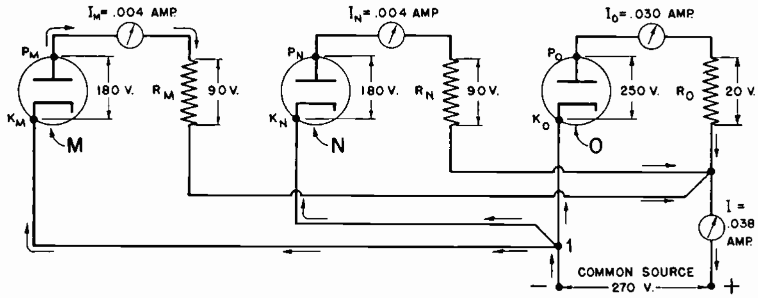


FIG. 8C. This is an actual radio test problem; it can be solved very easily by using Kirchhoff's Voltage and Current Laws at different points in the circuit.

The currents passing through each tube, as measured with a milli-ammeter, are: $I_M = .004$ amp.; $I_N = .004$ amp.; and $I_O = .030$ amp. These add up to .038 amp., the value which according to Kirchhoff's Current Law you should obtain when measuring the supply current I. In testing a circuit any difference from the values indicated by Kirchhoff's Laws indicates a defect somewhere, and this defect can be isolated. For example, if no voltage appears across resistor R_M, if I_M reads higher than .004 ampere, and if the voltage across tube M is 270 volts, we know that resistor R_M must be shorted. If I_M shows no current and the measured voltage across tube M is 270 volts, either the tube is defective or a tube connection has opened. (You will learn more about these facts later in the Course.)

From what I have just shown you can see that there are some very practical radio uses for Kirchhoff's Laws. These electrical rules are simply another variation of that fundamental law of nature—*you can't get something for nothing*. You can't take more current away from a point than flows to that point, and you can't have more voltage in a circuit than there is at the source. Keep these ideas in mind; their many applications will come to you as you learn more about Radio and gain actual experience in testing radio circuits.

RESISTORS IN SERIES AND PARALLEL

Series. When a source is supplying current to a number of loads which are connected together either in series or in parallel and you want to know how much current is being supplied, you must first combine these loads into a single *equivalent resistance*—a single resistance which would take the same current from the load as do all the separate resistors together. If the resistors happen to be in series, as they are in Fig. *9A,* all you have to do is add together the ohmic values of the individual resistances. Here *R,* the equivalent resistance, would be equal to $R_1 + R_2 + R_3$.

Parallel. When resistors are in parallel, as they are in Fig. *9B,* the calculation of the equivalent resistance is not so simple, except when all resistors are alike. Taking the latter case first, *when all resistances*

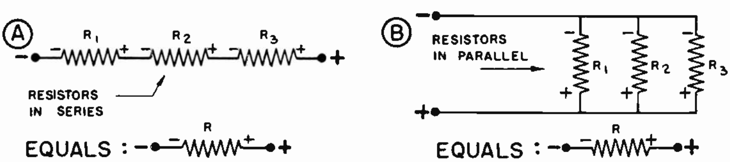


FIG. 9. Either series or parallel groups of resistors can be combined into a single equivalent resistance R. The polarity of each resistor with respect to the source (the heavy dot terminals) is given. Remember: that terminal of a resistor into which electrons flow is always negative.

are alike the equivalent resistance of the group is the resistance of one *divided by* the number of resistors which are in parallel. In all other cases you must use a formula* or the chart given on page 25 to secure the equivalent resistance. I will explain the use of the chart later.

The important thing to remember, when you are dealing with a number of resistors connected together, is that for resistors in *series* the *equivalent resistance* will *always be greater* than the value of the largest resistor in the circuit; when resistors are connected *in parallel* the *equivalent resistance* will always be *less than* that of the *smallest* resistor in the circuit. For example, if a 2 ohm, a 20 ohm and a 35 ohm resistor are all connected together *in parallel,* the equivalent resistance of the group will be less than that of the smallest resistor in the group,

* The formula for computing the equivalent resistance of a group of resistors connected in parallel is: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$, etc., where R is the equivalent resistance of the group and R_1, R_2 and R_3 are the resistors connected in parallel. Let me take one example: Let $R_1 = 2$ ohms; $R_2 = 4$ ohms; and $R_3 = 6$ ohms. Now $\frac{1}{R}$ equals ½ + ¼ + 1/6; $\frac{1}{R} = .50 + .25 + .17 = .92$; finally $R = \frac{1}{.92}$ or approximately 1.1 ohm. Use the chart which I have given on page 25 if you have any difficulty with division of decimal numbers.

and will therefore be *less than 2 ohms.* If these same three resistors are connected *in series,* however, the equivalent resistance of the group will be greater than 35 ohms. Current naturally flows over the path which offers the least resistance; when resistors are in parallel, then, the resistor having the lowest ohmic value has the least resistance path and it therefore governs the amount of current which will flow.

THE VOLTAGE DIVIDER AND POTENTIOMETER

In dealing with simple circuits containing only a source, a load and a resistor in the transmission line, I have up to this time considered the series resistor as a device which reduces the load voltage to a required value. I could just as well say, though, that the series resistor and the load divide the source voltage between each other, for each gets a part of the source voltage. Kirchhoff's Voltage Law says that *all* the voltage drops in a complete circuit must add up to exactly the generated voltage; in Fig. *10A* the voltage across resistor R and across the load are the voltage drops, and the source voltage of 250 volts is naturally the generated voltage. By regulating the value of the resistor R (assuming that it is of the variable type) any desired division of voltages between the load and the resistor can be obtained.

Knowing these facts, the advanced radio man can figure out the value of R for a desired voltage division. For example, if the load in Fig. *10A* must get 90 volts and a current of .01 ampere, this same current must also flow through the series resistor R. Since the source voltage is 250 volts, but the load wants only 90 volts, obviously resistor R must take the difference of 160 volts. In other words, the source voltage must be so divided that the load gets 90 volts and R gets 160 volts. Knowing the voltage across R and the current through it, Ohm's Law ($R = E \div I$) gives the correct ohmic value: $160 \div .01 = 16{,}000$ ohms. From this it should be clear that changes in the current taken by the load (caused by changes in the resistance of the load) will change the current through R and thus change the division of voltages.

Another commonly employed voltage divider circuit, shown in Fig. *10B,* differs from that in Fig. *10A* only in that it has a second resistor R_1, placed in parallel with the load. This is done for a very practical reason; in a circuit of this type, used in many radio receiver power packs, the load voltage must be kept as near rated value as possible while different amounts of current are drawn. Resistors R and R_1 here divide the source voltage, the load receiving the same voltage as R_1. Any changes in the load do not materially affect the currents passing through the two resistors; the presence of R_1 thus keeps the load voltage very nearly constant, giving better voltage regulation.

A little figuring will give you a better understanding of how this voltage divider in Fig. *10B* works. Let me take the case where the load requires 90 volts and draws a maximum current of .01 ampere. The source, we will say, is capable of supplying 250 volts and .025 ampere; any more current would overload and perhaps damage the source. This problem then involves choosing values of R and R_1 so that .010 ampere is fed to the load, and .025 ampere is drawn from the source. Obviously the current must divide at point *2*, .010 ampere going to the load and .015 ampere to R_1. Under these conditions R gets 160 volts, while R_1 and the load, connected in parallel, receive 90 volts. Using Ohm's Law, $R = 160 \div .025$, which equals 6,400 ohms; $R_1 = 90 \div .015$, which equals 6,000 ohms. Now I will go a step farther to find out just how much the load voltage will vary in this circuit if the load changes its resistance. If the load current drops to zero (such as when the load resistance becomes very large), the load is temporarily out of the circuit as far as its effects are concerned, and only resistors R and R_1 are connected to the source. Being in series, the total resistance of these two resistors is 6,400 ohms + 6,000 ohms, or 12,400 ohms. The total current in the circuit, according to Ohm's Law ($I = E \div R$), will now be 250 ÷ 12,400 or .020 ampere (approximately). The voltage across R_1 (which is the voltage applied to the load) can now be computed by Ohm's Law ($V = I \times R$); it is .020 × 6,000 = 120 volts. Although this is 30 volts higher than the rated load voltage, it is far lower than the 250 volts that would be applied to the load if resistor R_1 did not exist and the load current dropped to zero. By choosing a source which can supply a larger current, so that a larger current would flow through R_1, the increase in load voltage on "no load" could be made even less. The difference between the load current and the supply current is the current which is wasted to obtain better regulation—it is often called the *bleeder* or *regulation* current.

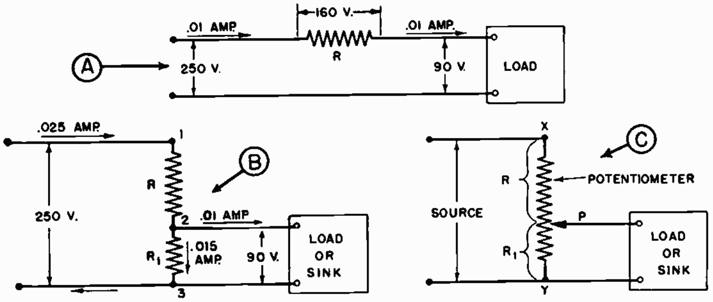


FIG. 10. These three typical voltage divider circuits illustrate practical uses for Ohm's and Kirchhoff's Laws.

In radio we encounter loads (we sometimes call them *sinks*) which require a definite voltage but draw negligible current; that is, their resistance is extremely high. The grid and cathode terminals of a vacuum tube (the input circuit) form a typical load (or sink) which draws, theoretically at least, no current. Under such conditions resistors R and R_1 in Fig. *10B* control the voltage supplied to the load.

If the load voltage must be variable to permit adjustment in case the source voltage becomes too high or too low, the potentiometer shown in Fig. *10C* is used to replace the two separate resistors. Here the total $(R + R_1)$ is constant, but R_1 can be varied, applying more or less of the source voltage to the load. The contact P is the variable arm of the potentiometer; when set near terminal Y the load gets only a small part of the source voltage; when placed near X the load gets nearly all the source voltage.

Oftentimes it is desirable to know the polarity of a certain resistor in a series combination. First you must determine the direction of electron flow in the circuit, and especially through the resistor in which you are interested. Now—that resistor terminal *into which* electrons flow is *negative;* the terminal *out of which* electrons flow is, of course, positive. When three resistors are in series and connected to a source, the polarity of each resistor is as indicated in Fig. *9A*.

RESISTORS IN A.C. CIRCUITS—PHASE

In the simple circuits considered up to now in this lesson, I have dealt primarily with D.C. voltages and currents. True, in Figs. *7D* and *8B* I did consider A.C. currents, but in these Ohm's Law and Kirchhoff's Laws were applied just as they were in the D.C. circuits. This is quite all right if only resistors are in the circuit, or where the voltage dropped in a coil or condenser which is in the circuit can be neglected, provided that we deal with *effective* volts and *effective* amperes in the case of A.C.

When coils and condensers are in an A.C. circuit and their effects are appreciable in value, it is necessary to modify Ohm's and Kirchhoff's Laws. All this will be explained later, after I take up the subject of *phase,* which is in small type for the technically-inclined student. Read through this discussion at least once, for it will help you in mastering later lessons.

Phase. You are already familiar with the sine wave curve shown at the right in Fig. *11A*, and you know that this curve can be divided into ½, ¼ or any other fraction of a complete cycle. This curve is used to represent either an A.C. voltage or current and can be drawn in a simple way. First the horizontal line *01* (at the left in Fig. *11A*) would be drawn to a length which represents the maximum height of the curve, height *03* in the circle, for example. This line, with an arrow at one end, forms what technicians call a *vector*. Let this vector or arrow line revolve around its other end; by general agreement radio and electrical men revolve it counter-clockwise, opposite to the direction taken by the hands of a clock. As this vector revolves all the way around, its arrow tracing a complete circle, it will pass in turn through positions *01, 02, 03, 04, 05* and *06*. It is the distance *V* between the vector arrow tip and the horizontal line *01* which is important, for if this vertical height is plotted on a graph for various positions of the vector, the sine wave curve in Fig. *11A* is obtained.

In making one complete revolution about point *0*, the vector has traced a complete cycle. At position *3* then, the vector has gone through ¼ cycle, at position *4*, ½ cycle, and at position *5*, ¾ cycle. Note that when the vector is in position *03* it makes an angle of 90 degrees with vector *01*. (In revolving one complete revolution the vector has gone 360 degrees; at position *03* it has made one-fourth of a revolution, and ¼ of 360 is 90.) When the vector is at point *2* we can say it is at 45° ("°" is the symbol for degree), instead of ⅛ cycle. Point *3* can be represented as 90°, point *4* as 180°, point *5* as 270° and point *6* as 360°. Note that point *6* is the same on point *1*, which is 0°, for a circle must start and end at the same point. Any one position of the vector, specified with reference to its starting point, is known as the *phase* of the vector. We talk about the phase of the moon—a quarter-moon, half-moon or full moon; in the same way we talk about the phase of vectors—the position of vectors. The difference in degrees between points *1* and *2* on the circle is 45°; the difference between points *2* and *3* is also 45°. This angular difference between any two points on the circle, corresponding to any two positions of a single vector or simultaneous positions of two vectors, is known as the *phase angle*, phase shift or *phase difference* (expressed in degrees or in fractions of a cycle). Thus it is possible to designate any position of a rotating vector by stating its angular difference with respect to a reference axis, the horizontal line *01*. Keep this important idea in mind: *A rotating vector is really just a simple abbreviation for a sine wave curve.*

Now I will take up a practical application of vectors, a case where a resistor is supplied with an A.C. voltage. Radio experts always say that the current through a resistor will follow any change in voltage; that is, when the voltage is a maximum the current is a maximum; when the voltage is zero the current is zero; when the voltage reverses its polarity, the current reverses its direction. The *V* and *I* curves of Fig. *11B*, representing the voltage across and current

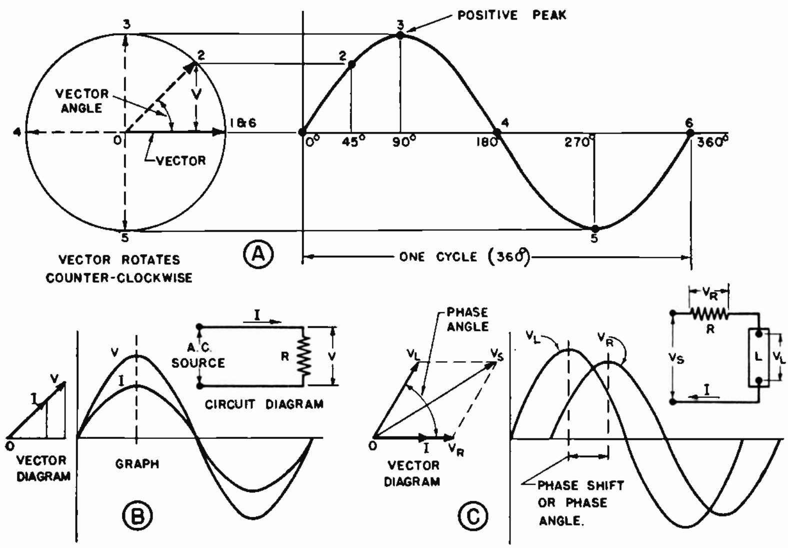


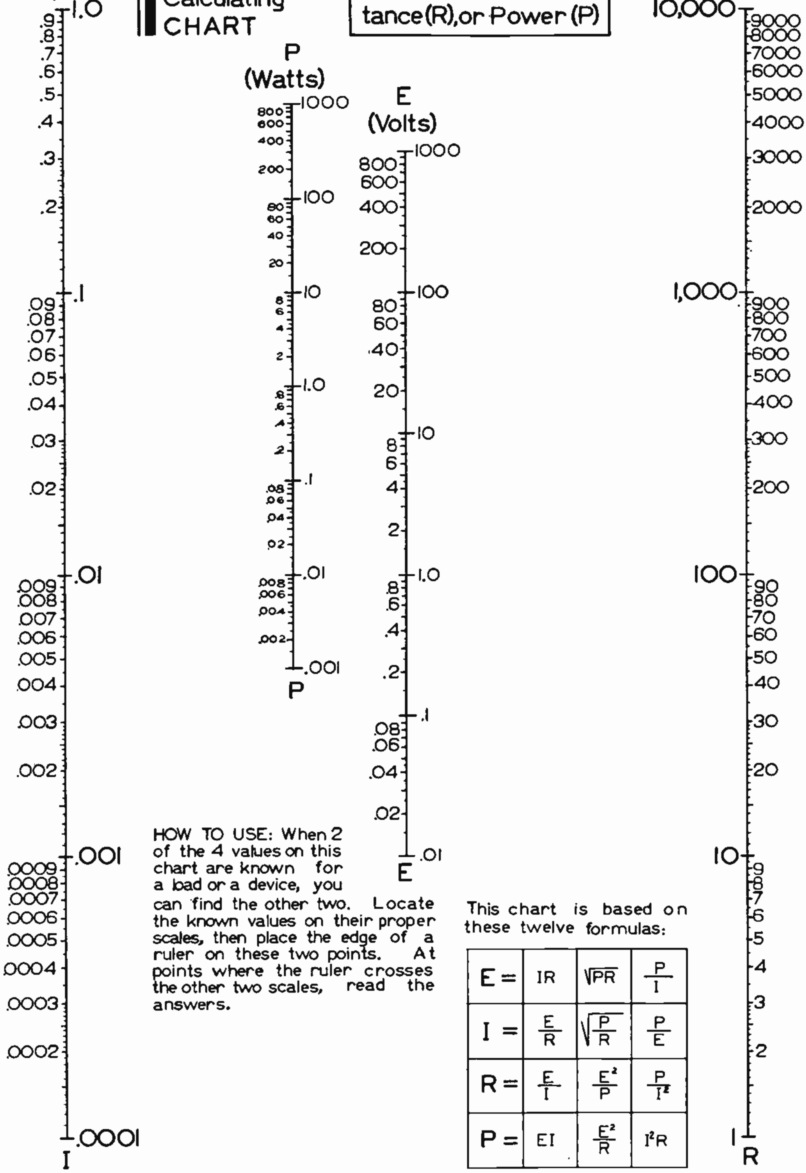
FIG. 11. Vectors, electrical abbreviations for sine wave curves, are explained here, and the meaning of "phase" in radio work is given.

through a resistance load in the A.C. circuit shown, illustrate clearly the relations between the two values. The vector diagram at the left of the curve gives exactly these same facts in a greatly simplified form. The arrow line *I*, representing current, and the arrow line *V*, representing voltage, are both on the same line; rotating them together around *O* will reproduce the two sine wave curves. There being no angle separating the *I* and *V* vectors, we say that *I* and *V* are *in phase.*

Now consider the case where an A.C. source feeds a resistor (*R*) in series with a coil (*L*), as in Fig. *11C*. Kirchhoff's Law says that V_R plus V_L in this example will equal the line voltage V_S only *if phase is considered* (since *L* is not a resistance). The current being the same through *R* and *L* (the same current flows through all parts of a series circuit), this can be used as a guide. You already know that V_R and *I* are in phase, for the current through a resistor is always in phase with its voltage. The device *L*, a coil, has such characteristics that its voltage (V_L) reaches its maximum value in each cycle *before* the current *I*; voltage V_L therefore reaches its maximum value before V_R.

N.R.I. EASY Calculating CHART

To Find Voltage (E), Current (I), Resistance (R), or Power (P)



HOW TO USE: When 2 of the 4 values on this chart are known for a load or a device, you can find the other two. Locate the known values on their proper scales, then place the edge of a ruler on these two points. At points where the ruler crosses the other two scales, read the answers.

This chart is based on these twelve formulas:

$E =$	IR	$\sqrt{PR}$	$\frac{P}{I}$
$I =$	$\frac{E}{R}$	$\sqrt{\frac{P}{R}}$	$\frac{P}{E}$
$R =$	$\frac{E}{I}$	$\frac{E^2}{P}$	$\frac{P}{I^2}$
$P =$	EI	$\frac{E^2}{R}$	I^2R

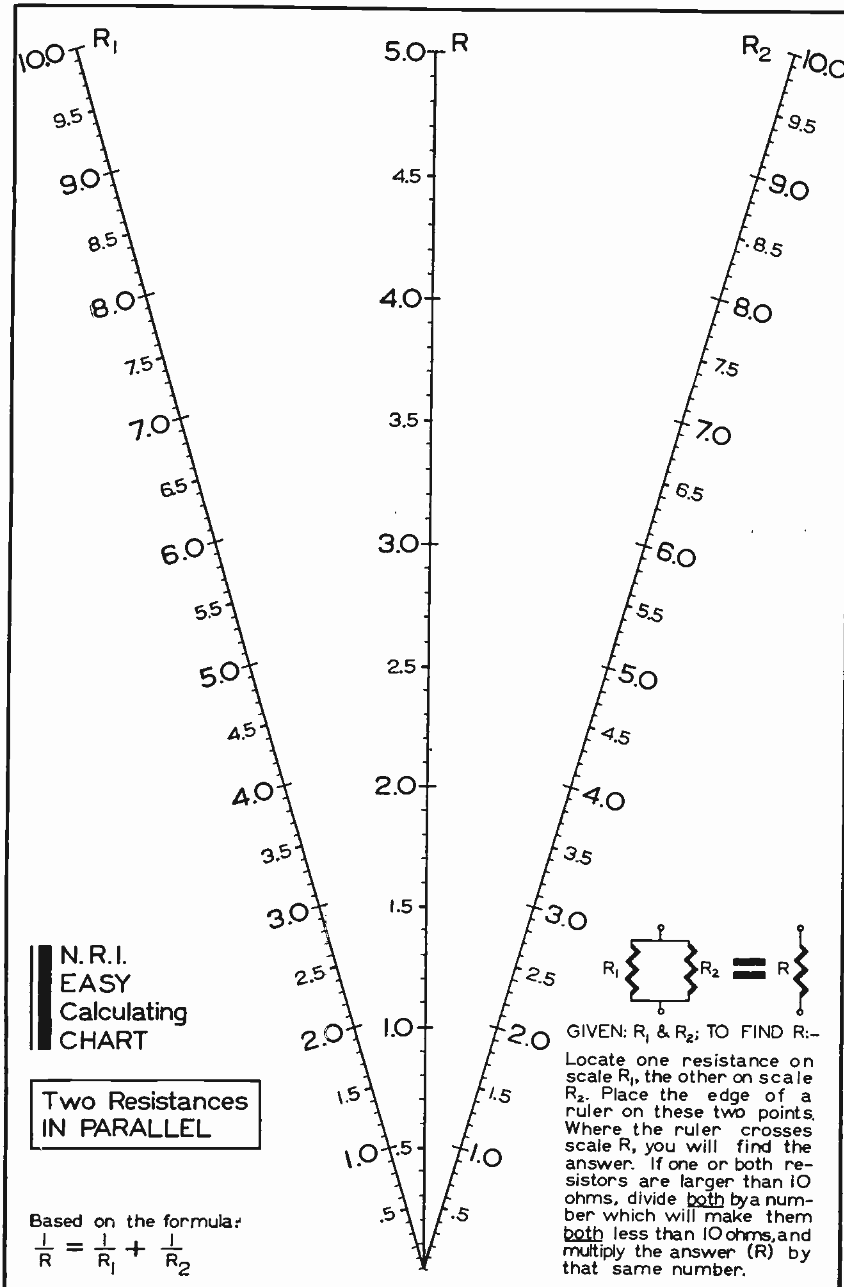
RULES for extending resistance range of chart when R, one of the known values, is between 10,000 and 1,000,000 ohms: Divide R by 100, work out problem on chart using smaller value of R, then:

If solving for E and {I is other known value, MULTIPLY chart answer on *E* scale by 100. P is other known value, MULTIPLY chart answer on *E* scale by 10.}

If solving for I and {E is other known value, DIVIDE chart answer on *I* scale by 100. P is other known value, DIVIDE chart answer on *I* scale by 10.}

If solving for P and {E is other known value, DIVIDE chart answer on *P* scale by 100. I is other known value, MULTIPLY chart answer on *P* scale by 100.}

When R is between 1,000,000 and 100,000,000 ohms, divide R by 10,000, work out problem on chart using smaller value of R, then divide or multiply the answer by 10,000 wherever 100 is indicated in the above rule; divide or multiply the answer by 100 whenever 10 is indicated.



Examples Illustrating Use of Parallel Resistor Chart. *1.* Given 9.7 ohms and 2.5 ohms in parallel. Locate 2.5 on the R_2 scale, 9.7 on the R_1 scale (you could just as well locate 2.5 on the R_1 scale and 9.7 on the R_2 scale), place ruler on chart to pass through these two points, and read answer, 2.0 ohms, at point where ruler crosses R scale.

2. Given 9.4 ohms, 6.2 ohms and 5.2 ohms in parallel. Combine 9.4 ohms and 6.2 ohms first, getting 3.75 ohms. Combine this answer, 3.75 ohms, with remaining 5.2 ohm resistor, getting 2.2 ohms as the equivalent resistance of the group.

3. When one resistance is about 25 times or more larger than the other, the equivalent resistance will be very nearly equal to the ohmic value of the smallest resistor, and this chart is not needed. Thus 99 ohms in parallel with 4 ohms can be considered as 4 ohms.

4. Given 250,000 ohms and 50,000 ohms in parallel. Divide each by 100,000, getting 2.5 and .5. Locate 2.5 on scale R_2, .5 on scale R_1, and read answer, .42 ohm, on scale R. Multiply .42 by 100,000 (see rule on chart) to get correct answer. 42,000 ohms.

These facts are shown by the two voltage curves and by the vectors in Fig. *11C*. But how can you add the two voltages V_L and V_R, which are not in phase, to get the source voltage V_S? This problem is not hard to solve if you use vectors. The radio engineer would draw the tilted rectangle (parallelogram) shown in Fig. *11C*, in which the dotted sides are parallel to the vectors V_L and V_R; the diagonal V_S would then represent the voltage of the source. To obtain the exact value, simply measure vector V_S with a ruler, and convert its length into volts according to the method you used in determining the length of V_L and V_R. The answer will agree with the value you would obtain in a real circuit by measuring the source voltage with an A.C. voltmeter. Thus do A.C. voltages add according to Kirchhoff's Laws.

The average radio man need only remember that because of phase the voltages and currents in A.C. circuits are sometimes reduced in effective value, and that A.C. voltages and currents can only be added if they reach their peak values at the same time, as they do in resistance circuits.

POWER

What would you be doing if you pushed an automobile a distance of twenty feet? Work, of course. If it took one man four minutes to push the auto this distance, and another man did it in one minute, which would be more powerful? "Naturally," you answer, "the man who did it in one minute."

Much the same thing takes place in an electrical circuit. A voltage or e.m.f. pushes electrons through the circuit. The source voltage, measured in volts, is the electrical force, and the current in amperes tells how many electrons are moving through the circuit in one second—speed. Just as we considered the strength of the man and the time in which he did his work when deciding whether he was powerful, so do we multiply volts and amperes together to find out whether an electrical source is powerful—to determine the power being delivered by the source. To find the amount of power which a device is absorbing in a direct current circuit if it is a load, or delivering if it is a source, or wasting if it is in a transmission system, multiply the voltage across that device by the current flowing through it. The answer will be the electrical power in watts.

The Power Formula. The formula which expresses what I have just said about the power in any D.C. circuit is: $P = E \times I$, where *P* stands for the power in *watts*, *E* for the voltage in *volts*, and *I* for the current in *amperes*. For instance, when 1 volt is multiplied by 1 ampere, the answer is 1 watt. If you know the voltage applied and the current (either A.C. or D.C.) flowing through any *resistor*, this formula $(E \times I)$ will tell you exactly how many watts of energy are converted into heat in the resistor.

The amount of power which a given resistor can absorb without getting too hot is called its *power* or *wattage* rating. The larger the physical size (length, diameter and surface area) of a resistor, the more heat it can withstand and the higher will be its wattage rating. I want to make it clear, however, that the wattage rating of a resistor has no relation to the ohmic value; resistors with *like* ohmic values but different wattage ratings will always offer the *same* opposition to current flow. When a voltage *E* forces current through a resistor *R*, the wattage rating simply tells you whether *R* will take that current (and power) safely. For example, if you have a 100-ohm resistor and apply 100 volts to it, a current of 1 ampere will flow regardless of what the wattage rating of the resistor may be. If the rating is only 10 watts, the resistor will naturally get hot and will probably melt; the resistor's wattage rating must be at least 100 watts in this example.

If you encounter a receiver in which a certain resistor becomes too hot and perhaps even burns out frequently, you should replace it with another resistor having the same ohmic value but a higher wattage rating.

EASY CALCULATING CHARTS

Although I have shown you how to solve radio problems by using Ohm's Law and the power formula, the required calculations are sometimes quite involved and often bothersome, especially when made so seldom that you forget between times just what procedure to use.

To simplify matters for you, I have prepared on page *24* a special *N. R. I. Easy Calculating Chart,* which automatically permits you to make all voltage, current, resistance and power calculations. This chart contains four vertical scales, *E* for volts, *I* for current in amperes, *R* for resistance in ohms, and *P* for power in watts; if any two of these four electrical values are known, all you have to do to find either one or both of the other two is to lay a ruler across the chart and read the answers. Simple, isn't it? Locate on the proper scales the values which are known in your problem, place the ruler to run through these two points and read, at points where the ruler intersects the scales for the unknown values, the answers to your problem.

For instance, if you know the current through a resistor and the voltage across it, you can read the resistance in ohms of that resistor and the power absorbed by it directly on the chart. If the power absorbed and the current through a resistor are known, you can read the voltage and the resistance of the unit just as easily. When dealing with resistances outside the range of the chart (greater than 10,000 ohms), follow the rules given under the chart.

In the lower right corner of the chart are twelve formulas which can be used to check the answers obtained or to obtain more accurate answers. I will go through one example to show how accurately this chart checks against Ohm's Law. Suppose you wanted to find the size of a certain resistor; by measurement you found that the voltage E across the resistor was 6 volts when the current I through it was .002 ampere. Locate these points on the chart scales, lay a ruler across, and you find that the resistance R is 3,000 ohms. Now check this value against Ohm's Law: $R = \frac{E}{I}$; $R = \frac{6}{.002}$; R = 3,000 ohms. Some of the formulas on the chart require advanced mathematics; do not try to use them until you have progressed further with your Course.

The Radio-Trician often has occasion to compute the equivalent resistance of two resistors connected in parallel. You will find the *Easy Calculating Chart* on page *25* of great value when dealing with parallel combinations of resistors. This chart will not give you exact values, but will tell you the important figures in the values; it is more than accurate enough for the practical radio man.

The Parallel Resistance Chart on page 25 can also be used to compute the equivalent inductance of two coils connected in parallel or the equivalent capacity of two condensers connected in series. Exactly the same procedure as for resistors is followed; in the case of coils, let the scale values on the chart represent millihenries, and when dealing with condensers let the chart values represent either microfarads or micro-microfarads, whichever is most convenient for the problem at hand.

EXPRESSING RESISTOR VALUES

The two symbols, ω and Ω, are often used as abbreviations for "ohms" when expressing resistor values, especially on circuit diagrams. Thus, 300,000 ohms would be written either as 300,000 ω or 300,000 Ω. Since this value is equal to .3 megohm, it can also be written as .3 meg. High resistance values are often expressed in *thousands* of ohms, the capital letter *M* being used to represent *thousands*. Thus, 300,000 ohms can also be written as 300 Mω or 300 MΩ. Here is one other example: 25,000 ohms may be written as 25,000 ω, 25,000 Ω, .025 meg., 25Mω, or 25 MΩ.

In a few instances you may find that the symbols ω and Ω are both used on one circuit diagram; in cases like this Ω represents megohms, and ω represents ohms. Incidentally, these symbols are both the Greek letter "omega."

LOOKING AHEAD

In this lesson I have given you a general idea of how resistors are made, what they look like, and how they work. Remember that resistors offer the same opposition in either A.C. or D.C. circuits, but that coils and condensers behave differently in different types of circuits. In the next lesson I will take up the problems of coils as they are used in radio circuits.

TEST QUESTIONS

Be sure to number your Answer Sheet 5FR-2.

Place your Student Number on every Answer Sheet.

SPECIAL NOTICE

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

---

1. What three basic electrical devices oppose current flow?
2. What happens to the electrical energy which is absorbed by a resistor?
3. If we have two wires of exactly the same diameter and length, one made of Nichrome and the other of copper, will the resistance of the Nichrome wire be *equal to, higher than,* or *lower than* the resistance of the copper wire?
4. When resistors are classified according to their *construction,* into what three groups can they be divided?
5. Give the form of Ohm's law to find the *current* flowing through a load when the voltage across it and the resistance of the load are known.
6. When a resistor is connected across the terminals of a storage battery, a certain value of current flows; will this current *increase, decrease* or *remain the same* in value when the resistor is replaced with one having a higher ohmic value?
7. State Kirchhoff's Law No. 1 (Current Law) and Kirchhoff's Law No. 2 (Voltage Law).
8. If a 2 ohm, a 10 ohm, and a 25 ohm resistor are all connected together *in parallel,* will the equivalent resistance be *less than 2 ohms, exactly 10 ohms,* or *more than 25 ohms?*
9. What is meant by the wattage rating of a resistor?
10. Does the wattage rating of a resistor have any effect upon the opposition which the resistor offers to current flow?

RADIO COILS—WHY AND HOW THEY WORK

6FR-2

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

DETERMINATION

Did you ever watch a steamroller—an old-fashioned one with clanging gears, escaping steam and great clouds of black smoke belching from the stack? Wasn't it a thrill to see that great machine level out obstacles in its path, leaving behind a perfectly smooth roadway?

The word "determination" always brings to my mind that picture of a steamroller—a machine which nothing can stop once the "full steam ahead" lever is thrown. The steamroller is determined to go places and do things—and it succeeds!

So, too, are *you* determined to go places, to achieve success and happiness. One by one you are completing your lessons, studying hard and making sure you understand everything; step by step you are approaching that greatest of all goals—SUCCESS.

Of course, the way is long and not at all easy. It's going to be hard at times to stick to your study plan; again and again, when the going gets a little harder than usual, you will become discouraged, but just bring out that old determination and back it up with every single ounce of ambition you've got. Be a steamroller, always confident of your own power, always moving ahead, always succeeding. Keep that determination of yours alive every single minute; keep on plugging day after day, and you can't help succeeding. I'm with you, ready to help you over the bumps at any time—*I'm determined to make you win.*

J. E. SMITH.

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
(REGISTERED U. S. PATENT OFFICE) (REGISTERED U. S. PATENT OFFICE)

JD6M241 Printed in U.S.A.

Radio Coils—Why and How They Work

INTRODUCTION

FROM what I have said so far in this course it is quite obvious that resistors, coils and condensers are important in radio circuits. You know that a resistor definitely opposes the flow of electrons in both A.C. and D.C. circuits; you know that coils (neglecting their ohmic resistance since it is very low) have no effect upon a continuous direct current but have an effective opposition to the flow of alternating current, this opposition increasing with the inductance* of the coil and the frequency of the A.C. voltage; and finally you know that a condenser completely blocks the flow of direct current but only limits or reduces the current flow in A.C. circuits.

In the previous lesson I gave you a detailed account of how resistors behaved in radio circuits; in this lesson I will take up the subject of coils in much the same way. First I will describe to you the construction and appearance of common types of coils, and tell in a general way how they are used in Radio receivers, in electronic control equipment and in television apparatus. Some of the applications may seem to be quite advanced to you, but I am sure they will make your study of coils more interesting.

PRACTICAL COILS AT WORK

Coils have thousands of important uses—in ship-to-shore radiotelephone equipment, where they allow you to ring the calling bell of one ship, and only that one ship far out to sea—in the police radio cars which protect our lives and property—in aircraft radio sets miles above the earth and in submarine radios submerged in the sea. Coils make radio and electrical currents do many queer and fascinating stunts.

Choke Coils. If a resistor will reduce the current in an A.C. circuit, then why use a coil for the same purpose? The answer, as you already know, is: Coils offer to the flow of alternating current an opposition or choking effect which *increases* as the frequency of the A.C. voltage is increased; whereas, a resistor would show no change in its opposition effect. I pointed out to you before that in Radio a wire or lead in a circuit may be serving as a path for two or even three different types of current—for D.C., for an R.F. signal, or for an A.F. signal. When it is necessary to separate these different currents, sending each to a different branch circuit, the "discriminating nature" of a coil enters into the picture.

* Inductance is the electrical value of a coil, just as resistance represents the electrical value of a resistor.

Figure *1A* is a vacuum tube circuit which can be used to amplify radio signals. Let me use this as a practical example of how choke coils behave, even though we have not yet studied radio frequency amplifiers. All I want you to know here is that there is a pulsating electron current flowing from the plate (*P*) of the tube to terminal No. *1* of the load, this current consisting of: *1*, a D.C. component (a D.C. part); *2*, an R.F. component. It is highly important that the R.F. component be stopped before it reaches the high voltage source, but at the same time we must not interfere with the flow of the D.C. component to this source.

A coil (marked *CH* in Fig. *1A*), inserted into the circuit as shown to stop the R.F. signal currents, is the solution to this problem, for it allows D.C. to pass unhindered. This coil is called a *choke coil* because of its ability to check or "choke" the flow of an A.C. current.

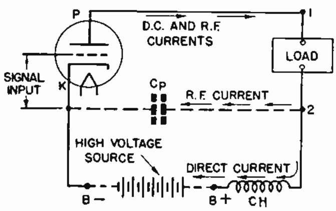


Fig. 1A. Coils and condensers can be very efficient "traffic officers" in radio circuits. Here they make two kinds of electron current separate properly at terminal *2*. This action takes place in radio receivers and transmitters.

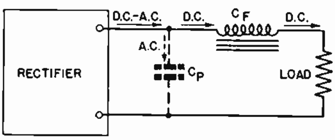


Fig. 1B. Another example of how a coil and condenser can control electron "traffic". Only direct current is allowed to reach the load in this simple rectifier-filter circuit. You will find this action in power packs.

Unless some other path is provided for the R.F. signal, it will be entirely "choked out of" the plate circuit, and no radio signals will be passed on to the next stage. To prevent this, condenser C_P is connected between terminal *2* of the load and the cathode (*K*) of the tube; this condenser has quite a low opposition to high frequency currents, and therefore offers a short path back to the cathode of the tube for R.F. currents. Yes, team-work between coils and condensers plays an important part in radio circuits.

Another practical example of a coil at work is in the rectifier or power pack system shown in Fig. *1B,* used to change A.C. to D.C. in radio sets. After this rectifier changes A.C. to a pulsating direct current, some device must be used to "wipe out" or "filter" the variations or irregularities in the pulsating D.C. Again a coil "saves the day"; referring to Fig. *1B,* coil C_F allows the D.C. to pass but effectively filters or chokes the variation in current. Although condenser C_P, providing a path back to the rectifier for blocked A.C. currents, is theoretically not absolutely necessary, it can be a valuable partner of the coil in this filtering action.

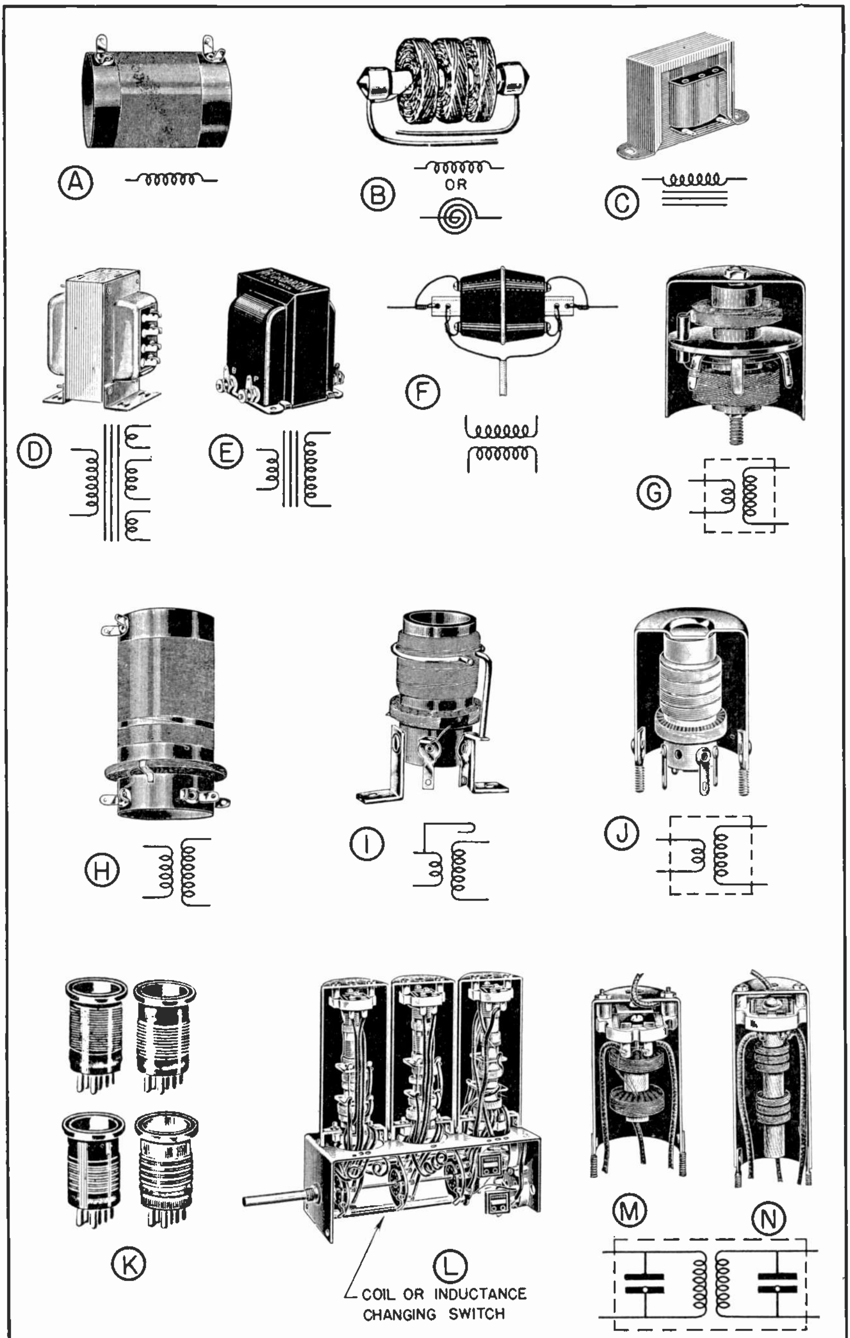


FIG. 2. *A*, single layer air core R.F. choke coil; *B*, multi-layer air core R.F. choke coil; *C*, iron core choke coil; *D*, typical power transformer used in radio receivers; *E*, audio transformer; *F*, R.F. transformer for all-wave doublet antennas; *G*, shielded R.F. transformer (part of shield is cut away); *H*, non-shielded R.F. transformer; *I*, non-shielded R.F. transformer with capacity coupling; *J*, shielded R.F. coil; *K*, plug-in type coils; *L*, rotary switch and tuned R.F. coil assembly for all-wave receiver; *M*, typical I.F. transformer; *N*, I.F. transformer.

What do these choke coils look like? Are they all constructed alike? In the circuit of Fig. *1A*, for instance, the A.C. signal in a practical radio frequency stage of an all-wave receiver may have a frequency of from 100,000 to 30,000,000 cycles per second, while in the rectifier circuit (Fig. *1B*) the A.C. current delivered by the device is rarely over 120 cycles per second. Since the choking effect of a coil increases with the frequency of the A.C. current passing through, it is quite obvious that the R.F. choke needs only a low inductance—a few turns of wire, while the rectifier filter coil must, on the other hand, have a larger inductance. Rectifier filter coils are therefore constructed with many turns of wire wound on *iron* cores.

Typical choke coils are shown at *A*, *B* and *C* in Fig. *2*. *A* is a single layer choke coil with an air core (by *air core* I mean that the wire is wound on a coil form made of insulating material, *with no iron inside*); *B* is a multi-layer choke coil with an air core (a wood coil form is often used, for wood, like all insulating materials, is little different from air in magnetic properties). Coil *B* is sometimes called a criss-cross coil, a lattice-wound coil, a duo-lateral coil or a universal coil, because of the method used in winding the wire. *C* is an iron core choke coil; here the wire is wound in layers which are separated from each other by insulating paper. Below each coil is shown its schematic symbol.

In general the copper wire used in winding coils is simply covered with an insulating enamel, or with enamel and an additional cotton or silk covering. Occasionally coils designed for very high frequencies, like coil *A*, are wound with bare wire, the turns being spaced to prevent them from touching. Coils are sometimes baked in a hot oven, then dipped in a paraffin compound or in varnish. The heat drives off moisture; the coating serves to keep the moisture out and to hold the turns of wire in position.

Tuning Coils. When a coil and condenser are connected together in series or parallel for the purpose of tuning to a certain A.C. signal, the coil is called a *tuning coil,* and of course the condenser becomes a *tuning condenser.* If the electrical size of either the coil or condenser can be varied, however, these are more properly called variable (or tunable) tuning coils or condensers.

Figures *3A* and *3B* show typical radio circuits in which coils and condensers are used together. In each case the two units form a tuning circuit which has a maximum effect on a current of some definite frequency. In the circuit of Fig. *3A*, for instance, currents of one particular frequency produce a large voltage across the *L-C* combination, while all other frequencies pass through the condenser or coil with little opposition. Incidentally, this circuit is called a *parallel tuned* (or parallel resonant) *circuit,* and the correct frequency for maximum effect is known as the *resonant frequency.*

Figure *3B*, on the other hand, shows what is commonly called a *series tuned* (or series resonant) circuit. Here the opposition characteristics of the coil *L* and the condenser *C* nullify each other at the resonant frequency, allowing resonant frequency currents to pass unhindered through the series resonant circuit; all other frequencies encounter opposition and cannot flow through this resonant circuit. In this case the *L-C* combination "traps" or by-passes certain frequencies, providing a lower opposition path for them than is offered by the load; currents of the frequency to which *L* and *C* are resonant are thus kept out of the load. Coil *L* in Fig. *3B* has an iron core (this is indicated by the parallel lines alongside the coil symbol), and this coil must therefore be in a low frequency circuit. Actually the circuit of Fig. *3B* is a resonant circuit often used in audio amplifiers to adjust the fidelity (the accuracy of reproduction of high and low notes by the receiver).

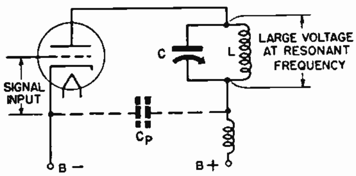


Fig. 3A. In this parallel tuned circuit, differing from Fig. 1A only in that *L* and *C* replace the load, "teamwork" between coil *L* and condenser *C* causes the combination to offer high opposition to currents of one particular frequency, which is known as the resonant frequency.

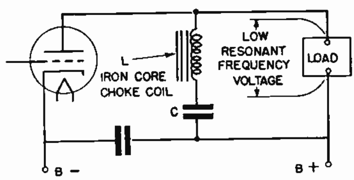


Fig. 3B. Here is a series tuned circuit (such as an audio amplifier noise trap), where L and C in series nullify each other and present very little opposition at the resonant frequency (the frequency at which undesirable noise is greatest), keeping this frequency out of the load.

As resonant and tuned circuits are very important in Radio, I will tell you more about them in later lessons. Here we are merely getting acquainted with all kinds of coils.

There is no radical difference between a choke coil and a tuning coil; a given coil may be called by several different names, depending upon how it is used.

*Coils Mutually Coupled Magnetically.** Do not let the words "mutually coupled magnetically" send big question marks to your mind. These three words are a radio engineer's way of saying that two or more coils are placed close enough to each other (are mutual) to allow the magnetic lines of force produced by one coil to link or pass through the other coil. Immediately you think of an audio transformer or a power *transformer*—and quite rightly too. You have met these devices before; I told you that a varying current in one coil of a transformer

* Often engineers merely say that coils are "mutually coupled." The fact that *only* coils are involved indicates that magnetic coupling or magnetic induction is meant.

produced a varying voltage in any other coil which was mutually coupled to the first coil. Because power of one voltage and current in the primary of mutually coupled coils can be transferred to a secondary coil where a different voltage and current but about the same power exists, coil combinations like this are often called *transformers*, even though in some cases they have little resemblance to the heavy iron core devices you usually think of as transformers.

Power Transformers. Figure *4A* gives a schematic diagram of a common type of power transformer, often used in A.C. radio receivers. P_G is the plug which is inserted into the wall outlet. The magnetic coupling is produced by an iron core which passes through the centers of all four coils, L_P, L_{S1}, L_{S2} and L_{S3}. Incidentally, the subletter P stands for *primary winding* and S for *secondary winding*. The numbers following the subletters simply distinguish one secondary winding from another. The general external appearance of a power transformer is shown at *D* in Fig. *2*.

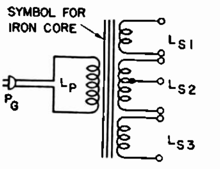


Fig. 4A. Schematic diagram of a power transformer having one primary and three secondary windings. Note that one of the secondary windings is tapped.

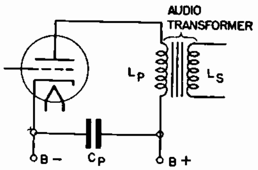


Fig. 4B. Learn to recognize this audio transformer symbol and its connections to the plate circuit of a vacuum tube, for you will encounter it many times in your radio work.

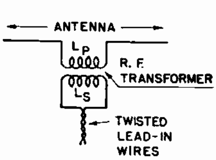


Fig. 4C. This schematic diagram reveals what is inside that little black device you see high in the air between the halves of an all-wave receiver doublet antenna.

Audio Transformers. A schematic diagram of an audio transformer, another familiar radio device, is given in Fig. *4B*, where it is shown connected into the plate circuit of a vacuum tube; an external view of a typical audio transformer appears at *E* in Fig. *2*. Here again an iron core, indicated by parallel lines, mutually couples coils L_P and L_S.

R.F. Transformers. You no doubt have seen all-wave antennas, designed to receive signals from European and other foreign stations, in which an odd-shaped device was inserted between the two halves of the horizontal wire high in the air; well, this device is nothing more than an R.F. transformer like that shown at *F* in Fig. *2* and in the diagram of Fig. *4C*. Another form of R.F. transformer, a type commonly used in radio receivers, appears at *G* in Fig. *2*.

Coil Shields. As you will later learn, both magnetic and electric lines of force produced by *high frequency* currents are stopped by metal cans. In radio receivers R.F. coils are invariably placed in copper, iron or aluminum cans like that shown at *G*, to shield the coils from the magnetic and electric fields produced by other parts, or to prevent the electric and magnetic fields of the coil from "straying" to other parts in the circuit. Metal coil shields therefore prevent stray fields from entering as well as leaving coils.

Tuned R.F. Transformers. Many of the R.F. coils used in radio frequency circuits are transformers in which one or both coils are tuned to a particular frequency or are tuned over a definite range of frequencies by a variable condenser. Such coil combinations are called tuned R.F. transformers. Two coils are invariably wound on the same form or are mounted close to each other, and one or both are shunted by a tunable (variable) or adjustable condenser. When you tune a radio receiver for a desired broadcasting station, you are really adjusting variable condensers which are connected across the coils of tuned R.F. transformers.

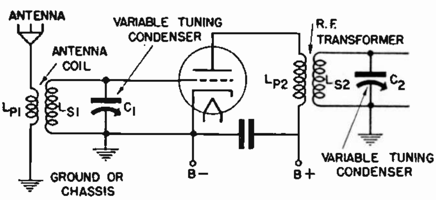


FIG. 5A. You will soon learn to recognize circuits like this as tuned R.F. stages. The antenna coil here works with condenser C_1 to "boost" the strength of the desired incoming signal; the vacuum tube gets the signal next and amplifies it some more; the R.F. transformer passes the tuned-in signal on to the next stage, "boosting" the signal another notch at the same time that it rejects all other signals.

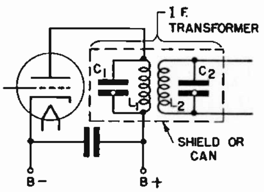


FIG. 5B. Another type of coil, the intermediate frequency transformer, is shown at work in this typical I.F. stage circuit. C_1 and C_2 are trimmer type condensers, mounted inside the coil shield, and are like those shown at *M* and *N* in Fig. 2. These trimmers are adjusted only by manufacturers and servicemen.

The schematic circuit diagram of a tuned R.F. stage in a broadcast receiver is generally like that shown in Fig. *5A*. Coil L_{P1} in the antenna circuit is usually called the primary and coil L_{S1} the secondary of the antenna coil (or antenna transformer); here the secondary is tuned by variable condenser C_1. An A.C. current (the R.F. signal current picked up by the antenna) passing through L_{P1} produces an A.C. voltage in coil L_{S1}; tuning condenser C_1 nullifies whatever opposition coil L_{S1} may have, allowing a large R.F. current to circulate in the closed circuit formed by L_{S1} and C_1 and producing a large voltage across both the condenser C_1 and the coil L_{S1}. Yes, indeed, a tuned transformer can "boost" or step up low voltages considerably.

Another R.F. transformer "in action" is shown in Fig. *5A*. The vacuum tube sends its amplified signal through primary L_{P2} of this air core transformer. When condenser C_2 is adjusted properly a much higher voltage signal is induced in the secondary winding L_{S2}, ready to be fed to the next vacuum tube.

The "heart" of a superheterodyne amplifier stage is the intermediate frequency (abbreviated I.F.) transformer shown in Fig. *5B*. The I.F. signal delivered by the vacuum tube is fed to C_1 and L_1, this circuit being tuned to the I.F. signal frequency, and as a result a large voltage appears across L_1 and C_1. This causes a large A.C. current to flow in L_1, this current in turn inducing a voltage in coil L_2. Since the secondary coil L_2 and condenser C_2 are also tuned to the intermediate frequency, a large voltage appears across C_2 and L_2, ready to be passed on to the next tube. Inasmuch as the intermediate frequency of a receiver does not change (this is one of the characteristics of a superheterodyne circuit), C_1 and C_2 are tuned (adjusted) once by the manufacturer, then left alone until the serviceman readjusts them when he finds that the I.F. amplifier requires retuning.

In Fig. *2*, *H*, *I*, *J*, *K*, *L*, *M* and *N* illustrate a few of the many tuned transformers which are used in radio receivers. The adjustable or trimmer type condensers which are used appear above the coils in *L*, *M* and *N*.

At *H* is an open (non-shielded type) R.F. transformer, the primary (lowest winding) being of the criss-cross wound type. The gap or space in the single layer secondary winding is for a definite purpose, to reduce the capacity between turns which is inherent in all coils. It is for this same reason that choke coils like that at *B* in Fig. *2* are wound in two or more sections.

At *I* is another open type coil. Here the primary is of the criss-cross type, but the secondary is a multi-layer winding, and a heavy wire connected to one end of the primary winding loops around but does not connect to the secondary. This heavy wire serves to couple (link) the primary and secondary coils by means of electric lines of force (condenser coupling). This capacity provides an additional coupling besides that secured by magnetic linkages between the primary and secondary coils. Capacity coupling is especially effective at the higher R. F. frequencies of a variable tuning range.

The coil shown at *J* is practically the same type of coil as at *I*, (without the capacity coupling), mounted in a shield can to isolate it from surrounding radio parts in a receiver.

The all-wave receiver needs coils of different inductances for each wave band tuned in by the receiver. As you probably know, all-wave receivers are of the 2, 3, 4 or 5 band types. Coils of the plug-in variety, like those shown at *K*, were used on the first models of all-wave receivers, one set of coils being designed for each band (a coil for each tuned stage); here it was necessary to interchange coils in order to receive stations in different bands. Changing plug-in coils proved too bothersome a procedure for the average radio listener, so radio engineers developed a rotary switch like that shown at *L*, which automatically changes (for each stage) the coil or the coil's inductance to meet the requirements for a particular band. The coils for each stage and for all the bands are housed in cylindrical aluminum cans, there being as many cans as there are stages in which inductances must be changed. The cans are usually mounted near the change-over switch. The switch either removes (electrically) one set of coils and connects another set into the circuit or uses only a part of each coil. Of course, the coils are tuned by variable condensers controlled by the tuning knob on the receiver panel, but small adjustable condensers, known as trimmers, are mounted inside some of the coils to help the manufacturer of the receiver and the serviceman to make accurate adjustments.

Typical intermediate frequency transformers are shown at *M* and *N*. Note that in transformer *N* each of the two coils is separated into three parts or "pies." This reduces distributed coil capacity * and results in a better transformer. Above the coils, just inside the shield can, are the adjustable or trimmer type condensers; usually there are two, one for each of the coil windings.

It seems that although I started out to tell you about coils, I have referred equally as much to condensers. This cannot be helped if I am to tell you how coils are used, for these two parts are team-mates in radio circuits. I will even have to consider resistance in this lesson, for it is impossible to wind a coil which has no real resistance (or other losses which are in effect a resistance).

Now that you are acquainted with a number of common types of coils, I am going to tell you how coils behave in radio circuits.

COILS STORE ENERGY FOR INSTANT USE

When a current flows through a wire it produces, as you know, a magnetic field which surrounds the wire. If the wire is wound into a coil the magnetic field will be concentrated through the center (in the core) of the coil. This magnetic field will attract iron and steel to the coil, and in addition will attract or repel (depending upon polarity) other coils through which similar currents are flowing. Since the magnetic field of a coil can act on objects in this way, it should be clear to you that this magnetic field represents *energy*, the ability to do work. That is why we say that a wire or a coil through which current is flowing stores energy in *magnetic form.*

Increasing the energy stored in a coil is very important in such Radio and electronic devices as relays, loudspeakers, robot controls, cathode ray television tubes, and electrical measuring instruments, for the more

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* Adjacent turns of wire in a coil form small condensers whose effects become appreciably large at high radio frequencies; since these tiny "condensers" are distributed uniformly through the coil, the total *capacity* of a coil is known as the *distributed coil capacity.*

energy there can be stored, the stronger an electromagnet the coil will become. But how can we increase the amount of energy stored in a coil? The answer to this is easy—increase the strength of the coil's magnetic field, either by increasing the current flowing or by increasing the inductance of the coil.

Coil inductance depends upon three things: 1, *coil dimensions;* 2, *turns of wire;* 3, *core material.* Increasing the diameter (or core area) of the coil or increasing the length of the coil will increase the inductance. Increasing the number of turns of wire wound on the coil form will also increase the inductance. Using core materials like iron or steel inside the coil likewise increases the inductance and makes the coil a more powerful electromagnet. Obviously, if the current flowing through the coil has a constant value, the energy stored will likewise be a definite fixed amount. But what happens when the e.m.f. causing current to flow through a coil is suddenly changed or even removed? The answers to these questions, which I will now give, should tell you a lot about the behavior of coils.

A COIL BEHAVES LIKE A FLY-WHEEL

Have you ever tried to turn the fly-wheel of a gasoline engine (with the spark plugs removed to release compression)? Have you ever turned one of the heavy grinding wheels, about 24 inches in diameter and 2 inches thick, which are so common on farms? Have you ever attempted to spin the jacked-up front wheel of an automobile? If you have, the following facts will be a matter of past experience.

The wheel is at a standstill; as you start to turn it, applying a steady turning force, you will observe that the wheel spins slowly at first, gradually picking up speed. Finally, as you continue applying the constant twisting force, the wheel assumes a constant speed. When you stop the twisting force, the wheel gradually and very slowly comes to a standstill.

Why does a heavy wheel behave like this? It is because the wheel has a "mass of rotation" or *inertia,* a characteristic which you and I would call simply "stubbornness." In bringing the wheel up to a constant speed you must exert energy to overcome this inertia. One more factor enters into the picture; if it were not for bearing friction and the friction of the wheel against air (the fanning action of the wheel), you would be able to bring the wheel up to a terrifically high rotating speed.

Likewise, when you stop applying a twisting force to the wheel, it keeps on turning because of inertia (mechanical stubbornness), until it is finally stopped by the friction of the bearing and of the air.

You have probably guessed already that this inertia is very much like the inductance of a coil. Electrical engineers, in fact, often call inertia a "mechanical inductance." The larger the wheel, the heavier the material, and the more weight there is concentrated in the rim of the wheel, the more mechanical inertia the wheel will have. Mechanical inductance thus depends upon the size and shape of the wheel.

Suppose that the wheel is rotating at a constant speed, its friction being overcome by a constant twisting force, and suddenly the twisting force is increased (or decreased). What do you think will happen? The wheel will "kick back like a mule"—refuse to change its rotational speed so suddenly. The mechanical inductance refuses to allow sudden changes, but if the increased or decreased force is continued for a period of time, the wheel has no alternative but to change its speed of rotation correspondingly.

COILS ARE "STUBBORN," TOO

Now I will compare coils with wheels and explain why electrical inductance is so much like mechanical inductance. If a steady D.C.

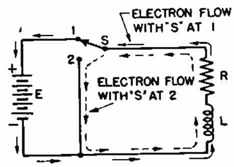


FIG. 6A. The stubbornness characteristic of a coil can be demonstrated with this simple circuit. *R* represents resistance of wire in coil *L*.

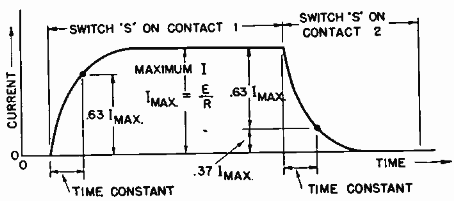


FIG. 6B. This graph gives the complete story of how electron current through the coil in Fig. *6A* increases when a D.C. voltage is applied by placing the switch at contact *1*, and how current decreases when the switch is quickly changed to position *2*.

voltage is applied to a coil having resistance, as in the circuit of Fig. *6A* where *R* represents the inherent resistance of the coil marked *L*, current will begin to flow, and gradually, as the battery voltage overcomes the effects of the coil's inductance, the current will reach a value which is determined solely by the voltage of the source and the resistance of the coil. As long as the D.C. voltage and the resistance remain unchanged, the current *I* will be the same and equal to the voltage *E* divided by the resistance *R* (Ohm's Law). Next the source of e.m.f. is suddenly removed by the simple switch arrangement shown in Fig. *6A*, which disconnects the battery, then shorts (connects together) the terminals of the coil. The current drops rapidly at first, then gradually reduces to zero.

The entire story is told in graph form in Fig. *6B*. The current flows through the coil in the same direction at all times here, a logical fact. Remember that the fly-wheel continues to move in the same direction when the twisting force is changed; well, so does the current through the coil when the driving force, the battery voltage, is removed. The coil's inductance and resistance together determine how fast the current will rise or drop.

The time required for the current flowing through a coil to rise from zero to 63% of its maximum value, or to drop from the maximum value to 37% of the maximum value when the coil is shorted, is definite for a given coil and resistor combination; this time (in seconds) is called the *time constant* of the coil.* The time constant of the coil can be *decreased* by placing a resistor in series with the coil.

The time constant of a coil is often very important in radio work; for example, if the vibrator contacts in an automobile radio receiver open and close too rapidly, the current cannot flow through them long enough to rise to the required value in the transformer. Two remedies are possible; either slow up the action of the vibrator, or change the time constant of the transformer to make it take current faster. In photoelectric control equipment, as another example, the light beam is in some cases interrupted for only a very small fraction of a second; here the relay coil *must* have a low time constant if the relay-operating current is to build up rapidly.

The electrical inductance or "stubbornness" characteristic of coils can be summed up as: When the voltage applied to a coil is suddenly increased or decreased, the current will *change gradually* to the new value; the more rapid the change in voltage, the greater will be the stubbornness of the coil. With A.C., increasing the frequency increases the rapidity of the voltage change, so naturally a coil's stubbornness increases with frequency. Before taking up alternating currents in coils, however, I will tell you more about how coils get this stubborn opposition-to-change characteristic.

INDUCED VOLTAGE LAWS

You already know that when the magnetic flux through a coil of wire is varied a voltage will be induced in the coil. Fix in your mind the picture in Fig. *7A* of a coil of wire of any size or shape, with magnetic lines of force (which you can picture as imaginary wires bundled together) passing through the center or core of the coil. Now—the *total number of turns* of wire in the coil *multiplied by* the *number of magnetic lines of force* passing through the coil (linking all of the turns) is called the *flux linkage* of this coil. The total turns are usually designated as *N*, and the total lines of force (magnetic flux) are labeled Ø (the Greek letter *phi,* pronounced "fee"); the flux linkage in a coil is thus equal to *N* Ø, which means *N* multiplied by Ø. The two examples in Fig. *7 A* show clearly how the same amount of flux linkages can be obtained from a small coil having a large flux as from a large coil having many

* The time constant of any coil can be figured by dividing the inductance of the coil (in henrys, a unit of inductance to be considered shortly) by the ohmic resistance of the coil.

turns but a small flux. Increasing the current through a coil increases the number of magnetic lines of force produced by the coil; this explains why a 3-turn coil can produce the same number of flux linkages as a 1000-turn coil.

The idea of flux linkage is very important, for it is closely related to the inductance of a coil. In order to understand how voltages are induced in coils, it is necessary to consider flux linkages.

When the flux linkage in a coil is varied (either by varying the number of turns or by varying the flux), a voltage will be induced in the

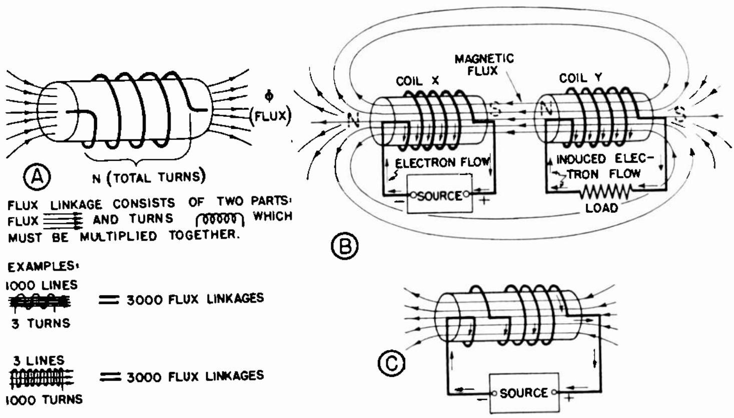


FIG. 7A. The total number of flux linkages is equal to *N*, the total number of turns of wire on a coil, multiplied by Ø, the total flux (magnetic lines of force) passing through all of the turns of the coil (that is, linking all of the turns).

FIG. 7B. The meaning of Lenz's Law is explained by this sketch. Electrons flow through coil *Y* in the indicated direction only when the electron flow through coil X is *decreasing*.

FIG. 7C. Self-induction causes a back e.m.f. to be induced in a coil to oppose any changes in the current through the coil.

NOTE: The number of lines of force which pass through a coil can be measured with elaborate laboratory-type measuring instruments.

coil; but in what direction will this induced e.m.f. act? The answer is given by Lenz's Law for coils, which says:

Whenever there is a change in flux linkage in a coil, the resulting induced e.m.f. is in such a direction that it opposes the original *change* in flux linkage.

Notice that Lenz said *opposes the original change in flux linkage*—this means that if the magnetic flux is *increasing,* the induced voltage will send a current through the coil in such a direction that this current's magnetic field will oppose the *change* taking place in the original magnetic field which passed through the coil; if the original coil flux is *decreasing* the new current will try to prevent the decrease in flux by producing a flux of its own, in the *same* direction as the original flux. Now are you getting the idea of electrical inertia, of how Nature opposes changes in the number of lines of force which link a coil? That famous scientist Lenz was simply saying: "Nature will not willingly give you an induced voltage," when he stated his law in 1834.

MUTUAL AND SELF INDUCTION

Mutual Induction. A few examples will help you to understand the exact meaning of Lenz's Law. Coil *X* in Fig. *7B* is just a plain coil of wire, connected to a D.C. source which causes electrons to flow in the direction indicated. A compass would prove that the magnetic lines of force pass through coil *X* in the direction shown.* Now if coil *Y*, a similar coil connected to a resistance load, is near one end of coil *X*, so that the magnetic lines produced by *X* pass through or *link* both coils, nothing will happen in coil *Y* as long as the current in coil *X* remains constant. Now if I cause the current in coil *X* to change, the magnetic field will also change and a voltage will be induced in coil *Y*. If the current, and therefore the flux, is decreasing in *X*, you know from Lenz's Law that coil *Y* must tend to prevent this decrease in flux. In other words, coil *Y* must produce a magnetic flux which has the same direction as the flux produced by coil *X*.

The Left-Hand Rule for Coils will now tell you the direction of electron flow through coil *Y*. Point your thumb in the direction indicated for the magnetic field in Fig. *7B*; your fingers curled around the coil will now be pointing in the direction of electron flow through the wires of the coil. Try this for yourself; it checks with the direction indicated for the electron flow in coil *Y*, doesn't it?

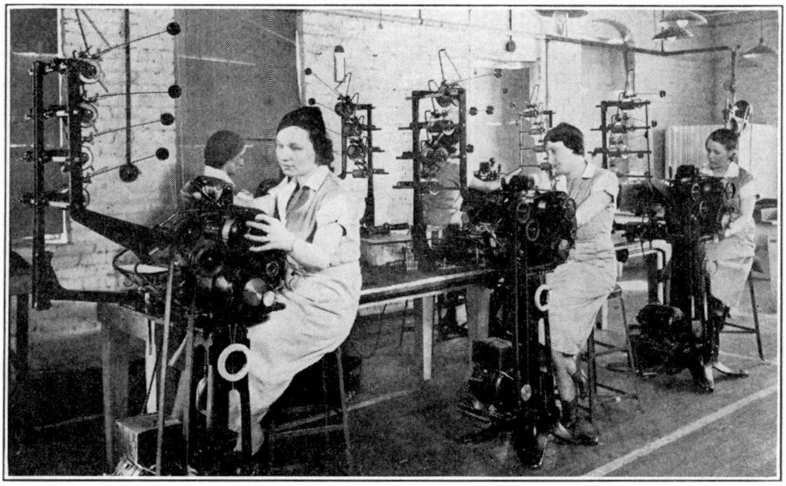
All this is quite logical when you consider that if things turned out any other way—if, for instance, the flux through *X* was increasing and coil *Y* helped it to increase—the magnetic field through both coils would increase indefinitely and you would be getting a tremendous amount of energy for nothing—a condition which you know is impossible in Nature.

Self Induction. Now I will consider coil *X* alone, with the first turn of the coil pushed apart from the others as in Fig. *7C*. Current passing through this lone turn produces a magnetic field which links all other turns in the coil. If this current is *increasing,* the magnetic field passing through that first turn of wire will be increasing too. Lenz's Law says that this change in flux must be opposed by any other coils or turns of wire which are affected; this means that all the other turns of wire on the coil must oppose the change in magnetic flux produced by this

* There is a simple rule, known as the *Left-Hand Rule* for *Coils,* for determining the direction of the magnetic field produced by a flow of electrons through a coil. It is: Hold the coil (or imagine you do) in your left hand so your fingers will be pointing in the direction of *electron flow* through the coil wires; your outstretched thumb will then be pointing in the direction of the magnetic field which passes through the coil. Try this rule on coil *X* in Fig. *7B*.

isolated turn. You already know that a coil opposes a change in flux by creating an induced voltage which sends an induced current through the coil and thus creates a magnetic field which will oppose the change. That is how one turn of wire affects all the others; every single turn of wire in a coil has the same effect on the other turns, and the net result is that there is an e.m.f. induced in all turns of the coil to oppose every change in the flux linkages in the coil. This effect is known as *self induction,* for it takes place in the coil *itself* rather than in a separate coil.

Continuing with this investigation of coils, I will now show you the importance of self induction. When you want to send a current through a coil, naturally you apply a voltage to the coil. If you increase the



Courtesy Universal Winding Co.

A corner of a coil winding factory, showing a battery of machines each capable of winding four coils at once, weaving the wire back and forth automatically to form self-supporting criss-cross wound coils. One machine, in the hands of a skilled operator, will turn out as many as 1,000 coils, each having around 600 turns, per day.

voltage you expect the current to rise, too, but two things will limit this rise, or rather will determine the opposition characteristics of the coil: *1,* the rate at which the voltage (and current) is increasing; *2,* the inductance (self induction effect) of the coil.

Any coil which is carrying current produces flux linkages, and *the number of flux linkages produced when this current is exactly one ampere is a measure of the inductance of the coil* (the opposition which the coil will offer to *changes* in current). The *henry* (named after the great American experimenter Joseph Henry) is the practical unit of inductance; if the number of flux linkages produced in a certain coil by a current of *one ampere* is exactly equal to *one hundred million,* that coil is said to have an inductance of *one henry.* The henry is in some cases too large a unit of inductance to be convenient for radio work, so technicians use instead a smaller unit, known as the millihenry, which is equal to one-thousandth of a henry. An even smaller unit, the microhenry, is occasionally used in connection with R.F. coils; one microhenry is one-millionth of a henry.

COILS IN D.C. CIRCUITS

Now I can explain to you *in electrical terms* exactly what happens when a D.C. voltage is applied to a coil. I will consider a simple coil made from a length of copper wire which has a certain definite resistance in ohms, since all coils have a certain amount of resistance. It is this resistance which limits the *maximum* D.C. current which can flow through the coil, but the self inductance of the coil prevents the current from reaching this maximum value immediately. The coil stubbornly opposes any change (increase in this case) in its current; the gradually increasing current sets up an e.m.f. of self induction—a back voltage which opposes the voltage applied to the coil.

There are, then, two opposition or back voltages which control the direct current in the coil: *1*, the resistance drop in the coil; *2*, the e.m.f. of self induction caused by the changing current. Gradually the current approaches its maximum value, until finally the applied voltage is constant and completely cancels the effects of self induction. Now the entire applied voltage is used to overcome the resistance drop in the coil (assuming that the circuit contains only a D.C. source, a coil and a transmission line of negligible resistance). A steady, direct current flows through the coil and magnetic energy is stored up in the coil, ready to oppose any future change in the coil current.

COILS IN A.C. CIRCUITS

Before I take up coils in A.C. circuits, I want to describe an interesting little experiment with a coil, an ordinary electric house lamp and two sources of power, 110 volts A.C. and 110 volts D.C. If you have access to both A.C. and D.C. power and can secure the necessary apparatus, you can try this experiment yourself in a few minutes.

First connect the lamp directly to the 110 volt A.C. line, then to the 110 volt D.C. line. The lamp burns equally bright in both cases, just as you expected, for the equivalent heating effects of the two voltages are exactly the same.

Now suppose that you repeated this experiment but placed in series with the lamp a coil which is wound on an iron core to have a high inductance (this coil should have low resistance so that any resistance effects will be negligible)—what effect do you think the coil would have in each case? Let me tell you what you would see.

When this circuit is connected to a D.C. source, as in Fig. *8A*, the lamp will be just about as bright as it was without the coil, but if your eyes are keen you will notice that more time is now required for the lamp to reach full brilliance. The self inductance of the coil slows down the initial rush of current, but otherwise the coil has little effect on the lamp.

With the lamp and coil connected to an A.C. supply, as in Fig. *8B*, the lamp is quite dim, indicating that the coil is dropping or wasting a considerable part of the source voltage. This is quite logical, for A.C. current changes continually and the e.m.f. of self induction, which opposes current changes, must therefore be continually opposing the applied voltage.

A.C. Voltage Drop Across a Coil. A coil, then, actually drops the voltage of the A.C. circuit to which it is connected. Practical radio men

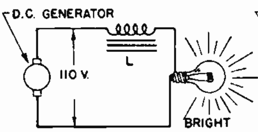


Fig. 8A. Choke coil *L* has little effect upon the current flowing through the lamp in this direct current circuit.

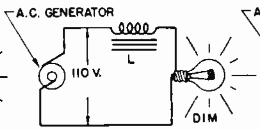


Fig. 8B. Choke coil *L* limits or "chokes" the flow of current through the lamp in this alternating current circuit.

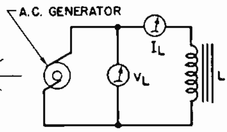


Fig. 8C. Here A.C. voltmeter V_L measures the voltage across coil *L*, while A.C. ammeter I_L measures the current.

usually prefer to measure the voltage drop with meters, but for those who are interested I will give a simple way of figuring it:

> **To find the A.C. voltage drop across a coil, multiply together four things—multiply the current (in effective amperes) flowing through the coil, by the inductance of the coil in henrys, multiply again by the frequency (in cycles per second) of the A.C. source, and then multiply the result by the number 6.28.**

Compare this with Ohm's Law (voltage equals current times resistance) and you will see that current appears in both formulas, but that three items (*frequency* times *inductance* times *6.28*) here correspond to the resistance in Ohm's Law.

A.C. Current Through a Coil. When a coil is connected directly to an A.C. source, as in Fig. *8C*, the current flowing through the coil, as well as the voltage across the coil (the source voltage), can be measured with A.C. instruments. Assuming that you knew the inductance of the coil, you would find upon checking your measurements that:

(1) The A.C. current through a coil is equal to the A.C. voltage divided by the product of three things—6.28* times frequency times the inductance.

This expression is often written in the following simplified manner:

(2) $$I_L = \frac{V_L}{6.28\,f\,L}$$

Where:

I_L is the A. C. coil current in effective amperes.
V_L is the effective A.C. voltage across the coil.
f is the frequency in cycles per second.
L is the inductance of the coil in henrys.

Inductive Reactance. Notice that this coil current formula differs from Ohm's Law ($I = V/R$) only in that the expression *6.28 f L* replaces *R*. This expression, *6.28 f L*, corresponds in one sense to resistance, for it is the *effective A.C. opposition* of the coil.

The opposition which a coil offers to the flow of A.C. is called *inductive reactance.* ("Reactance" means "opposition" to the flow of A.C., and "inductive" means that the opposition is due to a coil.) Just as the letter *R* was used to represent resistance, so is the letter *X* used to represent *reactance,* which is always expressed in ohms. The letter *L,* as you know, signifies a coil, so X_L stands for the inductive reactance of a coil.

Formula *2* can be simplified even more by putting X_L in place of the term *6.28 f L*, giving:

(3) $$I_L = \frac{V_L}{X_L}$$

Now the resemblance between this formula and Ohm's Law is even more noticeable. If you know the inductance of the coil in henrys and the frequency you can always figure out the inductive reactance in ohms from the formula $X_L = 6.28\,f\,L$.

Although practical servicemen seldom use this formula, they do remember that reactance increases with frequency and inductance. Sometimes, however, you may want to know the reactance of a certain coil at a particular frequency; in order to make this easy for you I have prepared two charts. Use the first, Chart No. *A* in Fig. *9*, to find out approximately how large the reactance will be, then use Chart No. *B* in Fig. *9* to determine the important numbers in the value. The inductance of the coil must, of course, be known before you can use these charts; if not available, this inductance is quite easily figured out by methods which I will explain shortly.

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* You will occasionally find the numeral 6.28 written as 2π, where π is the Greek letter pi (pronounced "pie") standing for the number 3.14, which is used in determining the circumference of a circle (circumference equals 2π times the radius). Pi enters into this formula because the path traced by the arrow end of a rotating vector which represents an A.C. voltage and current is a circle which must be considered when deriving the above formula with higher mathematics.

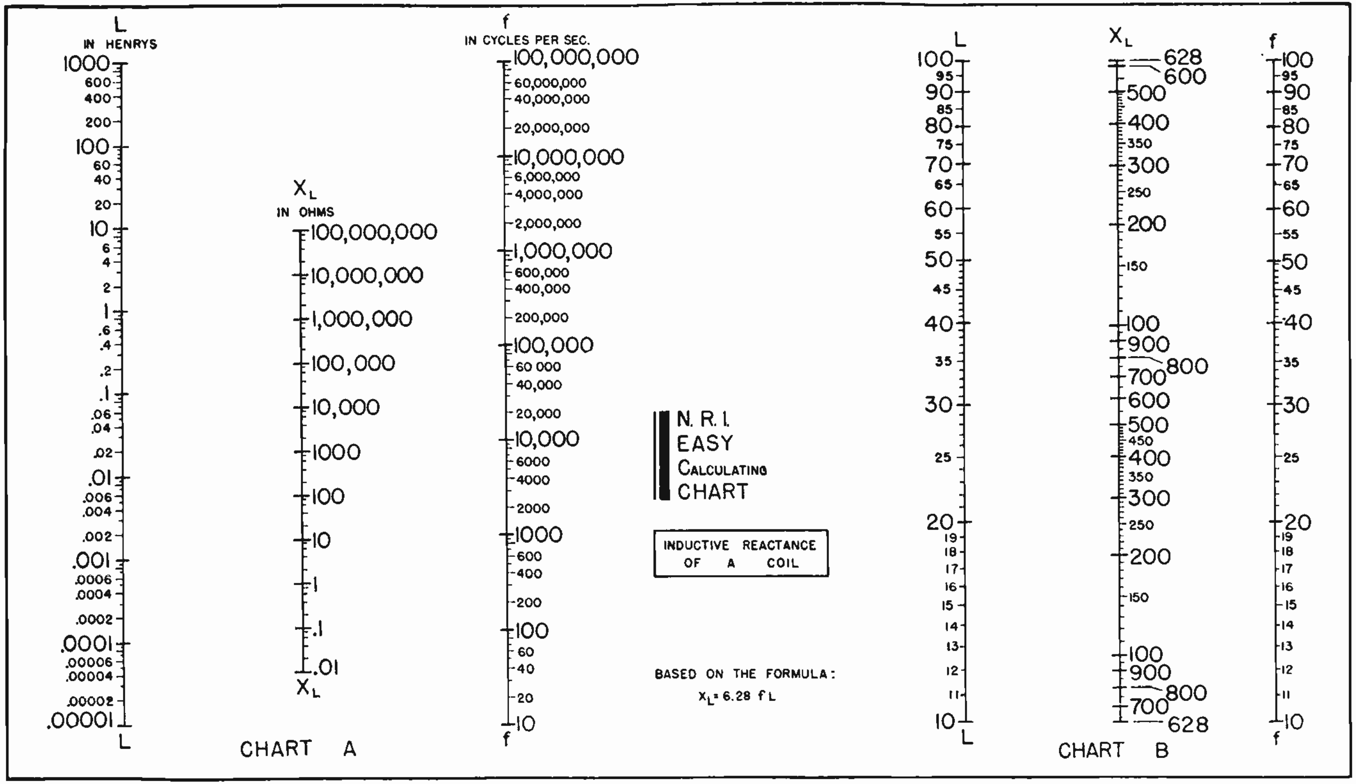


FIG. 9. Easy Calculating Chart for obtaining the inductive reactance of a coil when the inductance *L* and the frequency *f* are known.

HOW TO USE: Locate known values on proper scales of chart *A*, place ruler across these points, and read answer where ruler crosses scale of unknown value.

If greater accuracy is desired, repeat this procedure on chart *B*, neglecting decimal points, to get the correct first numerals for the chart *A* answer.

EXAMPLES: 1. L = 30 henrys, f = 500 cycles. Using chart *A* first, locate 30 on the L scale, 500 on the f scale and read the answer, 100,000 ohms, on the X_L scale. Using chart *B*, locate 30 on the L scale, 50 (neglect decimals here) on the f scale and read the answer, 950, on the X_L scale. This tells you that the first numerals in the chart A answer should be 95; the correct answer is then 95,000 ohms. Chart *A* gives approximate values; chart *B* allows you to make the approximate values more accurate.

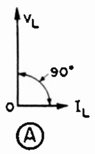
2. L = .002 henry, f = 6,000,000 cycles. From chart A, X_L = 75,000 ohms. From chart *B*, locating 20 on the L scale, 60 on the f scale, you get 75 for the correct first numerals in the answer. In this case, therefore, your chart A reading was accurate.

3. L = .000045 henry, f = 7,000 cycles. From chart A, X_L = about 2 ohms. Using chart B, locate 45 on L scale, 70 on f scale, and read 196 on center scale. Correct answer is then 1.96 ohms.

PHASE OF VOLTAGE AND CURRENT

I have told you how a coil controls or limits the amount of current flowing in an A.C. circuit; a coil has one other important effect on A.C. current. In a previous lesson I pointed out that when an A.C. voltage is applied to a resistor, the voltage across and current through that resistor will be in phase, increasing and decreasing at exactly the same time; with A.C. voltage applied to a coil, however, things are quite different. The voltage across the coil will reach its maximum value when the A.C. current through the coil is zero. In other words, the voltage at the coil leads the current by one-quarter cycle, which as you know is 90 degrees.

The relation between the voltage and current for a coil in an A.C. circuit is clearly shown by the sine wave curves in Fig. *10B*. V_L represents the voltage across the coil at each interval of time for one complete cycle, while I_L represents the current under the same conditions. Observe that whenever I_L is zero, as at points *1* and *2*, V_L is a maximum, just as I said before.



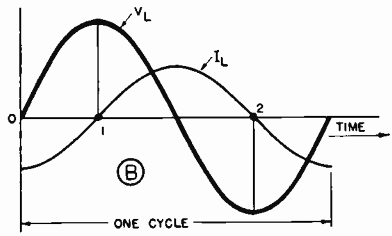


Fig. 10A. Vector diagram of current and voltage for an ideal coil.

Fig. 10B. These sine wave curves show the relation between the current and the voltage for an ideal coil (one having a resistance so low that it can be neglected).

The curves in Fig. *10B* can just as well be represented by the two rotating vectors in Fig. *10A*. Note that these are at right angles (90 degrees) to each other. Since vectors always turn counter-clockwise, it is easy to see that the voltage V_L *leads* the current by 90 degrees. This is the same as saying that the current *lags* the voltage by 90 degrees.*

Is phase important? Again I say that this depends upon how high in the radio profession you want to go. Phase relationships exist between currents and voltages in any receiver or transmitter; you will not need to know much about phase to repair or install radio apparatus, but to understand how the apparatus works and why it sometimes fails, phase must be studied.

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* There is one other way, using higher mathematics, of demonstrating that the current through an inductance lags behind the applied voltage; since this mathematical analysis is of no practical value to you, it has been omitted.

The opposition of a coil can be balanced by the opposition of a condenser because of *phase;* the voltage across a resistor and a coil connected in series does not equal the applied voltage because of *phase;* hum can be balanced out of a receiver because of *phase;* pictures are black when they should be white in television receivers because of *phase;* two tubes doing the job of one act correctly only if they are in *phase;* radio beacons which guide aircraft in the skies work because the designer took account of *phase;* and so the examples pile up. Phase, as I said before, is not a subject which you can grasp in one lesson; as you study more and more about this problem you will begin to realize its significance.

AN EXAMPLE OF PHASE

Suppose you connect to an A.C. source a resistor and coil which are in series, as in Fig. *11A*. If you took an A.C. voltmeter and measured the applied voltage V, the voltage across the coil V_L and the voltage across the resistor V_R, you would find to your surprise that the value of V_R added to the value of V_L would not equal the measured applied voltage V. Why? Phase was not taken into account.

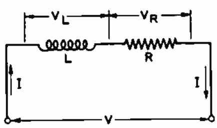


FIG. 11A. Kirchhoff's Voltage Law applies to this circuit, where *V* is an A.C. source, only when phase is taken into consideration.

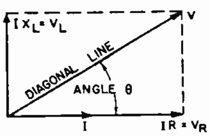


FIG. 11B. Kirchhoff's Voltage Law checks out perfectly here because vectors, which automatically take care of phase, are used.

First of all, the coil and resistor are in series, and so the same current must flow through each. Immediately you know that the voltage drop across the resistor is in phase with the current, as shown by the vectors V_R and I in Fig. *11B*. You have also learned that the voltage across a coil leads the current by 90 degrees. If you make the lengths of vectors V_L and V_R in Fig. *11B* represent the magnitudes of these values, you will have represented the relationships between V_L and V_R correctly on one simple diagram. Now draw a rectangle with V_R and V_L as sides, and put in the diagonal line. The length of this line represents the two voltages added together with phase considered, and you will find that the value of voltage which this line represents equals exactly the source voltage V. Furthermore, the source voltage will lead the current by the angle θ (the Greek letter theta, often used by radio men to represent *phase angle*).

All this brings us to a very important fact: When a coil has resistance the applied voltage will lead the current by an angle *less than* 90 degrees; that is, the greater the resistance (in ohms) of a coil, the more like a resistor it acts, and the more nearly in phase are the voltage and current. Good coils should have a very low resistance.

By this example I have shown you why vectors are so useful in representing currents and voltages, and how by adding vectors of suitable lengths, you can take phase into account. The advanced radio man can use Kirchhoff's Law in any A.C. circuit if he uses vectors (which are values with phase included) instead of values only.

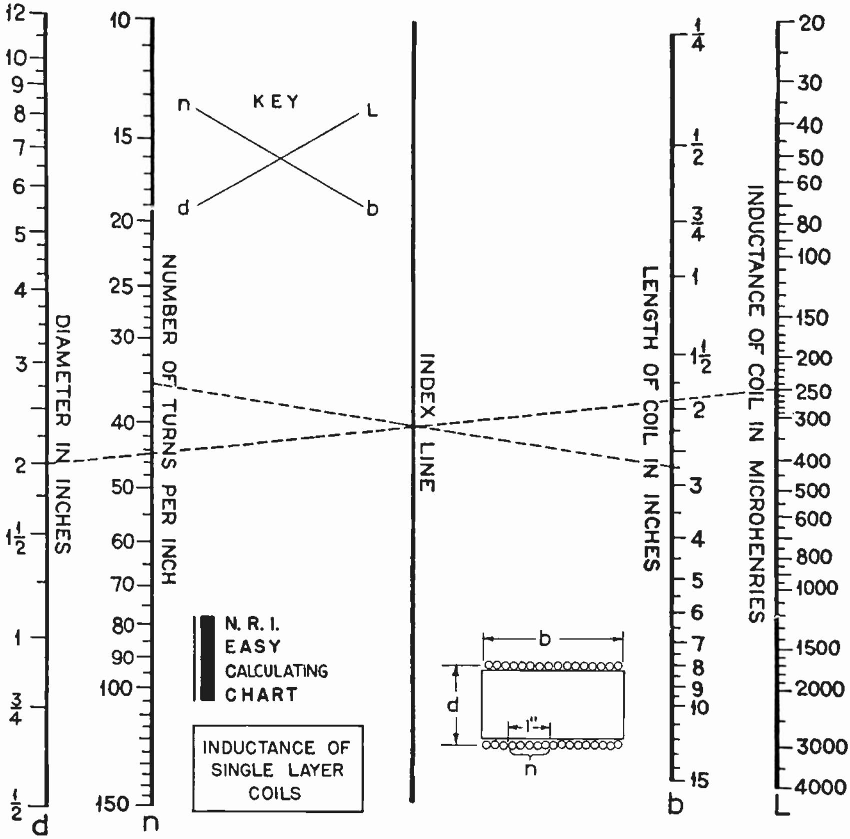
CALCULATING THE INDUCTANCE OF AN AIR CORE COIL

The inductance of a coil can be measured with meters when its exact inductance must be determined. Quite often, however, a radio experimenter requires a coil of a definite value; naturally it is best to order this from a dealer, for coils are available in practically every size required for radio work. Only the simplest coils, containing a single layer of insulated copper wire wound over a round bakelite tube, can be satisfactorily constructed at home; iron core coils and multilayer coils having a certain definite inductance should always be purchased, for their construction requires intricate machinery, and their design calls for a knowledge of advanced mathematics.

Single-layer air core coils are generally used as tuning coils or as choke coils. I will show you how to figure the approximate size required to get a certain inductance; you can always make the inductance exactly correct by adding or subtracting a few turns from the finished coil.

Now what determines the inductance of an air core coil? As I have already told you, inductance is determined by the flux linkages produced by one ampere of current; this means that the number of turns, the size of the coil and the shape of the coil all affect its inductance. Clearly, then, the inductance of an air core coil depends upon its length, its diameter (coils are generally wound on circular forms), and upon the number of turns of wire per inch of coil length. Scores of complicated formulas have been worked out to give the inductance of a coil, but they all are a burden to use, even by experts. The simple chart shown in Fig. *12* is much handier; even though the results are not exactly correct they are quite satisfactory for practical radio use. Caution: This chart applies *only* to *single-layer air core* coils.

Example: Needed, a 250 Microhenry Coil. Suppose that you have some No. 22 double silk covered wire and a 2-inch diameter fiber or bakelite tube at hand, and want to use these to make a 250 microhenry single layer air core coil for an ultra high frequency receiver. All right, look up this wire in the table in Fig. *12;* you find that you can wind about 35 turns of this wire per inch of coil length. Now you must find out how long the coil should be to give the required inductance. The Easy Calculating Chart in Fig. *12* will tell you; look at the key



d = diameter of coil in inches.
b = length of coil in inches.
n = number of turns per inch on coil.
L = inductance of coil in microhenrys.

Size of Wire (B & S Gauge)	NUMBER OF TURNS PER INCH			
	Double Cotton Covered	Single Cotton or Double Silk Covered	Single Silk Covered	Enamel
20	24	27	29	29
21	27	30	33	33
22	30	35	37	37
23	33	38	41	41
24	36	42	45	46
25	39	46	50	52
26	42	50	56	58
27	45	55	62	65
28	48	60	68	73
29	52	65	75	82
30	56	71	83	91
31	60	77	92	101
32	63	84	101	113
33	66	90	110	127
34	70	97	120	143
35	73	104	131	158
36	77	111	143	175
37	80	118	155	198
38	84	126	168	224
39	88	133	181	248

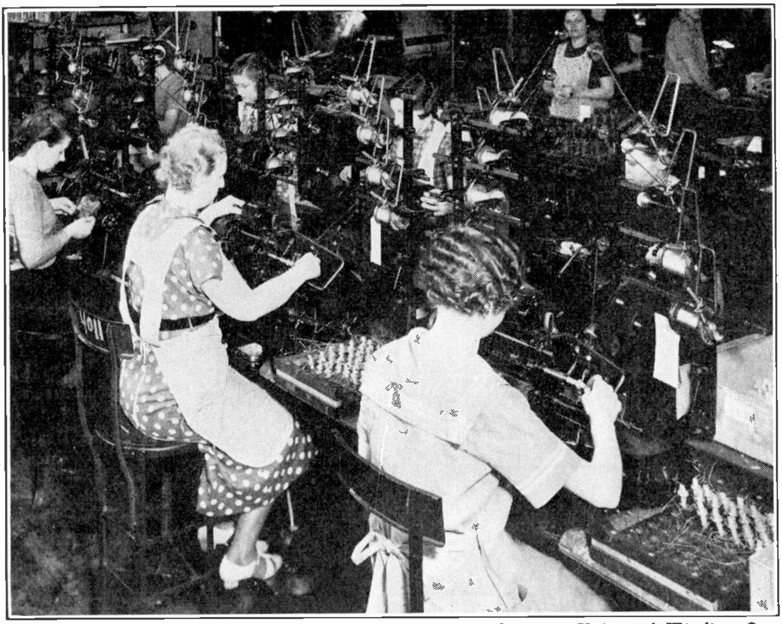
FIG. 12. This Easy Calculating Chart for the Inductance of Single Layer Coils (above) and the table of turns per inch (n) for different sizes of insulated wire (left) together allow you to determine quickly, by using only a pencil and ruler, the approximate inductance of any single layer air core coil used in radio work.

HOW TO USE: Three of the four values on the chart must be known. Note which two of these fall on same line in key; locate these values on chart and mark where line between them crosses index line. Now read answer where line between third known value and index line mark crosses scale of fourth value.

EXAMPLE: To find L, locate n and b on proper scales, mark index line where ruler crosses, then lay ruler across d and index mark and read answer where ruler crosses L scale.

(the crossed lines) first, and check each item which you already know about the coil. You know that *L,* the inductance of the coil, is 250 microhenrys; *d,* the diameter of the coil, is 2 inches; *n,* the number of turns per inch, is 35. Thus you know three of the four items on the key; the fourth can now be found in the manner explained below the chart (Fig. *12*).

In your case *d* and *L* are the two known items on the same line in the key; locate 2 on the *d* scale, 250 on the *L* scale, and place your ruler as indicated by the dotted line between these two values on the chart.



Courtesy Universal Winding Co.

Robot machines, end to end, row on row, turn out radio coils at the rate of 100 per hour in this great radio parts factory. Here I.F. transformers, criss-cross wound, are being made.

Mark the index line intersection; locate 35 on the *n* scale and move the ruler to go through 35 and the index line mark. The ruler now intersects the *b* scale at 2.75 (as shown by the other dotted line), so 2¾ inches is the correct length for your winding (the coil form will be a little longer, to give room for terminals and mounting holes).

Example: Finding the Inductance of a Given Air Core Coil. Measure the diameter of the coil (*d*). Using a ruler, count the number of turns per inch (*n*). Measure the length of the coil (*b*). Locate the *n* and *b* values first, since they are on the same key line; mark the index line intersection; place the ruler across *d* and the index line mark and read your answer where the ruler crosses the *L* scale.

Interesting Facts About Air Core Coils. After you work with the chart in Fig. *12* for a while you will discover a number of interesting facts, like these:

> If you double the number of turns without changing the coil diameter or length (that is, use a smaller wire to get twice as many turns per inch), the inductance will increase four times.
>
> If you cut the turns in half without changing the size of the coil (by using larger wire), the inductance will drop to one-fourth of the original value.
>
> If you increase the turns three times without changing the size of the coil, the inductance will increase nine times.
>
> If you double the diameter of the coil, all other factors remaining the same, the inductance will increase about four times.
>
> If you double the length of the coil by spacing out the turns, the coil inductance will be reduced about one-half.*

Once a coil has been made up according to calculations, it should be tested in the circuit in which it is to be used. Take off turns if the coil inductance proves to be too high; add turns if the inductance is too low. Remember that the inductance changes rapidly with turns; add or take off only one or two turns at a time. As you become more familiar with radio circuits you will learn to know when a coil tests correctly in its circuit.

CORE MATERIALS

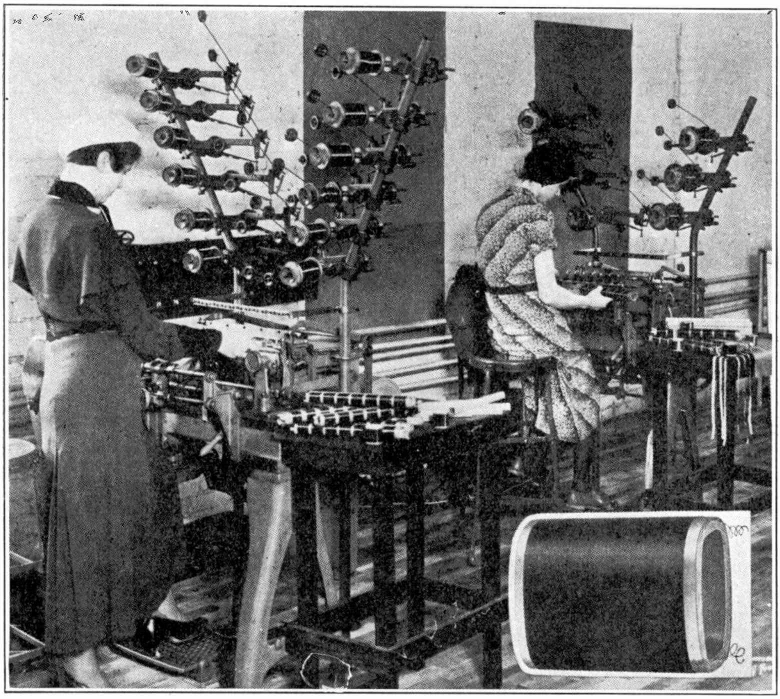
The inductance of a coil also depends upon the material used for the core or form on which the wire is wound. Air or materials having equivalent magnetic characteristics such as bakelite, Isolantite (a variety of porcelain), fiber, dry wood, paper, hard rubber, etc., are most commonly used for the cores of coils where high frequency currents are

---

* When the diameter or length of a coil is varied, the shape of the coil changes and a correction must be made if accurate results are to be obtained. Sometimes it is necessary to use the more accurate Bureau of Standards' coil inductance formula, which is: $L = .0251\, n^2 d^2 bK$, where L is the inductance in microhenrys, b is the length of the coil in inches, n is the turns per inch and d is the diameter in inches. K is called the Nagaoka correction factor for the shape of the coil. The value of K depends on $\frac{d}{b}$. Here are a few values: When $\frac{d}{b}=0$, $K=1$; $\frac{d}{b}=.5$, $K=.818$; $\frac{d}{b}=1$, $K=.688$; $\frac{d}{b}=2$, $K=.526$; $\frac{d}{b}=3$, $K=.429$; $\frac{d}{b}=4$, $K=.365$
From these values the advanced experimenter can draw a curve from which he can get K for any value of $\frac{d}{b}$ from 0 to 5. More exact results are thus obtainable if you do not mind long, tedious calculations. To figure out coil specifications for a certain inductance you first choose a suitable coil diameter and turn per inch value, then try various coil lengths, determining K for each and working out the Bureau of Standards' formula until you find the length which gives the correct L. The chart is much easier to use because no juggling is involved. Of course, if the coil is already built, you simply substitute the values for b, n, d and K in the formula to get L; remember n^2 and d^2 mean that n and d are each multiplied by themselves once.

involved, for in this case only a small inductance is needed to secure a high inductive reactance (high opposition characteristic). Since these materials are used merely to support the wires of the coil, only as much material as is required to give mechanical rigidity is employed.

Laminated iron and steel cores are used only where lower frequency currents, such as audio frequencies up to about 20,000 cycles, and power line frequencies are present. The core shapes are punched out of thin sheet metal, then assembled in stacks and bolted together. One "leg" or



Courtesy Universal Winding Co.

Round or rectangular, long or short multilayer coils for radio and electrical transformers of all types are made by these high-speed automatic winders. Sheets of "glassine" insulating paper are placed automatically between each layer of wire on the coil. The machines wind seven coils simultanously on a single long form, and cut the coils apart when the winding is completed. The output transformer coil shown at the lower right is an example of the type of coil produced. Up to 25,000 turns of wire can be placed on each coil at a maximum winding speed of 3,000 r.p.m.

section of the core passes through the coil. All power transformers and audio transformers used in radio sets have laminated cores.

The cores of coils are sometimes made of finely pulverized iron mixed with a binder; iron cores of this type increase the inductance without increasing the physical size of a coil. Both R.F. and I.F. coils are made with *pulverized iron cores;* these will in general be smaller in size than air core coils of corresponding inductances, because the same inductance can be obtained with fewer turns of wire.

The insertion of iron or steel in the core of a coil allows the current flowing through the coil to produce more magnetic lines of force than if air alone was present in the core. Sheet iron and sheet steel work this way at low frequencies, but only finely pulverized iron and steel will work at I.F. and R.F. frequencies.

The permeability of a magnetic core material is the number of times more lines of force obtained with the magnetic core instead of air. The sheet steel used for audio transformer cores, for example, has a permeability of about 6000, meaning that it gives 6000 times as many lines of force as would an air core.

COILS IN SERIES AND PARALLEL

Quite often when a large inductance is needed, the required coil may be too bulky as a single unit (the coil will be either too long or too wide); in cases like this technicians use several smaller coils connected in series, for inductances can be combined exactly like resistors.

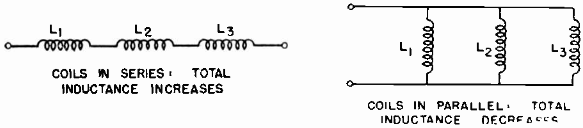


FIG. 13. Coils combine exactly like resistors. For coils in series, add inductances to get total inductance. For equal size coils in parallel, divide inductance of one by number of coils.

If two different inductances were required at the same position in a circuit (as in some two-band radio receivers), you could have one coil in the circuit permanently and use a switch to connect another coil in parallel when a lower inductance was required.

From these two illustrations you can see that when coils are *in series* their individual inductances are *added* to get the total—the greatest possible inductance; coils in parallel likewise combine exactly like resistors in parallel,* giving the smallest possible inductance for a certain group of coils.

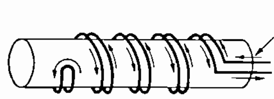
These rules for coils in series and parallel, given diagrammatically in Fig. *13*, are true only if the coils are shielded from each other or if the coils are placed at right angles to each other, there being no magnetic lines linking the coils. When coils are placed close together, so that there is magnetic linkage between them, one coil will tend to change the inductance of the other. If the inductance increases when the two

* In a previous lesson I gave you an Easy Calculating Chart for *Resistors in Parallel*; this same chart can be used for coils as well. The chart scales will now represent either henrys, millihenrys or microhenrys, depending upon which unit is most convenient; remember, though, that all three scales must represent the same unit for any one problem. If the inductance of the large coil is more than 25 times that of the small coil, the combined inductance is assumed to be that of the smaller coil, just as was done in the case of resistors.

coils are brought close together but you want it to decrease, simply reverse connections to one of the coils. The inductance of a coil is also reduced when a metal can (shield) is placed over the coil.

NON-INDUCTIVE RESISTORS

It is often quite important that resistors used in high frequency radio circuits, such as in ultra-high frequency television transmitters and receivers, in ultra-high frequency police radio equipment, and in diathermy apparatus (radio transmitters used for medical purposes) have little or no inductance. Wire-wound resistors, made by winding resistance wire around an insulating core (in much the same way that coils are made) are really small coils of high resistance, and cannot therefore be used in these cases.



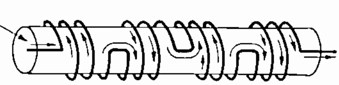


Fig. 14A. When resistance wire is wound on a cylindrical form in this manner, electrons flow in opposite directions through adjoining turns, and their magnetic effects cancel to give zero inductance. This is known as the hairpin type winding.

Fig. 14B. Non-inductive resistors are also made in this manner, where the winding is divided into an equal number of sections, the direction of winding being reversed for adjoining sections. The magnetic effects of the sections thus cancel each other.

A "rod" or "stick" type resistor, such as a ceramic carbon or a metallized unit, is by far the best non-inductive resistor. It is now possible to secure these in units which will retain their accuracy indefinitely and which will not change their resistance with changes in temperature. Naturally these have no appreciable inductance, for the current does not form a loop and there can be no concentration of flux linkages.

Before the advent of precision "stick" type resistors, it was necessary to use special windings to get non-inductive effects. Examples of these are shown in Fig. *14A* and Fig. *14B;* in each case the magnetic fields produced by different parts of the winding cancel each other, resulting in zero flux linkages and zero inductance. Many different types of these are still on the market, and are extensively used in test apparatus, especially D.C. testers.

THE NEXT LESSON

I have so far considered two of the important elements in a radio circuit, namely the resistor and the coil. In the next lesson I am going to take up the condenser, that valuable little electron-storing device which has so many uses in A.C. and D.C. radio circuits; after that will come the study of radio tubes and real radio circuits.

TEST QUESTIONS

Be sure to number your Answer Sheet 6FR-2.

Place your Student Number on every Answer Sheet.

SPECIAL NOTICE

Send in your answers for this lesson immediately after you finish them. Doing this insures that the graded answers will reach you while the subject matter is still fresh in your mind, and you will get the greatest possible benefit from our speedy personal grading service. *Never hold up a set of lesson answers.*

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1. Does the opposition or choking effect of a coil *increase, decrease,* or *remain the same* when the frequency of the A.C. current is increased?

2. What is the purpose of a metal coil shield?

3. On what three things does coil inductance depend?

4. Would the time constant of a coil *increase, decrease,* or *remain the same* if you placed a resistor in series with the coil?

5. Give Lenz's Law for coils.

6. What is the inductance of a certain coil if the number of flux linkages produced in the coil by a current of one ampere is exactly equal to one hundred million?

7. What is the opposition that a coil offers to the flow of A.C. called?

8. If you double the number of turns on an air core coil without changing the coil diameter or length, will the inductance *be doubled, increased four times, decreased four times,* or *remain unchanged?*

9. What kind of cores are used in R.F. and I.F. coils in order to make them smaller in size than air core coils of the same inductance?

10. Would you connect two coils together *in series* or *in parallel* to get the greatest possible inductance?

CONDENSERS—
HOW THEY BEHAVE
IN RADIO CIRCUITS

7FR-2

NATIONAL RADIO INSTITUTE

EST. 1914

WASHINGTON, D.C.

SUCCESS AND HAPPINESS

I would like to have you feel, as you read the short personal messages which appear on the inside front cover of each lesson text, that you are seated right alongside my desk. Years of experience with thousands and thousands of ambitious men have proved to me that a word of advice or cheer, just before you start a new lesson, can go a long way towards speeding your progress. As I see it, my responsibility goes farther than just giving you the *very best* training in Radio—my duty is to help you get the very most out of *life*—to attain *real happiness.*

You, in common with all other N. R. I. men, desire success. You think that success will bring happiness, but this is not necessarily true; I believe that a man must train himself for happiness, just as he must train himself for success! Many a successful man of today is not happy, just because he did not realize this important truth.

The first thing you must understand is this: *Happiness comes from within!* There is no guarantee that material things—money, success, friends and possessions—will make you happy, for happiness is a state of mind. You must learn to be happy within yourself.

In these one-minute chats, then, I am going to teach you how to get the most happiness out of the success which is in store for you.

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
RADIOTRICIAN & TELETRICIAN
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Condensers—How They Behave in Radio Circuits

HOW CONDENSERS BEHAVE—A REVIEW

THERE are literally hundreds of different sizes and types of condensers available, each suited for a particular job. It is highly important that you know how condensers are used, what electrical size a condenser should have for a certain use, how condensers are built, what causes condensers to fail and how much voltage a condenser can safely withstand. Knowing these facts, you will be able to use condensers correctly and to repair equipment which has defective condensers.

In its simplest form, a condenser* consists of two or more metallic sheets or plates separated by an insulator; this combination can store electricity, releasing it when a wire path is provided between the two sheets of metal. A good condenser prevents the flow of direct current but allows A.C. to pass. The *effective opposition* of a condenser to alternating current *decreases* as the electrical *size* of the condenser (its capacity) and the *frequency* of the current are *increased.*

PRACTICAL RADIO USES FOR CONDENSERS

Separating A. C. from D. C. by By-Passing. The first radio job for a condenser which I will take up is illustrated in Fig. *1A,* which shows the plate circuit of a vacuum tube. The pulsating D.C. current flowing out of the plate is made up of pure D.C. and the R.F. or A.F. signal; if the signal current gets into the power supply circuit it may cause squealing or weak reception, but the D.C. part must flow unimpeded to the B+ terminal of the source. How can we block one current while letting the other pass? Condenser *C*, connected between the load and the B— terminal of the source, is the answer; this condenser provides a *low-opposition* path for most of the A.C. current, but completely *blocks* the direct current. Choke coil *L* blocks A.C. current and compels it to take the desired path through the condenser, but allows the D.C. to flow right through. A condenser used to make

*A condenser does not really "condense" anything; the word *capacitor,* a more correct term, is often used in place of the word *condenser. Capacitance,* meaning a capacity for storing electrons, is likewise a more correct term than *capacity.* It seems, however, that *condenser* and *capacity* are the most popular terms with radio engineers. Simply remember that a *capacitor* is a *condenser,* and that *capacitance* means the same as *capacity.*

A.C. pass around a certain object (here the source) is called a *by-pass* condenser.

Blocking and Coupling. Looking at Fig. *1A* again, suppose that the load could operate only on A.C.; how would you go about keeping D.C. out of the load?

Figure *1B* gives the solution to this problem; condenser C_2, in series with the load, blocks out direct current, and resistor R provides a path for D.C. to the battery. Choke coil L keeps A.C. out of the battery, while condenser C_1 provides a return path to the cathode for A.C. When condensers are used in this way to block a certain path to direct current but allow alternating current to pass, they are called *blocking* or *coupling* condensers, depending upon which function is more important.

Filtering. In Fig. *2*, the source is delivering a pulsating direct cur-

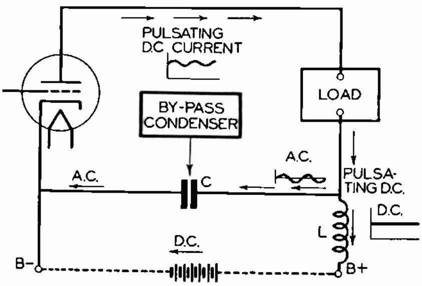


Fig. 1A. This condenser and coil circuit, to be found in every modern radio receiver, is the answer to the question: "How can one current be blocked while another is passed?" Condenser C blocks direct current but allows alternating current to pass.

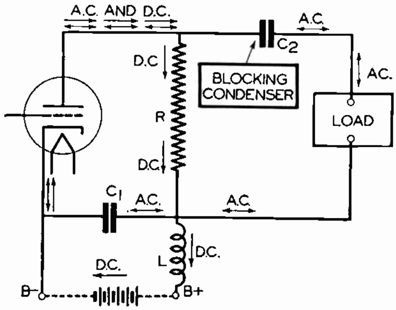


Fig. 1B. Condenser C_2, on duty continually here, keeps unwanted D.C. currents out of the load while allowing A.C. to pass. Condenser C_1 and choke coil L function exactly the same as they did in the circuit of Fig. *1A*.

rent such as is put out by a vibrator unit in an automobile radio receiver or by a rectifier tube in an ordinary home radio receiver. The load in this circuit may be a resistor which requires a pure D.C. voltage for a special purpose. Something is needed to take the variations out of the source voltage; here is how condenser C does the trick.

Remember that the source voltage in Fig. *2* is fluctuating continually between a maximum and a minimum D.C. value; rising to the maximum value, it charges condenser C with electrons at the same time that it sends direct current through the load. When the source voltage drops, the load current drops, too; condenser C then releases its charge and thus helps the source to send electrons through the load. Even though the source voltage changes considerably, the load current remains practically constant; the condenser absorbs electrons when the source tries to send too many to the load, and supplies extra electrons when the source voltage drops.

You can look at Fig. *2* in another way, if you prefer; think of condenser *C* as a by-pass condenser which allows the pulsating or A.C. part of the source voltage to get back to the source without going through the load. In either case the results are the same—condenser *C* smooths out the pulsations which would otherwise go through the load. The larger the electrical size of the condenser, the better it is able to do this job. Because condensers used in this way filter out or

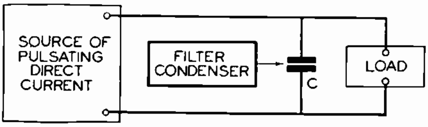


Fig. 2. A simple filter circuit in which condenser *C* takes the pulsations out of the source output, allowing only direct current to pass through the load. In other words, the condenser "lures" the pulsations back to the source before they reach the load.

remove the A.C. from the load current, they are called *filter* condensers.

Tuning. Another important condenser application, that of tuning a radio receiver to a given station frequency, is illustrated in Fig. *3A*. Here the opposition which L_1 offers to A.C. current is cancelled by the opposition of C_1. Either the coil or the condenser must be adjusted or *tuned* to the frequency of the supply to get this action; that is why L_1 is called a *tuning coil* and C_1 a *tuning condenser* when used in this way.

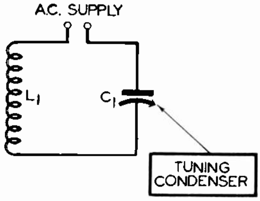


Fig. 3A. A variable condenser is used in this way to tune one stage of a radio receiver to a certain station.

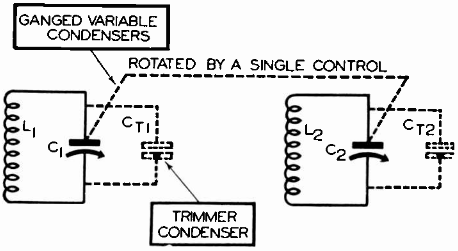


Fig. 3B. Two or more variable condensers are rotated by the same control in a modern receiver, tuning many stages all to the same station in one operation.

When C_1 is made continuously variable, so it will tune the combination to a number of frequencies, it is known as a *variable condenser*, and the circuit is called a *tuning circuit*.

Quite often, as in the single dial radio receiver, several of these tuning circuits must be adjusted to a certain frequency at one time; it is then necessary to connect the variable condensers together mechanically so they can all be turned by a single knob. Figure *3B* shows how dash-dash lines (often called dotted lines) are used to indicate that two variable condensers are rotated by the same control. Condensers operated simultaneously in this way are called *ganged variable condensers.*

Condensers C_{T1} and C_{T2} in Fig. *3B* are *trimmer condensers,* adjusted by the manufacturer or serviceman to offset any differences in the inductances of the tuning coils so that the two circuits will always be tuned to exactly the same frequency.

Neutralizing, Balancing and Phasing. In Fig. *4A* is a tuning circuit in which the vacuum tube operates on (amplifies) the incoming signal (picked up from another circuit by the coil) before feeding the signal to the load. Oftentimes, however, part of the signal voltage in the plate circuit will "feed back" to the grid circuit through the condenser path indicated by the dotted lines; should this occur, squealing will be heard in the loudspeaker, spoiling the program. Condenser C_T is really a very small condenser formed by the capacity between the grid and plate electrodes; it is known as the inter-electrode capacity.

This squealing can be cured by adding another condenser, as shown in Fig. *4B.* Here the plate circuit signal voltage is made to feed a current back through adjustable trimmer condenser C_C to the lower part of coil *L;* this current induces in the upper part of *L* a signal voltage which is equal in strength but opposite in direction to the signal voltage fed there by unwanted feedback through C_T. When C_C is properly adjusted, it serves to neutralize or cancel out the squeal current in the resonant grid circuit; for this reason C_C is known as a *neutralizing condenser.* C_C is also known as a *balancing condenser* (because it balances out the undesirable effects of C_T), or a *phasing condenser* (because it "shoots" into the tuned grid circuit a special out-of-phase current which "kills" the squeal current).

HOW CONDENSERS ARE CLASSIFIED

Condensers can be divided into two major groups, depending upon whether they are *fixed* or *variable* in electrical size. The capacity of a fixed condenser has a very definite value which cannot ordinarily be changed; the capacity of a variable condenser, on the other hand, is easily changed, either by changing the spacing between the plates, as in most types of trimmer condensers, or by changing the position of a movable set of plates with respect to a fixed set of plates, as in tuning condensers.

Variable condensers are of two types, those which are continuously variable and those which are adjustable. By this I mean that if a condenser is frequently adjusted, as for instance by a knob on the front panel of a radio receiver, it is a continuously variable condenser, most often called simply a variable condenser. If, however, the capacity of a condenser is merely adjusted once to get a desired effect, and then left at that value until abuse or aging of the receiver necessitates a new adjustment, the condenser is called an adjustable or a trimmer type.

Naturally you can further classify condensers according to the nature of the insulation or dielectric which separates the conducting surfaces of the condensers. Thus we have paper condensers, mica condensers, air condensers, electrolytic condensers (here the insulation is a chemical solution) and even glass condensers. If you divide condensers according to their shape and type of housing, you have tin-encased condensers, paper block condensers, cartridge condensers, tubular condensers, bakelite-encased condensers and moulded condensers.

Later in this lesson I will show you examples of some of these different types of condensers; now I want to tell you how a condenser operates.

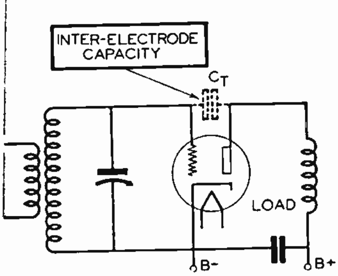


Fig. 4A. *CT*, the capacity between the grid and plate of a vacuum tube, sometimes is the cause of annoying radio set squeals.

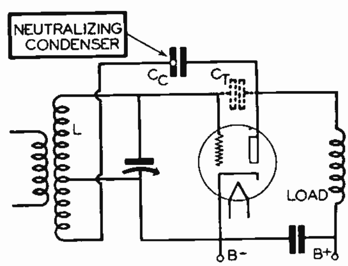


Fig. 4B. *Cc*, a small trimmer condenser, here acts as a neutralizing condenser, "killing" the squeals which are caused by *CT*.

SIMPLE THEORY OF CONDENSERS

A condenser in its simplest form is merely two surfaces which conduct electrons (called plates), separated by an insulating material. This insulation is called a *dielectric,* a word which means "electrical separator." Material such as air, glass, wax, paper, mica and waxed paper are good solid dielectrics; where liquid dielectrics such as oil or a chemical solution are used, the liquid must, of course, be placed in a sealed container in which the condenser plates are immersed but not touching each other.

The simplest condenser uses air as a dielectric. What happens when a simple air condenser is connected to a battery?

You will recall that a battery is a device which has two terminals, a negative terminal which has a surplus of electrons and a positive terminal which has less than a normal number of electrons. You know, too, that metallic surfaces which have not been connected to a voltage source are neutral (have a normal amount of free electrons).

Now study Fig. *5A* for a minute. Note that the two terminals of the battery are connected to the two plates of an air condenser. The instant the connection is made between the battery and the condenser, the minus terminal of the battery "empties" its free electrons into condenser plate *a*. At the same time the positive terminal of the battery draws free electrons from plate *b*. This action continues until the negatively charged plate *a* has just as many free electrons as the minus terminal of the battery can "pump" into it; the voltage across the condenser is then the same as, but opposed to, the battery voltage. The net voltage in the circuit is therefore zero (Fig. *5B*) and no more electrons flow.

Storage Ability of a Condenser. The amount of electricity which can be stored in a condenser depends upon two factors: 1. *The charging voltage;* 2. *The capacity of the condenser.* Increasing the charging voltage is a simple matter, for all you have to do is add more batteries to the source or use a higher voltage source.

But how can the electrical capacity of a condenser be increased? That is, how can you store more electrons in a condenser with a given charging voltage? I told you that extra electrons on plate *a* of the condenser in Fig. *5A* force electrons out of plate *b;* anything which will allow plate *a* to have a greater influence on plate *b* will increase the condenser capacity.

With this in mind, we can immediately say that *increasing the surface area of the plates* will increase the capacity, simply because then plate *a* will take more electrons from the supply and will force out more electrons from plate *b*. It is the overlapping plate area which counts in this respect, and not the size of either plate. Obviously, adding more plates to the condenser increases the capacity, for this increases the total surface area of plates connected to one terminal.

The capacity of a condenser can be increased by *reducing the space between adjacent plates.* When plate a (Fig. *5A*) is moved closer to plate *b*, the electrons in the two plates will be closer together and those in plate *a* will have a greater repelling effect on the electrons in plate *b*. With more electrons driven out of plate *b*, plate *a* can naturally take more electrons from the battery.

Finally, the capacity of a condenser can be increased *by using a dielectric which has a higher inductive capacity* (a better dielectric). Suppose that a dielectric (good insulating material) such as glass, wax paper, or mica is placed between the two plates of the condenser in Fig. *5A*, to give a unit like that shown in Fig. *5C*. Even though this dielectric material conducts electricity very poorly, it is influenced by the presence of free electrons in the condenser plates. Now the repelling action of the electrons gathered in plate *a* is *relayed* or *transferred* through the dielectric to plate *b;* this gives exactly the same effect as did reducing the separation between the two plates. The ability of a dielectric to transfer the repelling action of electrons from one plate to another is called *inductivity* or more often *inductive capacity.* The latter term is preferable since then there is no confusion with the induction effect in coils.

The inductive capacity of a dielectric material is quite easily measured and compared with that of other dielectric materials. A perfect vacuum has a lower inductive capacity than any material known, for there is nothing in a vacuum to relay the repelling action of the electrons from one plate to the other, and only direct condenser action takes place. The better (higher) the inductive capacity of a dielectric in a condenser, the higher will be the capacity of the condenser.

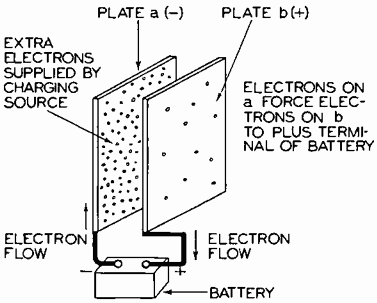


FIG. 5A. Electron flow is as indicated when this simple two-plate air condenser is first connected to a battery.

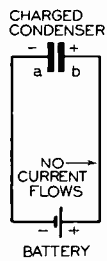


FIG. 5B. A charged condenser acts like a "bucking" battery.

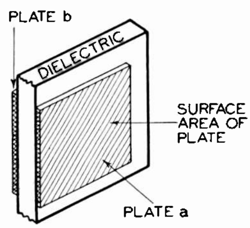


FIG. 5C. The capacity of a simple condenser is greatly increased by a dielectric.

The inductive capacity of air or any gas differs so little from that of a vacuum that the difference can be detected only by the very finest of laboratory testing equipment. We can therefore assume that, for all practical purposes, the inductive capacity of air is unity, and use this as a basic value.

Specific Inductive Capacity. The capacity of a condenser with a given dielectric material between the plates, divided by the capacity of the same condenser with only air between the plates, gives a value which is known as the *specific inductive capacity* or the *dielectric constant* of that dielectric material. For example, if a condenser which uses air (having a dielectric constant of 1) to separate its plates has a capacity of 100 mmfd., this same condenser will have a capacity of 250 mmfd. when immersed in mineral oil (having a dielectric constant of 2.5). The dielectric constants of various common insulating materials used in condenser manufacture are: air—1, paper—1.5 to 3.

paraffin—2 to 3, mineral oil—2.5, rubber—2 to 4, mica—4 to 8, glass—4 to 10, castor oil—4.7, porcelain—5 to 7. The exact values depend upon the density and nature of the particular material used.

The dielectrics commonly used in condenser manufacture and the insulating materials (which result in a capacity when used to separate conductors) can be divided into five distinct groups: *1, vitreous materials* such as mica, glass, porcelain, etc.; *2, rubber materials* like hard rubber, soft rubber, and rubber compounds; *3, fibrous materials* such as paper, cotton, wood, and moulded fiber compositions; *4, liquids,* such as oils, waxes and varnishes; *5, gases,* air and hydrogen being the most important.

Thus, the capacity of a condenser may be increased *by increasing the surface area of the plates, by reducing the space between adjacent plates and by using a dielectric which has a higher inductive capacity.*

WORKING VOLTAGE OF A CONDENSER

Breakdown Voltage. In most cases a condenser employing a solid dielectric becomes useless the instant it *begins to conduct* a large number of electrons through the dielectric. The critical voltage which causes a condenser to break down and pass current is called the *breakdown voltage.* When an excessive voltage is applied to a condenser, electrons which are bound to atoms in the solid dielectric material are drawn out of the atom and become free electrons, usually changing the dielectric substance to carbon, which is a conductor. Under the influence of the high applied voltage these free electrons move to the positive condenser plate, forming a current which is referred to as a *conduction current.* Condensers of poor quality may pass a conduction current even though the voltage is not high enough to cause breakdown; these condensers are then said to be *leaky,* meaning that current is leaking through the condenser.

Working Voltage. Condenser manufacturers almost always specify the safe working voltage of a condenser; this is *the highest voltage which can be applied continuously to a condenser without affecting its characteristics as a condenser.*

In general, for a solid dielectric condenser such as a mica or paper condenser, the working voltage is about one-half the breakdown voltage. This allows a safety factor of 2, which means that the voltage applied to the condenser can be doubled before a breakdown will take place.

The working voltage rating always refers to the peak voltage which may be applied *continuously* to a condenser. In the case of direct current circuits this voltage is naturally the D.C. voltage which would be measured by a voltmeter. In A.C. circuits, however, measuring instruments read effective volts rather than peak values, and it will be necessary to multiply the meter reading by about 1.5 (an approximate value) to get the peak voltage. For example, if you wanted to connect a condenser across a 110-volt A.C. source, you would multiply 110 by 1.5 to get 165 volts, the maximum or peak voltage in the circuit. The condenser used should then have a working voltage of at least 165 volts; ordinarily a condenser rated at 200 volts would be used (since this is a standard size unit, easily obtained). Some condensers also have a "surge voltage" rating (higher than the working voltage rating); this is the maximum voltage which the unit can withstand for *short periods* of time.

Contrary to general opinion, condensers using solid dielectrics such as wax paper, mica, or glass will not last indefinitely. The constant voltage stress on the bound electrons in the dielectric weakens the resistance of the atoms to voltage, just as the constant bending of a piece of iron eventually breaks the iron. A properly designed condenser, used at or below its rated voltage, should last from 10,000 to 20,000 working hours, which means that good condensers in a radio receiver should more than outlast the life of the receiver. In order to secure this life from a condenser, however, the unit must be kept cool. Heat allows the bound electrons in the dielectric to escape and conduct current, and this current in turn causes more heat, with the result that the condenser leaks and eventually breaks down. Condensers in radio equipment should therefore be kept away from any parts which give off heat.

Air condensers, on the other hand, have a very long life. Like oil and gas dielectric condensers, air condensers are self-healing and can be used even after a breakdown. Condensers of these types must be kept cool and dry, for otherwise they will leak and break down too often. Breakdowns are to be avoided, for each failure places a stress on some other part in a radio circuit, and may cause that other part to fail.

UNITS OF CAPACITY

Since a condenser is used to store electricity, it is quite logical to measure the capacity of a condenser in terms of its electron-storing ability. The higher the voltage applied to a condenser, the more electrons it will store; that is why a certain definite voltage, *one volt*, is used when defining the unit of capacity.

When an e.m.f. of *one volt* applied to a certain condenser will allow that condenser to store 6.3 million million million electrons (one coulomb of electricity), that condenser has a capacity of *one farad*.

Although the farad is the fundamental capacity unit, it is far too large to be convenient for radio work. Two smaller practical units are therefore used: *1*, the *microfarad,* equal to one millionth of a farad, and *2, the micro-microfarad,* equal to one millionth of a microfarad.

Radio men often speak of microfarads as "mikes"; they will say "the 8-mike filter condenser was blown" when they mean that a permanent breakdown occurred in an 8 microfarad filter condenser.

The two practical units of capacity which are smaller than the farad are commonly abbreviated as follows:

microfarads——*μf.*, *mf.*, or *mfd.*
micro-microfarads—*μμf.*, *mmf.*, or *mmfd.*

Oftentimes it is desirable to change microfarads to micro-microfarads and vice versa. The following simple rules will help you to do this quickly:

To change mfd. to mmfd., move the decimal point six places to the *right.*

To change mmfd. to mfd., move the decimal point six places to the *left.* For example, .001 mfd. equals 1,000 mmfd., and 250 mmfd. equals .00025 mfd. Incidentally, radio engineers ordinarily pronounce .001 mfd. as *point zero zero one* microfarad, or as *point double O one microfarad.* They would pronounce .00025 mfd. as either *point triple zero two five microfarads* or as *triple O two five microfarads.*

TYPICAL PRACTICAL RADIO CONDENSERS

In order to acquaint you with the practical aspects of condensers, I will now describe a number of typical radio condensers. I cannot possibly cover all of the types, but I will present enough of them to give you a good idea of what you will find underneath the chassis of a piece of radio apparatus.

Fixed Paper Condensers. This type of condenser, which is fixed in value and uses waxed paper as a dielectric, is by far the most common in Radio. Fixed paper condensers are available in any practical capacity and working voltage ratings.

Figures *6A, 6B* and *6C* illustrate in simplified form the manufacture of a paper condenser. Two long narrow sheets of waxed paper and two similar sheets of metal foil are arranged as indicated in Fig. *6A,* one sheet of foil extending beyond the waxed paper on one side and the other foil extending on the opposite side. The four strips are then rolled into the compact cylinder shown in Fig. *6B.* The foil strips are made slightly shorter than the waxed paper strips, so the two sheets of foil do not touch at any point. Only one sheet of foil projects at each end: the foil ends are pressed flat and wire leads whose ends are bent into spirals are soldered to the units as at Fig. *6C*. These leads, commonly known as pigtails, form the terminals of the condenser. The unit is now ready to be placed in a housing of some kind; waxed cardboard cylinders are commonly used, and the finished condenser is then known as a cartridge condenser. Metal housings are also used for paper condensers.

The metal foil used in the construction of paper condensers is generally lead foil (often called tin foil), but some manufacturers are today using aluminum foil because it can be made in thinner sheets for equal mechanical strength, giving a lighter and more compact condenser unit.

A number of examples of paper condensers are shown in Fig. *7*. At *A* is the cartridge condenser whose construction is shown in Fig. *6;*

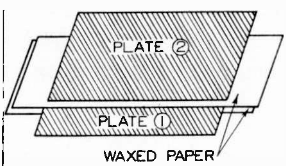


FIG. 6A. Steps in making a cartridge type paper condenser. Layers of waxed paper and tinfoil are assembled as shown, with one plate projecting on each side. This gives a non-inductive winding; a condenser which has some inductance in addition to its capacity appears in Fig. *15*.

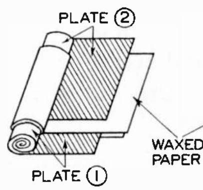


FIG. 6B. The four layers of material are rolled into a compact cylinder.

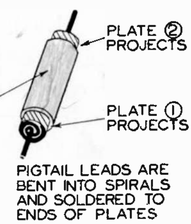


FIG. 6C. The projecting ends of the plates are compressed and pigtail leads soldered to each.

it is encased in a waxed paper tube, with the pigtail leads coming out at each end through eyelets in a round cardboard disc. Quite often paper condensers are compressed into an oval shape after being rolled into cylinders, in order that they can be encased in square or rectangular metal boxes like those shown at *B* and *C* in Fig. *7*. The foil ends are soldered to lugs which extend through but are insulated from the housing. Mounting brackets are usually provided with condensers of this type, so the units can be bolted, riveted or soldered to the radio chassis. Paper condensers are also made without housings. Flexible wire leads are soldered to the foil ends, and the units, after being compressed, are dipped into hot pitch. An example of this appears at *D* in Fig. *7*.*

High voltage paper condensers capable of withstanding from 1,000 to 2,000 volts are made by rolling together strips of aluminum foil,

* That terminal of a paper condenser which connects to the outermost layer of foil is often marked OUTER FOIL or GROUND; this terminal should be connected to the chassis or to the lowest R.F. potential in a particular circuit when the condenser is used to bypass R.F. currents, for otherwise the outer layer of foil would cause undesirable electrostatic coupling with nearby parts.

with several layers of waxed linen paper between each, and mounting the unit in a container filled with insulating oil, as at *E* in Fig. 7. Terminal leads are brought out through stand-off insulators.

In the power pack and in certain other sections of radio equipment, a number of condensers are needed. Not long ago it was common practice to mount these in a common case in the manner shown at *C* and *F*, one terminal of each condenser being connected to a common soldering lug and the other condenser terminals being connected to separate lugs. This practice of making condenser "blocks" is gradually being discarded because failure of one condenser in a unit means that the entire unit must be replaced or an extra condenser added to the chassis. You will, however, find condenser blocks in many of the older radio receivers.

Paper condensers are generally wound on high speed automatic machines. Each winding machine holds the necessary number of rolls of waxed paper and foil, one end of each roll being run down to the mandrel in front of the operator. The operator sets a dial on the

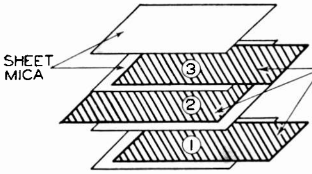


Fig. 8A. Assembly of a mica condenser. Alternate plates project on opposite sides.

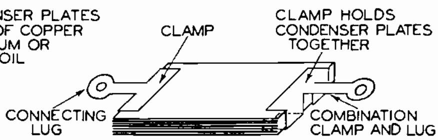


Fig. 8B. Projecting ends of the foil plates are bent over and clamped as shown here.

machine to the desired number of turns of foil to produce a certain capacity, attaches the ends of the strips of foil and paper to the mandrel, then starts the machine by pressing a foot lever. From then on everything is automatic; when the correct number of turns of foil are wound, the strips are cut off and the exposed ends of the foil squeezed.

Fixed Mica Condensers. Mica is a far better dielectric than wax paper where very high frequency currents are involved, such as in the signal circuits of radio receivers and transmitters. Mica condensers are bulkier than paper condensers of equal capacity, but fortunately only low capacities are required in these circuits; mica condensers are therefore made in sizes ranging from 10 to 10,000 micro-micro-farads.

The assembly of a fixed mica condenser is shown in Fig. *8A;* alternate sheets of the metal foil project on each side. Sheets of thin, clear mica are stacked with sheets of copper, aluminum or lead foil by nimble fingered operators until the desired number of plates is obtained. The foil ends are then bent over at each end and a combination clamp and terminal lug like that in Fig. *8B* is squeezed over each end while the unit is under pressure. Bakelite is then moulded around the con-

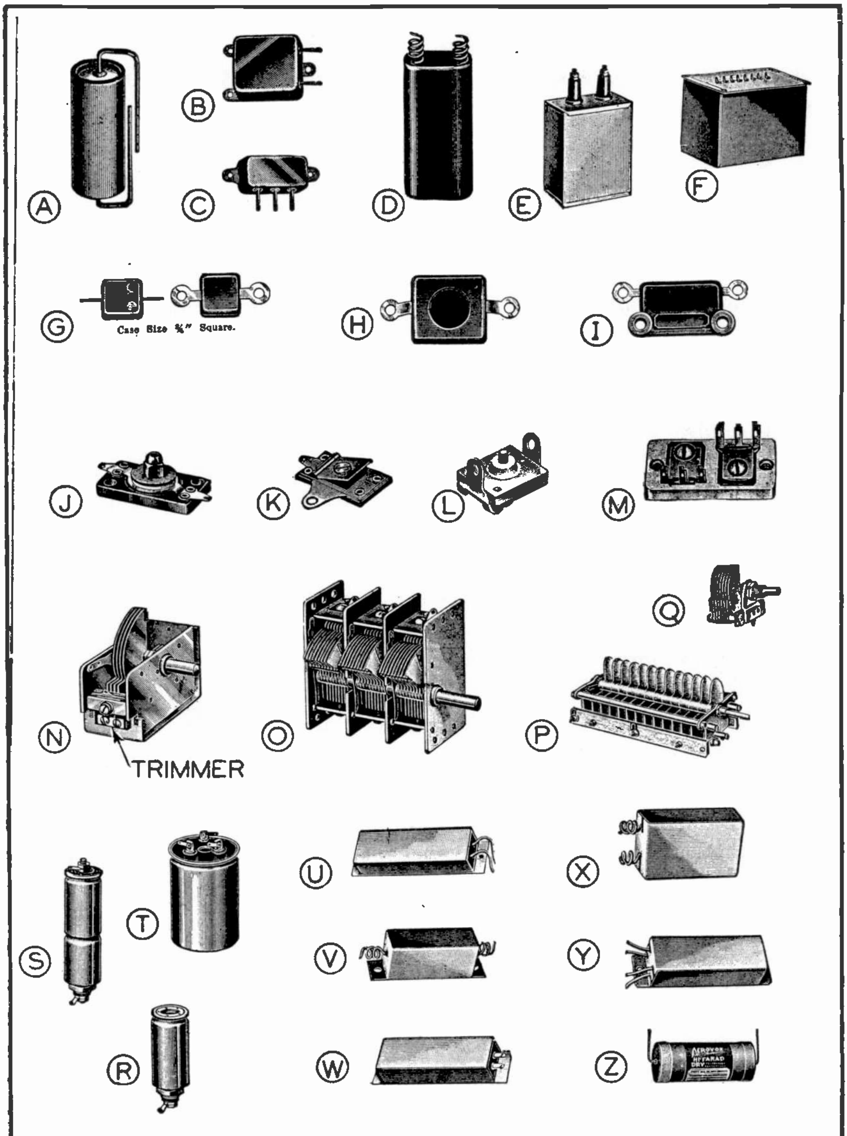


FIG. 7. How many of these different types of radio condensers can you identify?

A—Tubular or cartridge condenser with paper dielectric.
B—Paper condenser sealed into metal box with pitch or wax.
C—Multiple unit paper condenser in metal container.
D—Paper condenser without housing.
E—High voltage paper condenser in oil-filled housing.
F—Multiple section paper condenser "block" for power packs.
G, H and I—Fixed mica condensers in molded bakelite housings, with pigtail and lug type terminals.
J—Trimmer condenser with adjusting nut and circular plates.
K—Book type trimmer condenser.
L—Bottom view of book type trimmer condenser.
M—Two trimmers on one base.
N—Variable air condenser with trimmer.
O—Three-gang tuning condenser.
P—Variable air condenser for high voltage transmitter circuit.
Q—Midget variable condenser.
R—Wet electrolytic condenser.
S—Dual unit wet electrolytic condenser.
T—Triple unit wet electrolytic condenser.
U, V, W and X—Single unit dry electrolytic condensers.
Y—Dual unit dry electrolytic condenser.
Z—Cartridge type dry electrolytic condenser.

denser, leaving only the terminal ends exposed, to form a neat, waterproof insulated housing.

All except the two outer plates do "double duty." For instance, plate *2* in Fig. *8A* forms a capacity with the lower surface of plate *3* and with the upper surface of plate *1*. Note also that plates *1* and *3* project out on the same side, and are therefore connected together by the metal clamp. This construction, using *three* plates, gives a condenser having twice the capacity obtained with only *two* plates of the same size and separation.

Typical fixed mica condensers having moulded bakelite housings are shown at *G*, *H* and *I* in Fig. *7*. That shown at *G*, having either wire or lug type terminal leads, is one of the most popular of the mica condensers, for it is no larger than a postage stamp. The wire leads (pigtails) are soldered to the clamps which hold the plates together before the unit is encased in bakelite; these leads are stiff enough to support the condenser. A larger mica condenser, with terminal lugs, is shown at *H;* this unit is about one and one-half inches square. Because of its increased size and greater dielectric thickness, type *H* has a much higher capacity and voltage rating than the postage stamp type of mica condenser.

Being very light and compact, condensers of the type shown at *G* and *H* can be mounted by their own terminals. Where the condenser is to be bolted to the chassis or where several mica condensers are to be bolted together, a unit like that shown at *I*, in which mounting holes are moulded into the bakelite housing, is employed.

Trimmer Condensers. As you know, the purpose of the trimmer condenser is to allow a small adjustment in the capacity of another condenser. Air and mica are used together as a dielectric, the separation of the plates being varied.

The construction of a typical trimmer condenser is shown in Fig. *9*. One plate is riveted to the bakelite base of the unit, and the other plate, made of spring brass, is moved close to or away from the fixed plate by turning the adjusting screw. When the two plates are close together the sheet of mica is the only dielectric, and the capacity of the trimmer condenser is a maximum; when the two plates are far apart, there is air as well as mica between them, and the capacity is a minimum. The adjusting screw makes contact only with the moving plate. Where a large variation in capacity is desired, several pairs of plates are used, alternate plates being connected together.

Trimmer condensers are often called equalizing condensers, balancing condensers, neutralizing condensers, phasing condensers, or padding condensers, depending upon their use in a radio circuit. The symbol shown at C_C in Fig. *4B* is generally used throughout the N.R.I. Course and by a number of radio manufacturers to indicate a trimmer; the small circle on one of the plates is the clue which tells you that a trimmer condenser is being specified. Many radio authors and manufacturers, however, use the ordinary variable condenser symbols for trimmers.

Typical trimmer condensers are shown at *J*, *K*, *L* and *M* in Fig. *7*. In the unit shown at *J* the plates and the dielectric are circular in shape, and the capacity is varied by turning the nut at the top. The

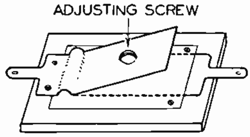


Fig. 9A. Appearance of a typical trimmer condenser.

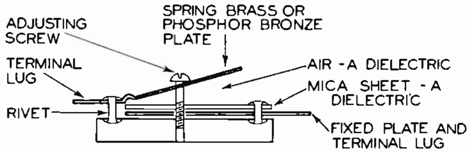


Fig. 9B. Cross-section view of a typical trimmer condenser.

trimmer shown at *K* is like that pictured in Fig. *9;* because it opens like the leaves of a book, it is often called a *book-type* trimmer. The bottom of a book-type trimmer, showing the built-in "nut" for the adjusting screw, is shown at *L*.

In modern all-wave receivers, where a number of trimmers are used together, it is customary to mount them on a single base like that at *M* in Fig. *7*.

Variable Air Condensers. The simplest and commonest method of obtaining a variable capacity is to rotate one set of air condenser plates, called the *rotor,* in or out of another set, called the *stator,* in the manner shown in Fig. *10*. For clearness I have shown here only a single fixed and a single rotating plate, but usually a variable air

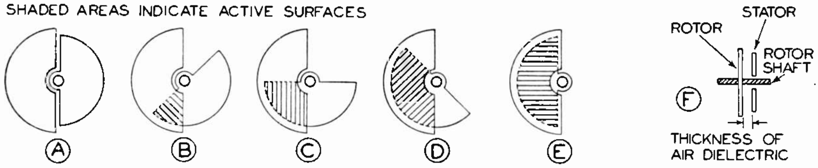


Fig. 10. Variable air condensers have a minimum capacity when plates are set as at A, maximum capacity when completely meshed as at E. A cross-section view of a two-plate unit appears at F.

condenser will have a great many more plates. When the plates are in the position shown at *A* in Fig. *10* the condenser has a minimum capacity. As the rotating plate is turned into the fixed plate, more and more of the rotating plate meshes with the fixed plate and the capacity of the condenser increases. When one pair of plates, completely meshed as at *E*, will not give the desired maximum capacity, either the size of the plates can be increased or additional rotating and fixed plates can be added. When plates are added, the total capacity is that of one pair of plates *multiplied by* a number which is *one less than the total number of plates.* For example, if a condenser made up of a total of 7 rotor and stator plates has a capacity of 10 mmfd. between each pair of plates, the total capacity when the plates are completely meshed will be seven minus one, or six times 10 mmfd., which makes 60 mmfd.

Typical examples of variable air condensers are shown at *N, O, P* and *Q* in Fig. *7*. The unit shown at *N* has four rotating plates and four fixed plates. A trimmer condenser, connected in parallel with the variable air condenser, is also mounted on the unit.

At *O* is a three-gang tuning condenser with the rotors all attached to the common metal shaft. Separate connections are made to each section of fixed plates. In order to make each condenser align perfectly with the others and with the associated circuits, special trimmer condensers are mounted on each condenser gang.

Oftentimes slots like those shown in Fig. *11* are cut into the rotor plates at each end of a variable air condenser. These radial slots allow additional alignment of the condenser at from four to six positions in the tuning range.

The shape of the rotor plate is also of importance to the radio man. The three different shapes commonly used are shown in Fig. *12*. The semicircular plate at *A* is preferred for most variable condensers used in experimental and research laboratories; this design gives a uniform increase in capacity as the condenser is turned from its minimum to its maximum capacity. Semicircular condensers are known as "straight line condensers," for if a graph or curve is drawn of condenser position against condenser capacity, the result is a straight line. The letters S.L.C. are a common abbreviation for straight line capacity.

As you know, radio stations in the broadcast band are located 10 kc. apart. In order to spread stations equal distances apart on the tuning dial of a receiver, the resonant frequency of the condenser circuit must increase uniformly as the rotor is turned. The exact shape required to give straight line frequency (S.L.F.) characteristics is shown at *B* in Fig. *12;* this is determined by complicated mathematical computations.

In actual practice, however, a straight line frequency (abbreviated S.L.F.) condenser seems to crowd stations at the high frequency end of the broadcast band. The straight line capacity condenser crowded the stations at the low frequency end of the broadcast band, so shapes *A* and *B* were combined to give the *mid-line frequency* condenser plate (abbreviated M.L.F.) shown at *C* in Fig. *12,* which is now being generally used in radio receivers for home use.

Another rotor plate design sometimes used is that which gives straight line wavelength (S.L.W.) characteristics; with this, wavelength readings on the tuning dial would be equal distances apart.

Electrolytic Fixed Condensers. If an aluminum rod or plate is immersed in a metal container filled with a solution of boric acid and water (see Fig. *13*) and an alternating current voltage is applied between the rod and the container, current will flow through the solution or electrolyte only during that half cycle when the container is positive. On the reverse half of the cycle gases liberated at the rod form a film which has a very high resistance, preventing current from flowing. When the current reverses again on the next alternation, the gas breaks down and conduction takes place as usual for another half cycle. During the half cycle when current flow is stopped completely,

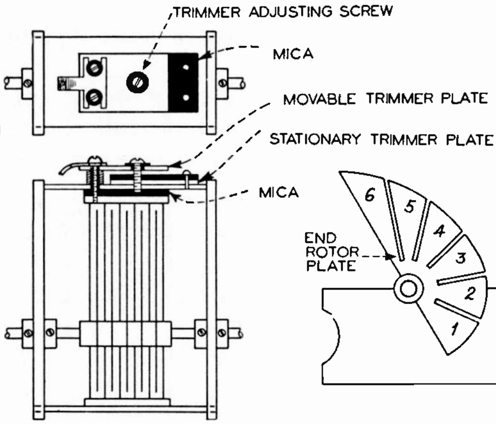


Fig. 11. Three views of a typical variable air condenser, with a trimmer condenser mounted on one side. The six segments of the end rotor plates are bent in or out by the serviceman to secure fine adjustments of capacity at various condenser settings.

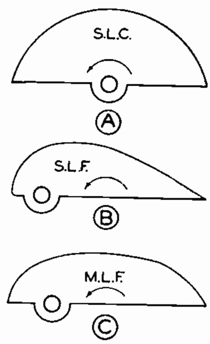


Fig. 12. Typical rotor plate designs. Plate *A* gives a straight line (uniform) variation in capacity; plate *B* gives a theoretical straight line variation in frequency; plate *C*, a combination of *A* and *B*, is used in most radio receivers and supposedly gives a better separation of stations.

the device acts as a condenser. This electrolytic unit really has two functions, one being that of a rectifier of alternating current and the other that of a condenser, but a commercial unit is designed for just one function. A condenser unit cannot ordinarily be used continuously as a rectifier without failing. It is the condenser action which is of particular interest to the Radiotrician for on it is based the construction of the electrolytic fixed condenser.

Let us see what happens when a D.C. voltage is applied to the electrolytic cell I have just described. With the aluminum rod (the anode) always connected to the positive terminal of the source, the cell always acts as a condenser; an aluminum oxide film builds up and becomes semi-permanent. The thickness of this film, which acts as the dielectric of the condenser, depends upon the electrolyte used and upon the voltage used to produce or "form" the film.

With a given electrolyte the thickness of the film increases as the forming voltage is made higher; there is, however, a maximum forming voltage which, if exceeded, will break down the film and make the cell conductive or leaky. This critical voltage is about 480 volts for one type of cell.

A capacity of approximately .125 mfd. is obtained for each square inch of aluminum surface exposed to the electrolyte at the maximum allowable forming voltage; this capacity is doubled if the aluminum is in sheet form and both sides are exposed. If the forming voltage of a given condenser is lowered, *the capacity increases.*

The practical electrolytic condenser differs little from the simple unit sketched in Fig. *13*, except that it is mounted in a spill-proof

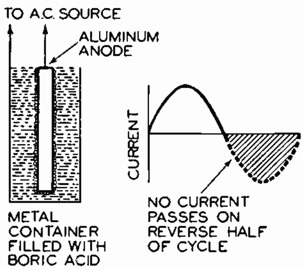


FIG. 13. Diagram of a simple electrolytic condenser. When connected to an A.C. source, current flows only during that half of a cycle when the cathode or container is positive (+).

Some electrolytic condensers are now being made with aluminum electrodes which have had their surfaces roughened by a chemical etching process; this roughening increases the surface area of the electrode and makes possible higher capacities with small electrodes.

FIG. 14 (right). Top and side views of a modern wet electrolytic condenser.

A—Anode, consisting of pure aluminum foil sheet folded in a zig-zag or crimped manner and riveted to an aluminum support rod. Anode surfaces are either plain or etched.

B—Cathode is a pure aluminum cylinder which also serves as container for the electrolyte and as a housing for the entire unit.

C—Aluminum cover.

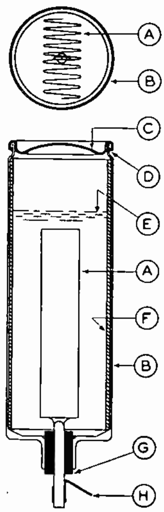
D—Semi-porous gasket under cover, which prevents leakage of liquid electrolyte yet allows gases to escape.

E—Level of electrolyte.

F—Cylinder of insulating material, which prevents short circuits between anode and cathode.

G—Insulating gasket, which separates anode terminal from cathode and seals container at this point.

H—Soldering lug for anode connection.



Courtesy Sprague Products Company

container and an anode of large surface area is used. The container is provided with a rubber vent or other type of valve which will open to allow excess gas to escape when the pressure inside becomes too high.

A cross-section view of a typical commercial electrolytic condenser appears in Fig. *14*. The sheet aluminum anode in this unit is "crimped" to secure maximum surface area, but some manufacturers wind the aluminum sheet in spiral form. The nature of the film in an electrolytic condenser corresponds to the nature of the dielectric in an ordinary condenser, while the thickness of the film corresponds to the spacing between plates in an ordinary unit.

To lessen the possibility of leakage of fluid, a thickening material can be added to the electrolyte, to give the jelly-like, almost spill-proof electrolyte used in "semi-dry" electrolytic condensers. Today, however, dry electrolytics are rapidly replacing semi-dry types.

Dry Electrolytic Condensers. In addition to the wet and the semi-dry types of electrolytic condensers, there is one additional type, called the *dry electrolytic.* Figure *15* shows how this is constructed; the cathode is a pure aluminum sheet, while the anode is an aluminum sheet which has previously been formed to give it a dielectric film. The two electrodes are separated by strips of gauze (cheese cloth), paper or cellophane which have been filled with an electrolyte in paste form. The four strips of material are rolled into a compact cylinder, flexible wire leads are attached to each electrode, the unit is mounted in a suitable sealed container and finally is dipped in hot wax several times to make it air tight.

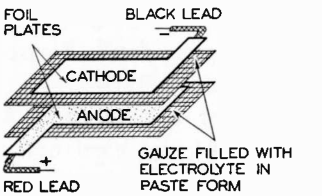


FIG. 15. Arrangement of plates in a dry electrolytic condenser. This is an inductive winding, as the foil strips are wound to form a coil. Compare with Fig. 6A, where the coil effect is shorted by the crimped overlapping ends.

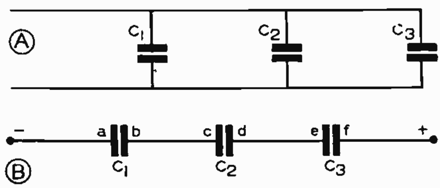


FIG. 16. Connect condensers in parallel as at A for more capacity; connect in series as at B for less capacity.

Capacity of Electrolytics. The capacity of any electrolytic condenser of given construction depends upon the forming voltage; *the lower the forming voltage, the greater is the capacity,* for low forming voltages give thin dielectric films. The forming voltage likewise determines the working voltage of the condenser, for electrolytic condensers should never be used at a higher voltage than the forming voltage.

The capacity of an electrolytic condenser *at a given forming voltage* can be increased only by *increasing* the surface area of the plates, assuming that the best available chemical dielectric is being used. Electrolytic condensers (often called simply "electrolytics") deteriorate rapidly when exposed to heat; always mount them as far as possible from any part which radiates heat.

Wet and semi-dry electrolytics are self-healing; that is, they will repair themselves after being broken down by excess voltage. Dry electrolytic condensers usually do not heal satisfactorily once the oxide film on the anode is broken; for this reason it is important that the applied voltage be kept below the rated value.

Polarity is even more important with dry electrolytics than with the wet and semi-dry types. Connecting dry electrolytic condensers with wrong polarity damages them permanently, since these units are not self-healing. With dry electrolytics, the red lead is for the anode, and should always go to the plus terminal of the circuit; the black lead is for the cathode, and should go to the negative terminal. With wet and semi-dry electrolytics, the metal container is the cathode, and should go to a negative terminal of a circuit; the other condenser terminal (usually the center terminal) is the anode, and should go to the plus terminal of the circuit. Be sure to consider polarity when using any of the three types of electrolytic condensers (wet, semi-dry and dry).

Identifying Electrolytics. It is sometimes difficult to tell by looking at an electrolytic condenser unit exactly what type it is. Units in metal cans having water-tight insulating gaskets around the terminals are generally either wet or semi-dry in construction; if you hear a swish when the condenser is shaken it is a wet electrolytic; if the unit has a vent through which gas can escape, it is wet or semi-dry. Flexible leads and cardboard containers mean it is a dry electrolytic.

A number of examples of the various types of electrolytic condensers are shown in Fig. 7. At *R* is a single unit wet electrolytic; at *S* is a double unit, one terminal serving for each condenser unit and the can being the common negative terminal. Both *R* and *S* are bolted to the chassis in most installations. At *T* is a triple unit electrolytic, the can again being the common negative terminal.

Dry electrolytic condensers, which are often housed in cardboard boxes, are illustrated at *U*, *V*, *W*, *X*, *Y* and *Z*. Flexible wire leads are used in all but types *W* and *Z*. Unit W has lug type terminals, while *Z*, a cartridge type unit, uses solid pigtail leads. In these types of condensers the container is usually marked plus (+) near the positive lead, and this should go to the + circuit terminal.

Electrolytic condensers are made in a wide variety of sizes, capacities, and voltage ratings to meet the demands of various radio circuits. Dry electrolytic condensers are often used as replacements for defective wet types. High voltage electrolytic condensers, capable of withstanding up to 480 volts, are usually available in sizes up to 10 mfd.; low voltage condensers have much higher capacities.

CONDENSERS IN SERIES AND PARALLEL

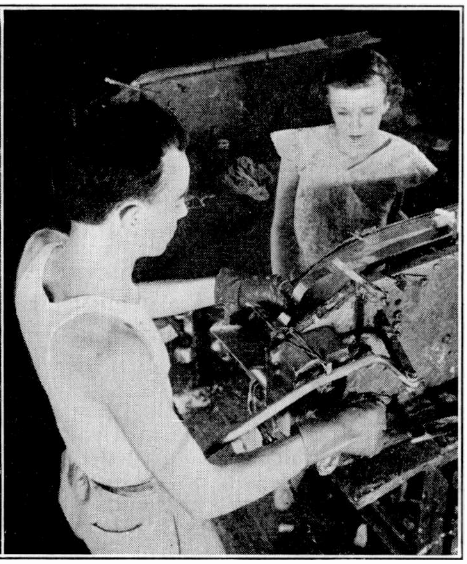
When the capacity of one condenser is insufficient for a certain purpose, two or more condensers may be connected in *parallel* to secure the necessary capacity. Each unit then draws electrons from the source and becomes charged to an amount which depends upon its capacity. Thus a combination of condensers in parallel draws more electrons from the source than would one of the condensers.

To find the capacity of condensers connected together in parallel, simply add together the capacities of the individual condensers. For example, when three condensers are connected together in parallel, as in Fig. *16A,* simply add together the capacities of C_1, C_2 and C_3. Naturally the capacities of the condensers must all be given in microfarads (mfd.) or all must be in micro-microfarads (mmfd.).

When condensers are in series and connected to a certain voltage, as at *B* in Fig. *16,* the charging voltage must be divided between all of the condensers. Since the condensers are in series, the same number of electrons must "flow through" each, and each condenser re-

Courtesy Aerovox Corp.

Scene in the Aerovox condenser factory, showing paper condensers of the cartridge type being wound by high speed machinery.



Courtesy P. R. Mallory Co., Inc.

Machines like this in the Mallory condenser plant wind dry electrolytic condenser units. Operators must wear gloves to keep the strips of foil clean.

ceives the same charge. The smallest condenser in the group requires the highest voltage for a certain charge, and therefore controls the capacity of the entire circuit. While electrons do not actually *flow* through all of the condensers, their movements are relayed from one plate to another to give the equivalent of electron flow. For example, if plate *a* is connected to the minus terminal of the source, electrons pushed to *a* by the source will repel electrons on *b* and cause them to gather at *c*. Electrons at *c* repel the electrons on *d* and push them over to *e*; finally the electrons at *e* drive the electrons off plate *f* and force them into the plus terminal of the source. Of course, when alternating current is applied to a condenser, the electrons reverse their direction each half cycle.

When condensers of *equal* capacity are connected in series, the net capacity of the combination is simply the capacity of one condenser divided by the number of condensers in series. For example, when two condensers of equal size are connected in series, the net capacity is exactly one-half of that of one of the condensers.* Keep this in mind, for you will use it often in your radio work.

WORKING VOLTAGES OF CONDENSERS

When condensers are connected together in parallel, each condenser is being charged by the same voltage; each condenser in a parallel group must, therefore, have a working voltage which is *at least equal to* the voltage of the source.

When condensers are connected together in series, a different situation exists. With an A.C. source, the condenser having the least capacity will receive the greatest portion of the supply voltage; it is, therefore, a good plan to choose the smallest condenser with a working voltage figured just as if that condenser were connected alone to the source. This means that the working voltage of the smallest condenser should be about 1.5 times the A.C. voltage of the source. When condensers in series are being charged by a D.C. voltage, the safest rule is to use condensers *each of which* will withstand the source voltage.

But how are we to handle a practical problem like this, which usually occurs in transmitters and high voltage power packs? We have a 1,000-volt D.C. source which must be shunted by a 2-mfd. capacity, but only have 500-volt paper condensers. We can use two 4-mfd. units in series, so that their combined capacity will be 2 mfd. But wait—we must consider another factor before we can be sure that this combination will operate safely; we must be sure that both condensers are identical as regards leakage of current.

A practical condenser is really equal to a perfect condenser connected in parallel with a very high resistance, this resistance being that which allows the leakage current to flow. This characteristic of a condenser is illustrated at *A* in Fig. *17;* the leakage resistance in a paper condenser is generally higher than about 50 megohms (50 million ohms) per microfarad of capacity.

You know that a perfect condenser will not pass direct current; clearly, then, it is the resistance of the condenser which governs the distribution of voltage when a number of condensers are connected in series to a source. The condenser having the highest leakage resistance will take the greatest voltage, according to Ohm's Law for a direct current circuit. Returning to our problem, in Fig. *17B* two 4-mfd. paper condensers are connected in series to a 1,000-volt direct current source. Suppose that one condenser has a leakage

---

* The formula for figuring the exact capacity of condensers connected together in series is: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$, where C is the total capacity of the combination and C_1, C_2 and C_3 are the capacities of the individual condensers in the group. The N.R.I. Easy Calculating Chart for Resistors In Parallel, given in a previous lesson, can be used for *condensers in series* if you wish to avoid computation; just be sure that the capacities of all of the condensers are expressed in the same unit; that is, all in mfd. or all in mmfd.

resistance of 50 megohms and the other a leakage resistance of 200 megohms; the total resistance in the circuit is then 250 megohms. Now you can easily figure out from Ohm's Law the current through each resistor and therefore the voltage drop across each resistor. You will find that there is an 800-volt drop across the condenser having a 200-megohm resistance, while the other condenser has only a 200-volt drop. Isn't this surprising in view of the fact that both condensers have the same capacity rating? You will agree with me that the condenser having the 800-volt drop (which is considerably higher than its safe working voltage of 500 volts), will break down first.

When condensers are to be connected together in series for use in a circuit where leakage current is not objectionable, you can use this simple trick to make each condenser take its correct share of the charging voltage. Connect in parallel with each condenser a resistor of high ohmic value, such as the 10 megohm unit shown at *C* in Fig. *17*. These resistors, in parallel with the leakage resistances of the condensers, are so much smaller in ohmic value that they will govern the distribution of voltage. Now each condenser gets approximately half of the total supply voltage, and 500-volt condensers may be safely used.

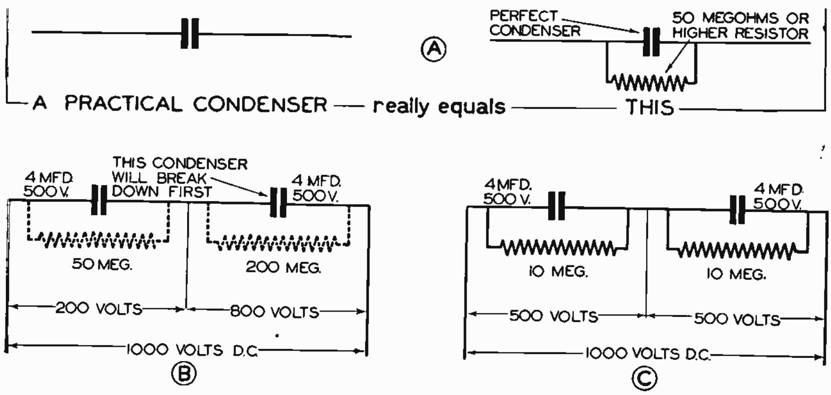


FIG. 17. All condensers have a leakage resistance which determines the voltage drop across each unit when the condensers are connected in series to a D.C. source.

Electrolytic condensers have much higher leakage currents than paper dielectric condensers; when electrolytics are connected in series, this same voltage distribution scheme can be used provided that the resistors used are of low ohmic value (between 10,000 and 50,000 ohms).

TIME CONSTANT OF A CONDENSER

Now I am going to introduce a topic which will mean a lot more to you as you progress with your radio studies—the fact that when a resistor is connected in series with a condenser, an appreciable amount of time is required before the condenser will receive a full charge. Figure *18A* will help you to understand why current flows through the circuit the instant the D.C. source is applied. An uncharged condenser momentarily acts as if it were short-circuited, and passes a current which has a maximum value equal to *the charging voltage divided by the ohmic value of resistor R.* This first rush of current causes all of the line voltage to be dropped or wasted in the resistor. Gradually, as the condenser becomes charged, it offers more and more opposition to the flow of current, and more and more of the source voltage is dropped across the condenser. Finally, when the condenser is fully charged, the current flow has practically dropped to zero and the full voltage of the source is applied to the condenser. This picture of a condenser charging through a resistor is graphically illustrated in Fig. *18B*. Notice how the condenser voltage increases as the resistor voltage and the current decrease.

It is very easy to figure out the time required for the voltage drop across a condenser to reach about six-tenths (63.6 per cent is more exact) of the final voltage value; simply multiply the value of C in mfd. by the resistance of R in megohms. The value you obtain will be time in seconds; it is called the *time constant* of the combination.

This time constant is quite important in radio work; you will find it referred to in connection with grid leak-condenser type detectors, with automatic volume controls, special oscillators (called relaxation oscillators) for generating A.C. power, and with resistance-capacity coupled audio amplifiers. For the present, simply remember that it takes a certain time to charge a condenser when a resistor is connected in series. Remember also that in charging and in discharging, the current through a condenser starts at a *maximum* value and gradually decreases to zero.

CONDENSERS IN A.C. CIRCUITS

Once a condenser is fully charged, it will not conduct a direct current (except for the very small leakage current which is passed by all ordinary condensers). With A.C. circuits, however, the condenser passes current at all times, and becomes an increasingly better path for A.C. current as the frequency of the source is increased. The alternating current which can flow through a condenser depends upon the capacity of the condenser and upon how fast the applied voltage is changing.

Condensers, like coils, have a reactance which is expressed in ohms. It can be determined by the following simple formula:

(1) To find the capacitive reactance of a condenser, divide the number 159,000 by the frequency of the current in cycles per second, then divide the answer by the capacity of the condenser in microfarads.

This same formula can also be expressed in this way:

(2) $$Xc = \frac{159{,}000}{fC}$$

Where:

Xc is the capacitive reactance in ohms,
f is the frequency in cycles per second,
C is the capacity in microfarads.

With this formula the capacitive reactance, which is really the effective opposition in ohms of the condenser at a certain frequency, is easily found. The formula also tells you that the *capacitive reactance* of a condenser *decreases* when the frequency of the applied voltage is increased. Likewise, lowering the frequency *increases* the capacitive reactance. For example, the capacitive reactance of a 1-mfd. condenser at 60 cycles is 2650 ohms; at 6000 cycles, it is 26.5 ohms; at 600 kc., it is .265 ohm; at 60 megacycles, it is .00265 ohm.

For the purpose of by-passing an A.C. current, then, a 1 mfd. condenser is about ten thousand times better at 600 kc. than it is at 60 cycles. This explains why by-pass condensers which are used in R.F. circuits can be very much lower in capacity than those used in A.F. circuits.

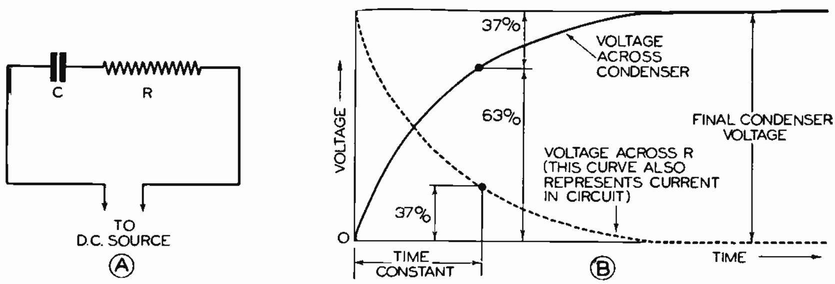


Fig. 18. When a resistor is connected in series with a condenser, the condenser voltage builds up gradually, not instantly, to its final value.

Does A.C. current flow through a condenser? Some say yes and some say no, so to clear up this question for you, I will explain why it is correct to say that A.C. current flows through a condenser.

First of all, what do we mean by current flow? Well, if we are talking about a flow of electrons in a D.C. circuit, we mean the slow drift or movement of the electrons in one direction, this movement being relayed instantaneously to all the other free electrons in the circuit, just as a row of billiard balls relays a shock from one ball to another. If a condenser is in the D.C. circuit, the electrons drift up to the condenser, pile up at the negative terminal and relay their effects through the dielectric to electrons at the positive terminal of the condenser.

In an A.C. circuit, however, there is no steady drift of electrons in any one direction. The electrons vibrate back and forth along the wire as the A.C. voltage changes its polarity twice each cycle (Fig. *19A*), and this vibrating motion is transferred to all of the other electrons in the circuit. Now consider Fig. *19B*, showing the two plates of a condenser with a dielectric between them, and one atom in the dielectric. You remember that an atom can be considered as being made up of a nucleus and a number of electrons revolving around it (only one electron is shown, for clearness). When an electron, under the influence of an A.C. voltage, approaches condenser plate *a* (Fig. *19C*) this electron repels the bound electron in the atom, causing that electron to take an "egg-shaped" path which brings it closer to plate *b* of the condenser. This bound electron in turn repels an electron on plate *b*, causing it to move away from the condenser into the conductor. On the next half of the A.C. cycle, the movement of the electrons and the shifting of the orbit of the bound electron are in the opposite direction. The bound electron does not detach itself from the atom, but relays the movement of electrons from one condenser plate to the other simply by shifting its path or orbit.

Figures *19D*, *19E* and *19F* show how the path of the bound electron varies during one complete cycle. Clearly the bound electron moves or vibrates just like the free electron in the wire at *D*, and so we say that an A.C. current flows through a condenser.

Losses in Condensers. When a D.C. voltage is applied to a condenser, the bound electron shifts to the egg-shaped path, and we say that the dielectric in the condenser is under a stress. When a condenser is charged, then discharged suddenly, all of the bound electrons

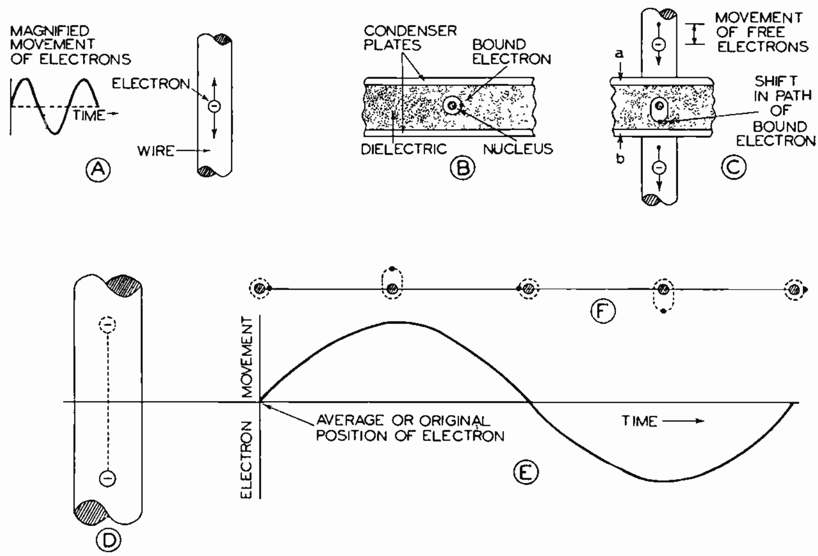


Fig. 19. These sketches give the complete story of the movements of an electron in a condenser circuit which is connected to an A.C. source. At *A* is shown an electron moving back and forth through an ordinary wire under the influence of an alternating current voltage. An uncharged condenser is shown at *B*, an atom in the dielectric being represented as having a nucleus around which revolves a single electron. *C* shows how the orbit (path) of this electron is distorted when electron flow through the connecting wires is in the direction indicated. Diagrams *D* and *E* show a little more clearly how A.C. causes an electron to move back and forth in a wire without getting any place, while *F* tells what happens to the bound electron in the dielectric as electrons move towards and away from the condenser plates.

do not return immediately to their original path or orbit; if you short the condenser terminals again a few minutes later, a further discharge of current will take place. This action is called *absorption;* in an A.C. circuit absorption is given the technical name of *dielectric hysteresis.*

Quality of Condensers. The ability of a condenser to retain its charge over a period of time is a valuable practical indication of condenser quality; the longer a condenser will retain its charge, the better is its quality. You can make a test yourself on a paper condenser; for example, to test a 1-mfd. condenser, connect it *temporarily* to a high voltage (200 to 400 volt) D.C. source to charge it, wait 2 or 3 minutes, then short the terminals with a screwdriver and note the strength of the spark obtained. If the spark is strong, you know that the condenser has retained its charge for several minutes, and the condenser is therefore of *good quality; that is, the condenser has low leakage and is in good condition.* This test applies only to paper condensers larger than .25 mfd.

There are two types of condenser losses: 1, *leakage or conduction losses;* 2, *hysteresis losses.* Both of these losses are present in A.C. circuits, but for simplicity we can consider their combined effect as being equal to a *low* resistance *in series with* a perfect condenser or a *high* resistance *in parallel with* a perfect condenser. See Fig. *20.*

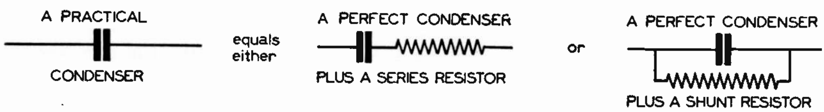


FIG. 20. All condensers have losses; these can be combined and considered either as a series or a parallel resistor associated with the condenser.

PHASE SHIFTING EFFECTS OF A CONDENSER

In a previous lesson I pointed out that the A.C. current through a resistor was always in phase with the applied voltage; that is, both voltage and current reached maximum values at the same time, dropped to zero at the same time, and reversed their direction at the same time. I also told you that the current through a perfect coil

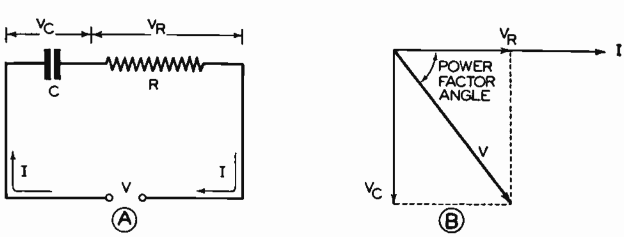


FIG. 21. When a resistor and condensor are connected in series to an A.C. source, their voltages must be added together vectorially as at the right.

lagged behind the voltage applied to the coil by 90° or one-fourth cycle. The current through a perfect *condenser,* however, *leads* the applied voltage by 90°; accept this as a proven statement, for scientists using higher mathematics have definitely shown it to be true.

Condensers in Series with Resistors. When a condenser and a resistor are connected in series to an A.C. voltage as in Fig. *21A*, the same current flows through *R* and *C;* this current can be used as a reference (vector I in Fig. *21B*) in drawing a vector diagram which will show what happens in the circuit. We know that the voltage drop across the resistor will be in phase with the current, and that the voltage drop across the condenser will lag 90° behind the current, so we can draw these two vectors, V_R and V_C, to lengths which correspond to their voltage values. According to Kirchhoff's Laws, V_R and V_C should equal the line voltage *V* when added together vectorially; we do this by completing the rectangle and drawing its diagonal, which is *V*. The angle between the applied voltage vector *V* and the current vector is important, for it is a measure of the actual power which will be absorbed by the circuit. This angle is called the *power factor angle.*

It is a little difficult to use the power factor angle in figuring out the power itself, so we make two simple measurements on the vector diagram, getting the lengths of *V* and V_R. The *power factor* of the circuit is then the length of V_R divided by the length of *V;* it will always be less than one, for V_R will always be shorter than *V*.

Power factor can be measured as well as computed. To do this, the power input to the circuit is measured with a wattmeter, the current drawn is measured with an ammeter, and the voltage applied to the circuit is measured with a voltmeter. The power factor is then the power input in watts *divided by* the apparent power input (the product of the current and the applied voltage).

The power factor of a condenser, which tells how much power is wasted by the condenser, can be expressed in three different ways—as a numerical value, as a percentage value (equal to 100 times the numerical value) and as an angle (the power factor angle). The table below gives power factor in these three ways for common types of condensers; the *higher* the numerical or per cent power factor, the *greater* will be the power wasted by the condenser. From a practical viewpoint, the power factor rating is of importance to Radiotricians only because it shows the relative merits of different types of condensers.

Type of Condenser	Power Factor	Per Cent Power Factor	Power Factor Angle
Moulded Mica Type Condensers	.0005 to .0011	.05% to .11%	89.9°+
Waxed Paper Condensers	.001 to .03	.1% to 3%	89.9° to 88.3°
Dry Electrolytic Condensers	.05 to .15	5% to 15%	87.1° to 81.4°
Wet and Semi-Dry Electrolytics	.1 to .2	10% to 20%	84.3° to 78.5°

Tubes are Coming Next. Your next lesson is devoted entirely to the subject of vacuum tubes. You will learn how they are constructed, how they operate, why they operate, and a lot more interesting information about their uses in radio circuits. Later you will study the action of resistors, coils and tubes used together in radio circuits.

TEST QUESTIONS

Be sure to number your Answer Sheet 7FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. Can direct current flow through a good condenser?
2. Upon what two factors does the amount of electricity which can be stored in a condenser depend?
3. Give three ways of increasing the capacity of a condenser.
4. What is meant by the "working voltage" of a condenser?
5. Name the two practical units of capacity which are smaller than the farad.
6. If the forming voltage of a given electrolytic condenser is lowered, will its capacity *increase, decrease* or *remain unchanged?*
7. Is it necessary to consider polarity when using any of the three types of electrolytic condensers?
8. If you needed a large capacity for a certain job, but only condensers of low capacity were available, would you connect the units together *in series* or *in parallel* to secure the required capacity?
9. Does the capacitive reactance of a condenser *increase, decrease* or *remain the same* when the frequency of the applied voltage is increased?
10. What is indicated as to quality if a certain 1-mfd. paper condenser will retain its charge for several minutes?

TYPES OF RADIO AND ELECTRONIC TUBES; HOW THEY OPERATE

8FR-3

PIONEER HOME STUDY RADIO SCHOOL

NRI

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

YOU HAVE AN AIM IN LIFE

When you enrolled as a student member of the National Radio Institute, you took the first step on your road to success and happiness. While you may have to wait awhile before you begin to see success coming to you, you need not wait for happiness.

You have set a *goal* for yourself—you have an aim in life—you are looking forward to the sort of work you like, the sort of income you want, and the respect and admiration of your friends.

Right now you should be very happy in anticipation of these things and in knowing that you are fast approaching your goal.

Realizing that you have every reason to be happy in your work right now, you will have an enthusiastic attitude toward your work. Study will not be a burdensome task, but instead a real pleasure. The difficulties you may encounter will only make you more determined to succeed.

Keep your goal in mind. Never forget it for a moment. Of course you will have your moments of discouragement—we all have. But if you make a thorough search for the cause of your discouragement, you will most likely find that you ate something which did not agree with you, or were kept awake last night by the neighbor's dog—and realizing this, you will put your lessons aside for the time being and tackle them the next day with renewed vigor and a renewed determination to succeed.

When things look blackest, say to yourself: "I have a goal to reach and I'm going to reach it." Then think how unhappy you would be if you did not have this goal. I am sure you will agree with me that there is nothing as pathetic as a rudderless ship or a man without an aim in life.

Here's to success and happiness—*your goal.*

J. E. SMITH.

NATIONAL RADIO INSTITUTE

WASHINGTON, D.C.

1941 Edition

A LESSON TEXT OF THE N. R. I. COURSE
WHICH TRAINS YOU TO BECOME A
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Types of Radio and Electronic Tubes; How They Operate

INTRODUCTION

SOON after the electron was discovered, engineers uncovered a number of interesting facts about the behavior of electrons; they learned that metals and metallic compounds have an abundance of free electrons which can be forced out into space in three different ways: *1,* can be *evaporated* or driven out of the material *by applying heat; 2,* can be *jerked out* of the material *by very high positive potentials; 3,* can be *driven out* of the material *by bombarding* with strong light rays (which are electromagnetic waves) or with very small high-speed particles (such as electrons). Electrons which are driven out into space by one of these three methods can be collected by a positively charged body or repelled by a negatively charged body.

The discovery that electrons could be forced from a metal more readily if that metal were placed in a vacuum resulted in the first *vacuum tube;* it contained one metallic element called the *cathode,* which emitted electrons when heated by an electric current, and a metal plate called the *anode,* which was at a positive potential and collected the emitted electrons.

Vacuum tubes which serve to control the electron flow in a circuit are known as *electronic tubes;* when used in radio apparatus, electronic tubes are more often called *radio tubes* or vacuum tubes. In Great Britain, however, radio engineers call all tubes used in radio sets "radio valves," arguing that the tubes control electron flow through wires in much the same way that valves control the flow of water through pipes.

Up to a few years ago, radio claimed almost sole ownership of the electronic tube, but today a large number of other industries and professions are finding important uses for these tubes. Industry uses electronic tubes to count and sort moving objects, to safeguard health and life, to control the operation of machines, to test and inspect products; the medical profession searches for and cures human ailments with various forms of electronic tubes; prospectors locate oil and mineral deposits far below the earth by means of these tubes. Year after year this list of electronic tube applications grows; we call the entire field *electronics.* Radio holds rather an unusual position in that it is the "parent" and at the same time an important branch of electronics.

THE CATHODE AND ANODE

Every electronic tube must have at least two electrodes, a cathode and an anode, and the leads or terminals connected to these two electrodes must always be in the circuit whose current you wish to control. In the simplest tube the cathode and anode (also called the *plate*) face each other, a short distance apart, in a glass container or envelope from which all possible air has been pumped. This air is removed for a very simple reason, to remove physical obstructions (such as molecules of air) which might interfere with the flow of electrons from the cathode to the anode or plate.

When Can Electrons Flow? Figure 1A shows a simple electronic tube connected into a circuit consisting of a source and a load. The tube here serves as the transmission system, controlling the flow of electrons from source to load under these three important conditions: *1*, if the cathode of the tube is not emitting (supplying) electrons, the space between cathode and plate acts just like any other gap in a circuit, stopping all flow of electrons; *2*, if the cathode is emitting electrons, these electrons flow to the anode and through the circuit when the anode is *positive* with respect to the cathode; *3*, if the anode is *negative* with respect to the cathode, no electrons can flow even though the cathode is emitting electrons.

Suppose that electrons are being emitted by the cathode in Fig. *1A*, and the plate is charged negatively (is connected to the minus terminal of a D.C. source)—what will happen? Quite obviously, the electrons approaching the anode will be repelled by the negative charge there; no electrons will ever reach the anode and there will be no electron flow in the circuit. Of course, when the D.C. source is so connected into the circuit as to make the anode of the tube positive, electron current will flow through the circuit continuously. Now let us see how practical use can be made of these characteristics of a two-electrode tube.

Valve Action in Electronic Tubes. When an A.C. source like that represented by the upper curve in Fig. *1B* is connected to the circuit of Fig. *1A*, you know immediately that the anode of the tube will be positive for one-half of a cycle and negative for the other half. The tube will therefore allow electrons to flow only for one-half of each cycle, as shown by the lower curve in Fig. *1B*. An electronic tube thus acts as a one-way *valve*, allowing electrons to flow through a circuit only in one direction; in other words, such a tube changes A.C. power to D.C. power. The current flowing through the load will be pulsating D.C., but the variations in current can be filtered or smoothed out by connecting a condenser or filter in parallel with the load.

Heating the Cathode. Heat, as you know, forces the free electrons in a metal into violent, chaotic (haphazard) motion. Extreme heat forces these electrons out of the surface of the metal, and we then have an electron emitter; the chief problem is that of obtaining a metal which will emit sufficient electrons for electronic tube purposes without melting because of the intense heat.

Now is a good time to clear up the difference between the terms "cathode" and "filament" as used in connection with electronic tubes. The *cathode* is that electrode which emits or supplies electrons; the *filament* is the fine resistance wire (usually tungsten) which when heated by an electric current either emits electrons directly (as in the case of filament type tubes) or heats an entirely separate electron-emitting cathode (as in heater type tubes). An electronic tube may contain either a filament or a cathode, or both; in many tubes the filament also serves as cathode.

A simple electronic tube having a tungsten filament is shown schematically in Fig. *2A*; the heated filament here serves the same purpose as the cathode of the tube shown in Fig. *1A*, that of supplying electrons. Note that current for the filament is supplied by the low

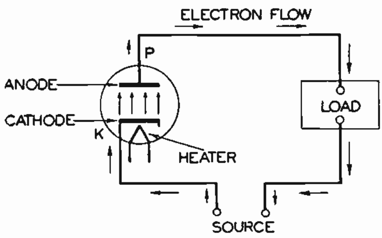

FIG. 1A. A simple two-electrode vacuum tube, shown here in symbolic form, allows electrons to flow in this circuit only in the direction from cathode to plate, as indicated by the arrows above.

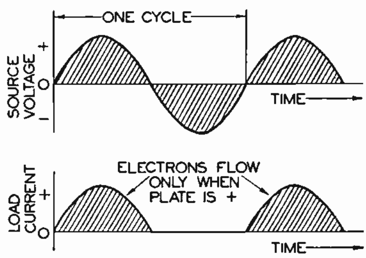

FIG. 1B. These curves tell what happens in the circuit of Fig. 1A when the source is A.C.; electron current flows through the circuit only on that half of each cycle when the source voltage makes the tube anode positive.

voltage winding of the transformer, and plate voltage is obtained from a separate high voltage winding. Electrons, therefore, flow in this circuit under exactly the same conditions as when the source in Fig. *1A* is A.C.

Anode Requirements. The *anode* or plate of an electron tube must withstand heat fairly well without melting or emitting electrons, for constant bombardment by the electrons which it attracts produces a great deal of heat; the anode must not emit free electrons too readily when bombarded. Best results are obtained by keeping the anode cool. Nickel, molybdenum, carbon and pure iron (in forms known as Swedish iron and Svea metal) are materials which have proved suitable for use in constructing anodes. In high power tubes such as are used in large transmitters, water cooling or a forced air draft is often necessary to keep the plates at a safe low temperature. Whatever the metal used, it must release any gases in its pores when heated by external means while the tube is being evacuated (air pumped out), for otherwise the tube would release these gases gradually while in use, destroying the vacuum. The anode generally has a dull black surface, for black surfaces radiate heat readily and therefore keep cooler than polished surfaces.

Types of Cathode Materials. The three types of electron-emitting materials used for cathodes in modern electronic tubes are: *1. Pure metals such as tungsten; 2. Thoriated filaments; 3. Oxide-coated emitters.* Tungsten filaments are generally used in high-power transmitter tubes, where large filament currents are easily provided, while the other two types are used in medium and low power tubes; coated cathodes are the more common. The tubes illustrated in Figs. *2A* and *2B* are direct electron emitters, for electrons are emitted directly by the filament which supplies heat; tubes like that shown in Fig. *2C* have indirectly heated cathodes, the heat-providing unit and the electron-emitting surface being separated by an electrical insulator such as porcelain.

Pure Metals. We know that certain pure metals, such as tungsten and tantalum, are good *thermionic emitters* (*thermo* means heat; *ionic* refers to electrons). Tungsten is used far more widely than tantalum for the filaments (the heating elements) of radio tubes and incandescent electric lamps; current sent through the thin tungsten wire filament encounters an appreciable resistance, and the electric power wasted there is converted into heat. The more current flowing through the filament, the more heat is produced, and the more electrons are emitted.

Thoriated Filaments. Quite by accident it was found that certain impurities in a metal improve its electron-emitting properties. Tungsten is a hard, brittle metal, and when pure is very difficult to draw into the form of wire. Lamp engineers found that a little thorium (a metal) mixed with tungsten overcame the brittle properties, giving a more sturdy filament for incandescent electric lamps. Radio engineers tried these thoriated tungsten (thorium and tungsten) filaments and found them much better electron emitters than pure tungsten filaments.

Oxide-Coated Cathodes. Wehnelt discovered in 1904 that certain metal oxides (compounds of metal and oxygen) would, when coated over a filament, emit an extremely high amount of electrons with only moderate heating. Oxides of barium, strontium and calcium (called the alkaline or earth metals) proved to be ideal as emitters. Coated cathodes are of two forms: *1*, where the earth metal oxides are applied directly to the filament wire, as in Fig. *2B*; *2*, where the oxides are applied to a metal sleeve, as in Fig. *2C*. This latter type is better known as the *heater type* cathode; there is no electrical connection between the cathode, which emits electrons, and the filament, which heats the cathode indirectly. Both forms of the coated cathode are used in modern radio tubes.

Cold Cathode Emitters. From the basic principle that an electron is attracted by a positively charged body comes the *cold cathode* tube. If two metal surfaces, one charged positively and the other negatively, are brought together, the positive surface or electrode will pull or "jerk" electrons from the other electrode, provided that the potential difference between them is sufficiently high. This "jerking" action is improved by using a sharpened wire for the positively charged electrode (the anode). In Fig. *3A,* where *P* is the pointed anode and *K* is the large-surface negative electrode (the cathode), the electric lines of force are concentrated, while in Fig. *3B,* where *P* is a flat-surface anode, the electric lines of force are distributed over the entire anode surface, reducing their resultant effect It is this same effect which causes lightning to strike sharp, high points; electric lines of force from electrically charged clouds "feel" these sharp points before the lightning discharge occurs.

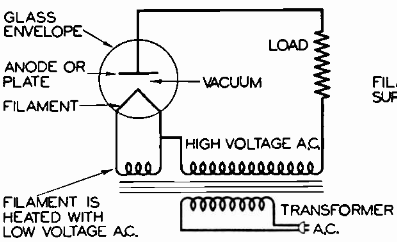

Fig. 2A. All power for this simple rectifier circuit is obtained from the A.C. line by means of a transformer which changes the line voltage to the correct value.

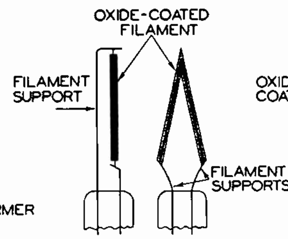

Fig. 2B. Types of coated filaments used in electronic tubes.

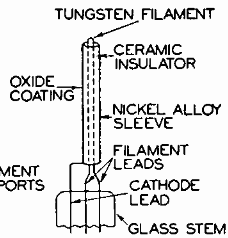

Fig. 2C. One type of indirectly heated cathode, using a "hairpin" filament.

This principle has been utilized in a simple two-electrode, cold cathode rectifier tube, commonly known as the *Raytheon BR tube.* Figure *3C* shows the general construction of the tube; a sharpened wire serving as anode draws electrons from the metal cathode when the anode is positive and at a sufficiently high potential. When the cathode is positive, it has only a very small area on the anode from which it can pull electrons, for the greater part of the anode, below the point, is protected by a porcelain sleeve; as a result only a very small current flows when the anode (the pointed electrode) is minus, and a large current flows when the anode is plus.* The tube is thus quite a good rectifier of alternating current; it requires no filament current for its operation.

Cold cathode rectifier tubes were used extensively shortly after A.C. operated receivers became popular, but in recent years these tubes

* Actually the current flow is increased considerably by ionization, due to the presence of a gas in the tube, but this process will be considered later.

have been replaced by the ordinary thermionic rectifier tubes. You will still find a few cold cathode rectifier tubes (either the type BR half wave rectifier or the BH and BA full wave rectifiers, having two anodes) in old model receivers. An illustration of a BH tube appears at *D* in Fig. *3*.

Electron Emission by Impact. A third way of making a metal body emit electrons is by bombardment. In a radio tube, for example, electrons emitted from the cathode travel toward the anode at high speed and knock off electrons from the metal plate upon impact; here this "secondary emission" of electrons from the plate is not desired, and special devices are built into most radio tubes to reduce the effect. In certain tubes, however, such as the "impactor"* tube developed by Philo T. Farnsworth and the multipactor tube* devised by Zworykin for use in television circuits, secondary emission is utilized to advantage.

Light is really made up of electromagnetic waves of very short length, traveling at very high rate of speed (186,000 miles per second); since any moving magnetic field, such as that created by high speed electrons, represents energy, light can therefore be said to represent energy. Heinrich Herz, a famous scientist, was the first to prove that this energy in light could affect an electrical circuit; other scientists found, a few years later, that light rays actually could drive electrons from a metal such as zinc. This important discovery is now known as the *light-sensitive effect* or the *photoelectric effect;* it made possible the modern photocell, an electronic tube which is very widely used in television apparatus of certain types and in industrial light beam control equipment.

Next came the discovery that metals like lithium, sodium and caesium (commonly called alkaline metals because of their chemical properties) liberated electrons quite freely when exposed to light. An oxide of caesium, placed on a metal surface, is very widely used in commercial photocells.

Photocells. A typical photocell appears in Fig. *4;* it is simply a semi-cylindrical metal surface, on the inside portion of which is a coating of light-sensitive material such as caesium oxide, and a wire or rod (of small diameter so it will not block light) located in the center of the cathode and serving as anode; these two electrodes are mounted in an evacuated glass envelope. Light falling on the sensitized surface of the cathode causes electrons to be emitted; these electrons are collected by the anode, which is placed at a positive potential.

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* In these tubes, the electrons emitted from a cathode are made to reflect from a number of surfaces before reaching the anode; at each reflection, additional electrons are added to the electron stream because of secondary emission.

If a resistor (*R* in Fig. *4*) is connected in series with the battery which supplies a D.C. voltage to the photocell, the current flowing through *R* will produce a voltage drop which can be used to control an amplifier, electrical relay or switch, which in turn can perform any desired control operation. Thus a ray of light directed on a photocell can start an electric motor, sound an alarm, operate a counting device, or give any one of a thousand other desired actions. If a small searchlight is directed on a photocell, any person walking through the light beam would cut off the light, the current through the photocell would drop, and the resultant voltage drop across *R* could be amplified and used to control any desired device.

CONTROLLING PLATE CURRENT

I have just pointed out that there are three important methods of liberating electrons from the cathode of an electron tube: *1,* by pulling the electrons from a cold cathode with a high voltage; *2,* by knocking

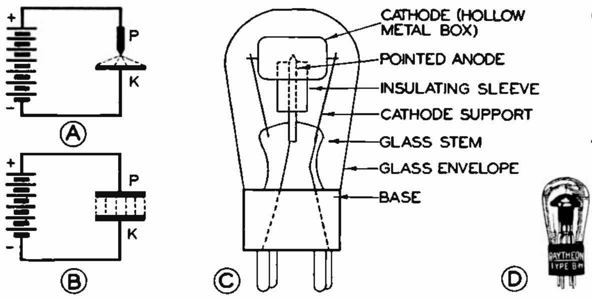

FIG. 3. Illustrating the basic principles and the construction of a cold-cathode tube. When argon or some other gas is used in a tube of this type, the distance between anode and cathode can be increased and the operating voltage reduced, for ionization of the gas then allows a much heavier current to flow than in the case of a perfect vacuum.

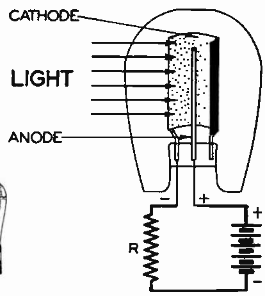

FIG. 4. The positively charged anode of this photocell attracts electrons which are released from the light-sensitive cathode under the action of light.

electrons from a cold cathode with a bombardment of light rays or small high-speed particles; *3,* by heating the cathode either directly or indirectly, thus causing the electrons to be "boiled off" or emitted. The remainder of this lesson will be devoted to electronic tubes using the third or thermionic method.

Circuit For Obtaining Characteristics of Tubes. A number of interesting characteristics of a simple two-electrode thermionic tube can be determined when the tube is connected into a circuit like that in Fig. *5A*. By now you should have no difficulty in reading schematic circuit diagrams like this. *P* represents the anode or plate, which is here given a continuous positive charge by battery B_B; *K* is the cathode, a metal sleeve coated with a good electron-emitting material such as a mixture of strontium and barium oxides; *H*, the heater or filament, is not counted as an active electrode in this tube, for it is connected to an independent circuit and simply heats the cathode.

At first thought one might think that as the cathode was made hotter and hotter by increasing the filament or heater voltage V_F, the number of electrons emitted by the cathode would increase correspondingly and the electron current flowing from cathode to plate and through the circuit would likewise increase. But this condition does not always hold true; the graph in Fig. *5B* shows exactly what does happen when the plate voltage V_P is kept constant and the filament voltage V_F is varied (by varying rheostat R_F). Graphs like this are obtained by making systematic measurements in a circuit while only one value is varied at a time. Naturally, if you want to know the effects of filament voltage changes on the tube, you will not change the plate voltage; when you are studying the effects of plate voltage changes you keep the filament voltage constant. Considering only the heavy, solid curve (1) of Fig. *5B* now, notice that as the filament voltage is gradually increased from zero the plate current I_P (measured by D.C. milliammeter *M* in Fig. *5A*) rises, slowly at first, then very rapidly, up to point *x* in Fig. *5B*. Further increases in filament voltage now have very little effect on plate current, for the plate of the tube is here attracting all the electrons it can at that fixed value of plate voltage.

Temperature Saturation. If we now reduce the filament voltage to zero and set the plate voltage at a new constant value, higher than before, the plate current will follow a similar curve as before up to point *x* as filament voltage is increased. Further increases in filament voltage now cause the plate current to follow the dash-dash curve (2), which continues to rise for a time, then stops increasing just as did curve *1*. The condition where increases in filament voltage have very little or no effect on plate current (such as at point *x* for curve *1* and point *Y* for curve *2*), is known as *filament saturation* or *temperature saturation.* (A sponge is said to be saturated with water when it will hold no more water; a radio tube is at saturation when the plate can attract no more of the emitted electrons.) Most radio tubes are operated at filament voltages which just produce saturation; higher filament voltages simply shorten the life of the tube without increasing its output current.

Voltage Saturation. Figure *5C* shows what happens when the filament voltage is held constant at a normal operating value and the plate voltage V_P in Fig. *5A* is varied. As plate voltage is increased from zero, plate current rises as shown by curve *1* until, at a point just beyond *x,* additional increases in plate voltage have no effect on plate current. Remember that the filament voltage is constant for this curve; the filament is therefore emitting a certain definite number of electrons. When the plate voltage reaches the point where the plate is attracting practically all of the emitted electrons, plate current can no longer increase; this condition is known as *plate saturation* or *voltage saturation.* Increasing the filament voltage to a new constant value makes the curve follow the dash-dash path (curve *2* in Fig. *5C*) beyond point *x,* giving just what you would expect—a higher plate current at the saturation voltage.

THE SPACE CHARGE

You have learned that temperature saturation exists when the cathode emits more electrons than the plate is able to attract. But *why* isn't the anode able to attract all these electrons? The answer is this: great numbers of electrons gather in the space between the cathode and the plate to form what is called the *space charge* or *elec-tron cloud. It is this space charge which prevents the positively charged anode from attracting all of the electrons emitted by the cathode of a two-electrode tube.* I can best explain the space charge by starting with a familiar example, the voltage drop of a resistor.

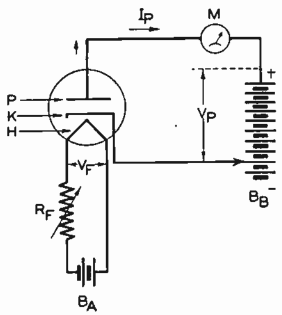

Fig. 5A. Circuit used in obtaining characteristics of a two-electrode vacuum tube. The curves obtained, shown at the right, are average values and do not apply to any particular tube.

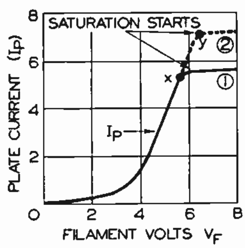

Fig. 5B. This graph shows what happens to the plate current of a two-electrode tube when filament voltage is varied. Plate voltage was held constant for each curve.

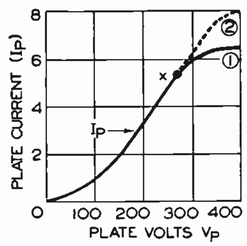

Fig. 5C. Variation of plate current with plate voltage for a two-electrode vacuum tube. The filament voltage was held constant for each curve.

If a resistor unit ten inches long were connected to a 100 volt D.C. source, as in Fig. *6A,* and a D.C. voltmeter were used to measure the drop from *K,* the negative terminal, to various points along the resistor, a reading of 10 volts would be obtained one inch from *K,* 30 volts at three inches from *K,* 60 volts at six inches from *K,* etc. These readings are best represented by the graph in Fig. *6A.*

The same sort of measurements could be made in the space between the cathode and the plate of a *vacuum tube;* of course, some means would have to be devised for introducing a wire or very small plate into the tube at various points. The voltage measurement could be made with a special voltmeter of the electrostatic type, which draws no power once it is charged. If this experiment were performed with a *cold* cathode in a *high vacuum,* the voltage measured with respect to K would increase uniformly with the distance from K, just as is shown by the graph in Fig. *6B*. Thus the voltage between the electrodes of a cold cathode *vacuum* tube varies in much the same manner as the voltage at various points along a resistor.

Now let us see what happens when this experiment is repeated with a *heated* cathode, such as in the circuit of Fig. *6C*. When making measurements in the region between the cathode and point *2*, scientists found that this region was actually *more negative* than the cathode. This condition can exist only if the region contains a cloud of electrons; here, therefore, is experimental verification of my statement that an electron cloud or space charge exists in the region surrounding the cathode of an electron tube.

When voltage is first applied between the cathode and plate of a vacuum tube, the electrons emitted by the cathode gather in the nearby space, and there act as a barrier which hinders further movement of electrons from the cathode to the plate. As more and more electrons are emitted by the cathode, the space charge, being negative, repels many of these and forces them back to the cathode; only those electrons having sufficiently high speeds to penetrate the space charge can be attracted by the plate. Those space charge electrons which are closest to the plate are also attracted to it; when these leave, more electrons enter the space charge from the cathode, thus giving a sort of relaying action. With these facts about the space charge clarified, I can explain temperature and voltage saturation.

Temperature Saturation Explained. When the plate voltage of a tube is held constant, increases in the filament voltage increase the heat generated by the filament and electrons leave the cathode with greater speed, forcing their way into the space charge. Not all of these emitted electrons can get through the space charge to the plate; this region quickly becomes so dense with electrons that additional emitted electrons are forced back to the cathode by the space charge when the filament voltage is further increased. Thus is temperature saturation obtained when the plate voltage is held constant.

Voltage Saturation Explained. Increasing the plate voltage allows the plate to draw more electrons from the space charge, and more of the electrons emitted by the cathode can therefore enter the space charge. If the plate voltage is made sufficiently high, it is possible that the entire space charge and all of the electrons leaving the cathode can be attracted to the plate, giving voltage saturation; in actual practice, however, voltage saturation is seldom obtained.

principally because with the high voltages required, electrons strike the plate with so much energy that they make it red or even white hot, and this excess heat soon destroys the tube.

High voltage is therefore unsatisfactory as a means of getting rid of the space charge; other methods, which will be considered in this lesson, are used to nullify or control this electron cloud. Before going on, however, I want to stress the fact that once the cathode reaches a definite temperature (its usual operating temperature), the space charge becomes the real source of electrons in the tube; all other electrodes (modern tubes may have as many as six extra electrodes) act on this space charge. This is why the space charge is sometimes called the *virtual* (or true) *cathode.*

GAS ELIMINATES SPACE CHARGE

Certain types of radio tubes, such as rectifiers, require a large plate current at a low value of plate voltage. Radio tube designers found

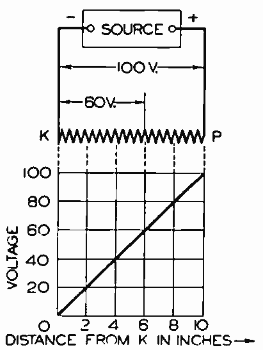

FIG. 6A. This graph, obtained by means of the above resistor circuit, shows that the voltage at any point along a uniformly constructed resistor is proportional to the distance from K, the negative end of the resistor.

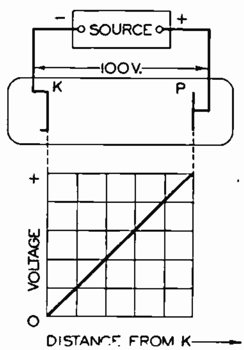

FIG. 6B. This graph shows that the voltage at any point inside a two-electrode vacuum tube having a cold cathode is proportional to the distance from the cathode of the tube. The tube sketch is for illustrative purposes only, and does not represent an actual tube.

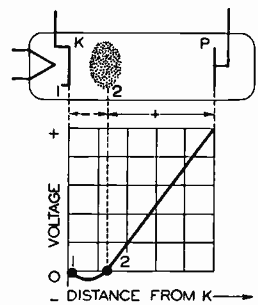

FIG. 6C. The voltage at various points between cathode and anode of an average two-electrode vacuum tube having a heated cathode is given on this graph. The *space charge* prevents all of the emitted electrons from being attracted by the positively charged anode.

that using a small quantity of a gas inside the tube nullified the effects of the space charge and allowed a larger current to flow. Almost any gas can be used for this purpose, but best results are obtained with a heavy gas such as mercury vapor. The tube shown in Fig. 7 illustrates the action of this gas in nullifying the space charge; the schematic symbol for the tube has been elongated for clearness. Suppose that an electron emitted by the cathode has traveled at high speed through the space charge and is headed for the plate; there are a number of mercury atoms (in gaseous form) in this region, and this electron collides with one of them, knocking off a second free electron. Both the original and the second electron speed on to the plate, since they are beyond the space charge and under the influence of the plate. The heavy mercury *ion* (the gas atom which has lost one electron) is positively charged and is therefore repelled by the plate and attracted by the space charge. When this ion gets to the space charge it "snaps up" or combines with one of the electrons there, to become a mercury atom again. This action reduces the number of electrons in the space charge; just imagine millions of other mercury atoms acting in the same way over and over again and you can see how the entire space charge can be neutralized by ionization of gas.

CONTROLLING SPACE CHARGE WITH A GRID

You have just learned how gas can be used to advantage in neutralizing the space charge in a *rectifier* tube; in most of the other tubes used in radio transmitters and receivers, however, it is more important to have a simple means of accurately controlling the plate current than to have a very large plate or space current. Of course, you could vary the plate voltage in order to vary the plate current, as has already been shown, but in general this does not prove satisfactory for radio

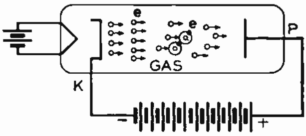

FIG. 7. A small quantity of gas in this heated cathode two-electrode tube eliminates the undesirable space charge or electron cloud in front of the cathode by a process known as ionization.

purposes. The simplest method, first proposed by Lee DeForest, involves the use of an extra element called a grid, inside the tube; this is located near the heated cathode and is therefore in the region of the space charge. A certain charge on this extra electrode has far more effect on the space charge than has an equal charge on the plate, simply because the plate is farther away from the space charge. By using for this electrode a structure having many openings, such as a wire screen or wire spiral, the electrons moving from the space charge to the plate can readily pass through. This grid or third electrode in the tube (the other two are the cathode and the plate) is used primarily *to control the flow of electrons between cathode and anode*—that is why it is called the *control grid*.

If the grid is given a negative charge with respect to the cathode, by using a separate battery for it in the manner shown in Fig. *8A*, the grid will actually aid the space charge in preventing electrons from reaching the plate. Even though the positively charged plate attempts to pull electrons out of the space charge, the grid is so much closer to the space charge that a small negative grid voltage (much lower in value than the plate voltage) will reduce or even stop the flow of electrons.

The E_G-I_P Characteristics. I think it is clear to you now that when a grid is placed in a vacuum tube, it exercises some control over the current flowing to the plate; naturally this question arises: What is the exact nature of this control? You can easily find this out by using the circuit shown in Fig. *8A,* applying various voltages to the grid and noting their effects upon the plate current. There are three batteries (or D.C. supplies) in this circuit. B_A is used to heat the filament of the tube, B_B is used to apply a positive charge to the plate in order to attract electrons which are emitted by the heated cathode, and B_C is the battery which is used to charge the grid either plus or minus, depending upon how the battery terminals are connected to the grid.

Perhaps you have wondered why batteries are labeled A, B and C in this way. It so happened that these batteries came into use in connection with the development of vacuum tubes in the order listed, the filament supply first, then the plate battery, and finally the grid

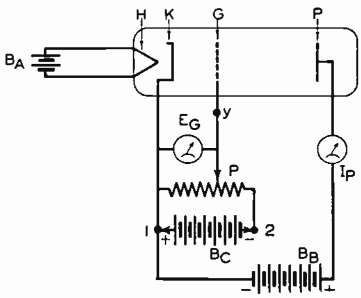

FIG. 8A. Circuit for determining the operating characteristics of a three-electrode vacuum tube. The tube shown here does not represent any particular radio tube.

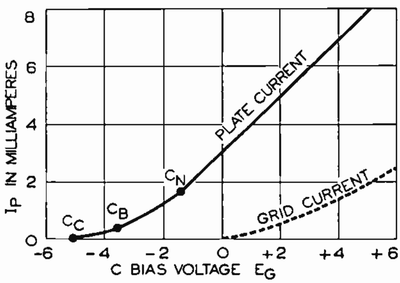

FIG. 8B. Variation of plate current and grid current in a three-electrode vacuum tube (a triode) as the grid voltage is varied by circuit like that shown at the left, while filament and plate voltages are held constant.

control or grid bias battery. This is why the filament battery is usually called an *A battery,* the plate circuit battery is called a *B battery,* and the grid bias (or grid voltage) battery is called a *C battery*.

Coming back to the experimental circuit in Fig. *8A,* we can neglect the effects of variations in the A and B battery voltages, since these will produce the same results as were obtained with the simple two-electrode tubes shown in Fig. *5A*. To determine the effects of the C voltage, therefore, we set the filament and plate voltages at fixed values and vary the C voltage. With battery B_C connected as shown, we can apply any desired value of negative voltage to the grid; by reversing the connections to the C battery at terminals *1* and *2* we can give the grid any desired positive voltage within the voltage range of the battery. The voltage variations in either case are obtained by changing the setting of the potentiometer control marked *P*.

The voltage applied by battery B_C to the grid of this tube is called the *C bias voltage* or simply E_G; the effects of this voltage can be determined by varying it and noting the value of I_P, the plate current, as indicated on the meter I_P. The grid bias voltage at each setting of potentiometer P is indicated by a voltmeter (marked E_G) connected as shown in Fig. *8A*. The results of this experiment have been plotted on the graph in Fig. *8B*. Observe that when the grid of this triode tube has a *very large* negative C bias, the plate current flow is *practically zero*. When the C bias is zero (meaning that the grid is at the same potential as the cathode), the plate current which flows is about equal to that which would flow if the grid were removed from the tube. When the grid bias is positive the plate current increases rapidly, as you can see. Three points along this plate current curve are of especial interest. Point C_C is that where the plate current first drops to zero; the bias voltage required to produce this condition is called the *cut-off* C bias. Point C_B, located where the curve has the sharpest bend, marks the point where the plate current starts to increase rapidly; this point is called the *bend* of the curve. Point C_N marks the spot where the plate current first starts to increase uniformly as the grid bias is made more positive; above this point changes in grid bias voltage produce proportional changes in plate current.*

It is important that you remember these three points, for their location controls to a great degree the use to which a certain tube can be put. For example, point C_B is of greatest importance for detectors; point C_N is considered when dealing with amplifiers; point C_C is of importance in connection with oscillators and some amplifiers. I am merely pointing out these interesting features now; we will come back to them later in the Course and study more detailed explanations.

The careful experimenter, who is interested in knowing whether grid current flows under any of the conditions just described, would insert a D.C. milliammeter into the circuit at some point such as *y* in Fig. *8A*, and note the grid current meter reading for each value of grid voltage. The dotted (- - -) curve shown in Fig. *8B* for grid current tells you that appreciable grid current flows only when the C bias voltage is positive.

The two curves in Fig. *8B* will naturally change their position when the values of filament voltage and plate voltage are changed and the experiment is re-run, but the general shape of the curves will remain the same. Usually, only the plate voltage is varied; increasing the voltage of battery B_B increases the plate voltage, and this in turn changes the position of points C_N, C_C and C_B on the graph in Fig. *8B*.

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* Read the section devoted to graphs and curves in reference book 2X, "The Language of Radiotricians," if this method of showing the results of experimental data is not quite clear to you.

If a continually varying voltage, such as the output of an A. C. generator, is inserted in the grid circuit at some point such as at *y* in Fig. *8A,* this varying A. C. voltage will make the net C bias voltage increase and decrease, for voltages in series add and subtract, depending upon their polarity. The result is that the plate current passed by the tube will change correspondingly. There are many practical applications for this action of a three electrode tube; for example, if the A. C. signal impressed on the grid is a weak audio signal, the resulting plate current will be a strong audio signal which, if fed into a loudspeaker which is connected into the plate circuit, will produce sound. If a resistor is inserted in the plate circuit instead of a loudspeaker, the voltage developed across this resistor will be much larger than the A. C. voltage which originally was impressed on the grid.

MULTI-GRID TUBES

Screen-Grid. In 1926 Hull and Williams, research scientists, found that an extra grid, placed between the control grid and the plate and positively charged with respect to the cathode, helped the plate to draw electrons out of the space charge. They found that this second grid served also to "screen" (or electrically separate) the plate from the grid; for this reason double grid tubes came to be called *screen grid tubes.* In addition to its screening effect, a screen grid tube gives considerably more amplification than a tube which uses only a control grid, for it allows the control grid to be placed closer to the cathode without undesirable effects. A schematic diagram for a screen grid tube is shown in Fig. *9A.* The screen grid is always next to the control grid on the side facing the plate.

Suppressor Grid. Shortly after the development of the screen grid tube, it was found that this screen grid speeded up the electrons so greatly that their impact with the plate actually resulted in electrons being knocked off. These electrons, created by collision with the plate, wandered around in the space between the second grid and the plate, forming there another space charge which interfered with the normal flow of electrons from the cathode to the plate. The screen grid, which was at a positive potential, eventually attracted these to its surface thereby reducing the plate current. A vacuum tube research engineer suggested that another grid be placed in the tube, in the region of this second electron cloud, and this grid be connected to the cathode in the manner shown in Fig. *9B,* or even to a negative potential. Now electrons which bounce off from the plate, due to the impact of high speed electrons, are compelled to return either because of the attraction of the plate or because of the repelling action of the third grid. Because this third grid suppresses an undesirable space charge, it is commonly called a *suppressor grid.*

Tube designers have been able to create many different types of tubes, each with certain desired characteristics, by using various sizes and shapes of electrodes and by arranging the electrodes in various ways. Fig. *10,* showing the so-called *beam amplifier* tube, gives you some idea of the ingenuity of modern radio tube designers. In this tube, the electrons are emitted from a heated cathode. The first grid surrounding the cathode, the usual control grid, is placed at a negative potential and has the greatest effect upon the current passed by the tube. Surrounding the control grid is a second grid, called either a screen grid or a "speed-up" grid, which is formed of rather widely spaced wires. This screen grid, being at a positive potential, acts to pull emitted electrons through the control grid, but since the screen grid has many "wide open spaces," electrons go right through it and form a second space charge just outside. There are two beam-forming electrodes or plates, one at each side of the tube, which are at ground potential or at a negative potential and serve to concentrate the electrons on the other two sides of the tube. Thus beams of electrons go out from the cathode in two directions, the exact dimensions of the beams being controlled by the voltages on the two grids and on the beam-forming plates. Concentrating the electrons in definite regions inside the tube and near the plate allows the plate to draw an extremely large number of electrons from the second electron cloud. The first grid is always the control, concentrating more or less electrons in the second electron cloud. The beam amplifier tube (6L6) gives high plate current for low plate voltages; low grid voltages can control this high plate current, and the tube is therefore ideal for use in audio frequency stages.

GAS-FILLED TUBES

You have already learned that the presence of a gas in a two electrode tube results in ionization and the production of positive ions which neutralize the space charge. The electron flow from cathode to plate in a gas tube is therefore many times greater than that in the same tube constructed without a gas. But what effect has gas in a three electrode tube, where the control grid ordinarily determines the number of electrons flowing?

In any given two electrode tube containing gas, there is a definite plate-cathode voltage at which ionization takes place and the full plate current flows. If, now, a grid is placed in this tube and charged negatively, it will slow up the electrons emitted by the cathode, thus preventing them from acquiring the speed required to produce ionization. Varying the negative bias voltage on the grid varies the voltage at which the plate overcomes the effects of the grid and begins to draw electrons, starting ionization. Once ionization occurs in a three electrode gas tube (gaseous triode), the usefulness of the grid is ended as a control unit until such time as the plate voltage drops low enough to stop ionization. A gaseous triode is often called a *trigger-action tube,* for at low plate voltages practically no current flows through the tube; as the plate voltage is gradually increased, ionization suddenly takes place and maximum plate current flows almost instantly.

Thus gaseous triodes, which are called *Thyratron tubes* by the General Electric Company and *Grid-Glow tubes* by Westinghouse Electric and Manufacturing Company, have special features which make them useful in certain electronic control applications. If a gas triode is connected into a circuit where a signal voltage is fed to its control grid,

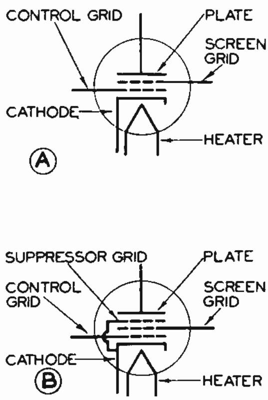
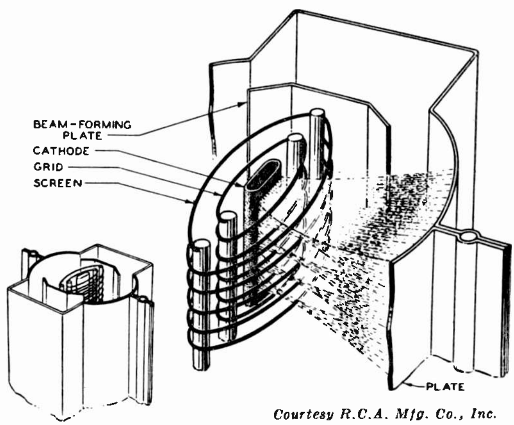


Fig. 9. Schematic symbols for a tetrode (or two-grid) tube (A) and for a pentode tube (B).



Courtesy R.C.A. Mfg. Co., Inc.

Fig. 10. Sketch showing arrangement of electrodes in the type 6L6 beam amplifier tube.

plate current increases very suddenly the instant a certain strength of signal exists; this plate current can be used to operate electromagnetic relays which in turn control motors or any other electrical equipment.

TYPES OF THERMIONIC TUBES

General Information. Having given you a general idea of the construction and operation of thermionic tubes, I can now begin describing the types of tubes which are in general use. First of all, thermionic tubes are either of the gas type or vacuum type. They may be called either glass or metal tubes, depending upon whether the electrodes and elements are enclosed in a glass or a metal envelope.

Cathode Construction Classification. Since each thermionic tube must have a heated cathode, we can also classify tubes according to the method of making the cathode emit electrons; there are, therefore, *directly heated* cathode tubes and *indirectly heated* cathode tubes. For simplicity, we often call the first type a *filament* type tube and the other a *heater* type tube.

Classification by Numbers of Electrodes. Another important thermionic tube classification depends upon the number of elements or electrodes in a tube. The cathode is always considered as one element, the filament in a heater type tube not being counted. The plate (or anode) is another element or electrode; since it takes at least a cathode and an anode to make a tube, the simplest tube is a two-element tube, called a *diode.* Three-electrode tubes are called *triodes.* Double grid tubes, containing four elements or electrodes in all, are called *tetrodes.* The triple grid tube, having five elements, is known as a *pentode,* while a tube with four grids (six elements) is known as a *hexode.* A tube with five grids is called a *pentagrid* tube, this word meaning that it has five grids. Hexodes and pentagrid tubes are often called *multi-element* tubes. Bear in mind that each of these tubes must have a cathode and an anode in addition to the grids.

It is perfectly possible to build two tubes, such as two triodes or two diodes, into one glass or metal envelope; such tubes are referred to as *multi-function* tubes. The double diode, triode-pentode, double (or twin) triode, and the diode-pentode are typical examples of double-function tubes. Three or even more tubes are being built into one envelope in some cases; examples of typical triple-function tubes are the double (or duplex) diode-triodes and the duplex diode-pentodes. This latter tube, for example, would have two diodes and a pentode in one envelope.

Classification by Filament Voltages. Thermionic tubes may also be classified according to the filament voltage which they require. This classification is often of great importance, for the radio receiver or apparatus designer tries to use, in any one unit, tubes which have the same filament voltage rating. This is done because parallel connections of filaments are highly desirable. Although tubes are built with many different filament voltages, the standard voltages are 2, 2.5 and 6.3 volts.

Classification According to Use. The final classification of tubes is according to their use or rather according to the use for which they were originally designed. Thus we have rectifiers, detectors, mixers, oscillators, R. F. and A. F. amplifiers and power amplifiers. Oftentimes, however, it is possible to use one tube for several different purposes. The correct usage classification for a given tube can be obtained only by studying the circuit diagram of the radio device, for this will show the actual use of the tube.

Cathode Construction. The two types of cathodes, the directly heated or filament type and the indirectly heated or heater type, are shown in Fig. *11*. At *A, B, C* and *D* are typical methods of supporting the filament wire. The more filament wire used and the more surface there is to emit electrons, the higher are the currents the tube will handle. The construction shown at *D* is used in some power audio tubes of high output.

Filament type tubes are well suited for operation from a steady source of filament power, but when operated on A.C. the space charge may vary with each alternation, causing some interference in the tube circuit. When filament type tubes are used on A.C., the filament wire should be quite thick so it will not heat and cool too rapidly, and A.C. hum interference must be balanced out.

Where large electron emission with low power consumption is desired, nickel alloy ribbon or wire coated with strontium and barium oxide

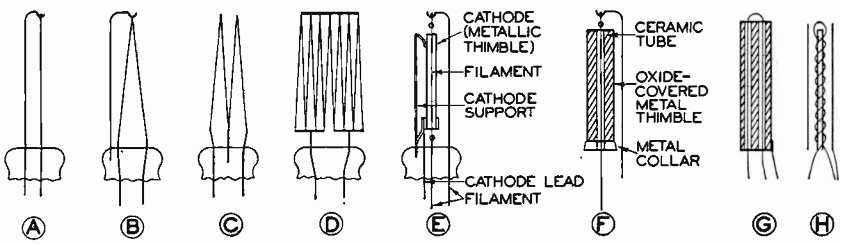


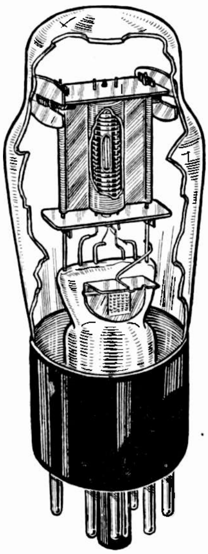
Fig. 11. Construction of various types of directly and indirectly heated electron emitters for electronic tubes.

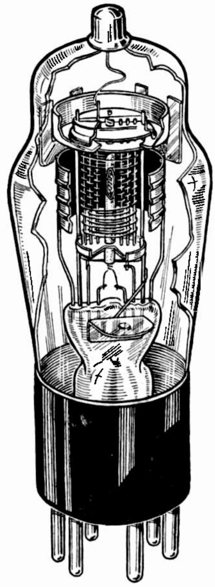
and operated at a dull red heat is used for the filament. A great many filament type radio receiver tubes are made in this way.

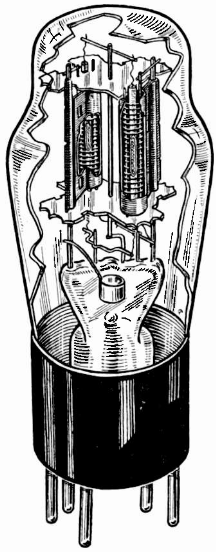
Indirectly heated cathodes generally consist of a thin metallic sleeve coated with oxides of strontium and barium and heated indirectly by a pure tungsten filament which runs lengthwise through this sleeve. Typical heater type cathode constructions are shown at *E, F, G* and *H* in Fig. *11*. A quick heating tube, which is ready for use in ten seconds or less, is obtained when the filament is simply suspended in this sleeve in the manner shown at *E,* but if the tungsten wire sags as it becomes hot, the filament may touch this sleeve and cause a short circuit. To eliminate this trouble, the filament is often surrounded by a ceramic (porcelain tube) in the manner shown at *F;* this results in a slow heating tube, requiring thirty seconds or more before it is ready for operation.

Because the use of a single filament wire allowed the A. C. magnetic field to affect the space current and produce hum interference, it became common practice to use a hairpin-shaped filament like that shown at *G*, running the two wires through two longitudinal holes in the ceramic sleeve. A variation of this method, where the two filament wires are twisted around a support, sprayed with a thin coat of ceramic insulation and baked until the insulation is hard, is used on most of the heater type tubes made today. This type is shown at *H*; these heater filaments require only about ten to twenty seconds to attain full heat, and they have only a negligible hum interference effect.

Tubes having heater type filaments were originally designed especially for use on A.C. power, and are often called A.C. type tubes. The







Courtesy National Union Radio Corporation

FIG. 12A. Cut-away view showing construction of 6L5G glass tube with 6-prong octal base. Filament is of hairpin type, threaded through a ceramic sleeve inside the coated cathode.

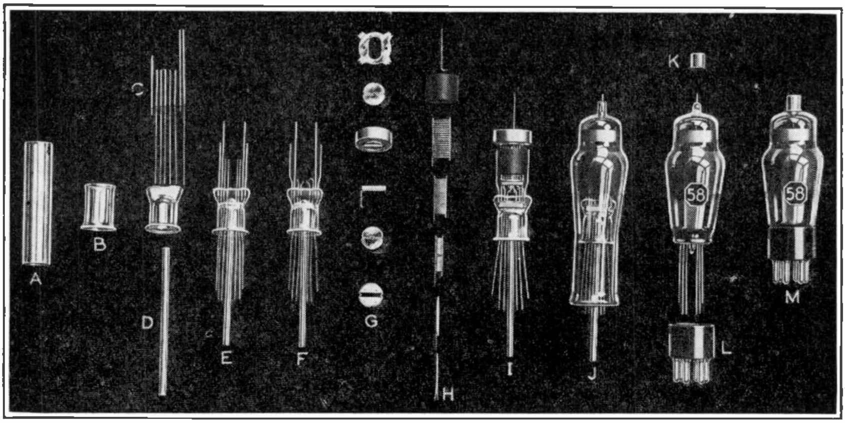
FIG. 12B. Cut-away view of 6D6 glass tube. Electrodes, starting from center, are: Twisted, ceramic sprayed heater wire, oxide-coated cathode, control grid, screen grid, suppressor grid, and cylindrical plate.

FIG. 12C. Cut-away view of type 84 glass tube, a full-wave rectifier which is constructed much like a dual triode except that the two cathodes connect to a common lead and the grids are shorted to their respective plates.

first A.C. tubes developed were of the 2½ volt type, requiring a filament current of from 1 to 2½ amperes, depending upon the design of the tube; the development of the automobile radio made necessary an indirect heater type tube having a higher filament voltage and lower filament current, and the 6.3 volt, .3 ampere tube came into use. The filament of this tube can be connected directly to the average 6-volt car battery; it is now widely used for both A.C. and D.C. receivers, and is almost entirely replacing the 2½ volt type tube in the latest sets.

Grid and Plate Construction. The actual construction and the positions of the grids and plates of radio tubes vary considerably with the purpose of the tube and with the different manufacturers. I suggest that you examine various glass tubes which you have at hand, in your own radio receiver or otherwise; in addition, study the diagrams in Figs. *10* and *12,* which show internal views of a few typical tubes. Grids and plates are usually made either of nickel, of molybdenum, a metal also known as "molly metal," or of Svea metal (pure Swedish iron), special care being taken to secure a rigid design.

The step-by-step assembly of a type 58 glass tube is shown in Fig. *13;* study this carefully, for the construction is typical of almost all glass tubes.



Courtesy RCA Manufacturing Co., Inc.

FIG. 13. This assembly photograph shows you how a typical glass tube (type 58) is made. Ends of glass tubing *A* are flared outward to give a shape like *B*. Copper clad wires *C*, which have same rate of expansion with changes of temperature as the glass used, and glass tubing *D* (to be used for evacuating the tube) are placed in the flared large tubing, held in position by accurate jigs (tools which hold wires and parts in their proper positions) and upper flare is heated and squeezed as at *E* to hold wires and glass tubing in position. Another machine bends the projecting wires to the shapes shown at *F*. Mica and metal spacers used in assembly of electrodes appear at *G;* electrodes themselves are at *H*, and are, starting from bottom: heater wire coiled over porcelain rod, coated cathode, innermost or control grid, grid No. 2 or screen grid, grid No. 3 or suppressor grid, plate (highly carbonized) and wire lead which goes from one of grids to top cap. These electrodes are assembled and either riveted or welded to projecting wires, as at *I*. Glass envelope is now slipped over electrode assembly as at *J*, top of envelope is fused around top cap wire and envelope is fused to glass stem by complicated automatic machinery. Tube is now ready to be evacuated; when this is completed, exhaust tube *D* is sealed off. The tube type number is placed on the envelope, top cap *K* is cemented over top cap lead and soldered, and bakelite base shown at *L* is cemented to bottom of envelope to give complete tube shown at *M*. Prongs of tube base are hollow, permitting wire leads to be slipped through, projecting ends clipped and drop of solder applied to tip of each prong.

Schematic Diagrams of Tubes. From a practical point of view, the schematic symbol or diagram of a tube is far more important than the details of its construction. Typical schematic diagrams of radio tubes are shown in Figs. *14A* to *14J*. Observe that in these drawings the filament is the lowest symbol; you can almost always identify the filament by looking for an inverted *V* such as is shown in Fig. *15*. Common symbols for the cathode, plate and grid are likewise shown in Fig. *15;* with these for reference you should have no difficulty in identifying each of the symbols in Fig. *14*. Tube *A* is clearly a filament type diode (two electrode tube); *B* is a heater type diode, for here the cathode is the electron-emitting electrode and the filament is not considered as an electrode; *C* is a filament type triode, having three elements; *D* is a heater type triode; tube *E* has two grids, the one closest to the plate being the screen grid, and is known as a heater type tetrode (four electrode tube); *F* is a heater type pentode. Instead of being designated by name, the grids are often numbered 1, 2, 3, etc., starting with the grid closest to the cathode, as shown at *E, F* and *G* in Fig. *14*.* In general, it is a better practice to number the grids than to call them control grids, screen grids, or suppressor grids, because in special applications of tubes these electrodes may have other uses than those which you specify.

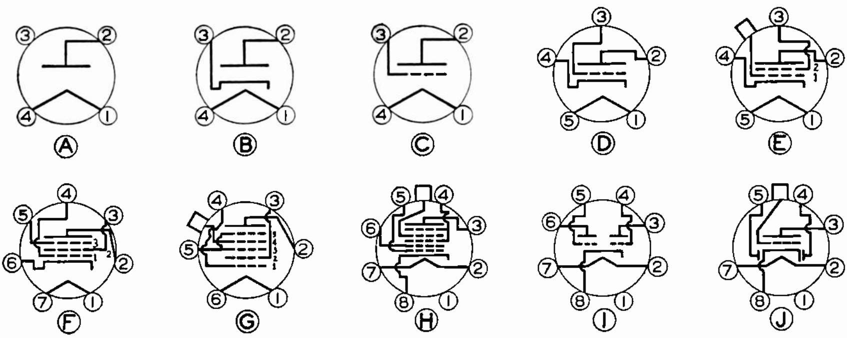


FIG. 14. Schematic diagrams of a number of modern glass and metal tubes are given here, inside the large circles; the small circles with numbers inside represent the R.M.A. numbers for the tube socket terminals, as they are when looking down on the top of the tube socket.

Tube *G* in Fig. *14* is a filament type pentagrid tube in which grids No. *3* and No. *5* are connected together internally (inside the tube); *H* is a heater type pentagrid tube having grids *3* and *5* tied together in the same way; *I* is a heater type twin triode in which a twin cathode is used for both triode sections and only one heater is used. *J* is a heater type duplex diode-triode tube in which the diode plates are connected to terminals *4* and *5*, while the triode plate connects to terminal *3*.

R.M.A. Prong Numbering System. The Radio Manufacturers Association (R.M.A.) have standardized the physical size of tube bases and the arrangement of prongs on the bases. Numbers have been assigned to each prong or pin; this numbering is shown in Fig. *14*, where the numbers are arranged as they would be if you were looking down upon the top of the socket.

* The grid numbering system is entirely different from the tube socket terminal or prong numbering system which will be considered later.

Tube Bases and Sockets. Unlike other devices used in radio and electronic apparatus, the radio tube is a delicate instrument having limited hours of service. Most manufacturers of radio tubes guarantee their products for one thousand hours; while tubes in general give much longer service than this, it is not impossible for a tube filament to burn out during the first week of its use. For these very practical reasons,

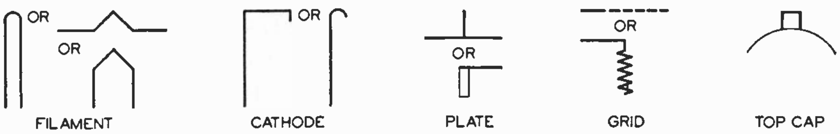


Fig. 15. Radio-Tricians generally use the schematic symbols shown here to represent the various electrodes in electronic tubes, but you will often find slight variations of these symbols used, especially on older schematic circuit diagrams.

tubes must be built in such a way that they can easily be removed for testing and replacement. Most radio receiving tubes are mounted in moulded bakelite bases having hollow *prongs* or *pins* which serve as the terminals of the tubes. The wire leads from the tube electrodes are

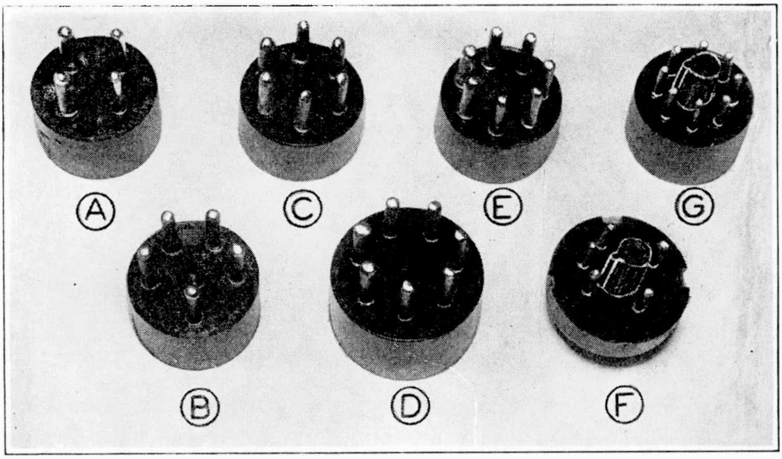
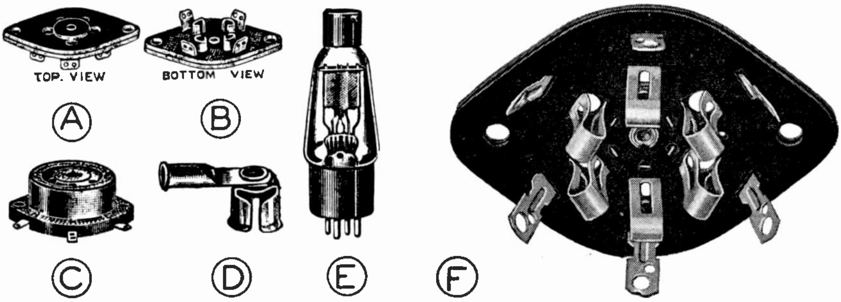


Fig. 16. Representative types of tube bases have been photographed here to show prong arrangements. *A*—standard 4-prong base; *B*—standard 5-prong base; *C*—standard 6-prong base; *D*—standard large 7-prong base; *E*—standard small 7-prong base; *F*—5-prong octal base on metal tube; *G*—8-prong octal base on glass tube.

brought out through the glass or metal envelope, threaded through the prongs and soldered at the prong tips. Standard tube bases can have either four, five, six, or seven prongs, as shown in Fig. *16*. The seven prong base comes in a small and a large size, while five, six, seven and eight prong bases are made in the "octal" type, a new kind of base which was first used on all-metal tubes and is now being used on a great many different types of glass tubes as well. A five-prong octal base on a metal tube and an eight-prong octal base on a glass tube are also shown in Fig. *16*.

The prongs of the older type glass tubes were spaced uniformly on their bases regardless of the number of prongs, so only tubes having the same number of prongs would fit in any one socket. Octal tube bases, on the other hand, require only one type of octal socket, even though they may have five, six, seven or eight prongs. Although all prongs in an octal base are of the same thickness, an aligning key in the center of the base fits into a corresponding hole in the socket and assures that the tube will always be inserted in its correct position. Where octal bases have less than eight prongs, the socket clips for the missing prongs are simply left unconnected. Omission of a prong in an octal base does not alter the positions of the remaining prongs; for example, in the octal base tube shown at *J* in Fig. *14* the prong which ordinarily would be numbered 6 is omitted, but this does not change the position of the other terminals (the numbered terminals in Fig. *14* have the same

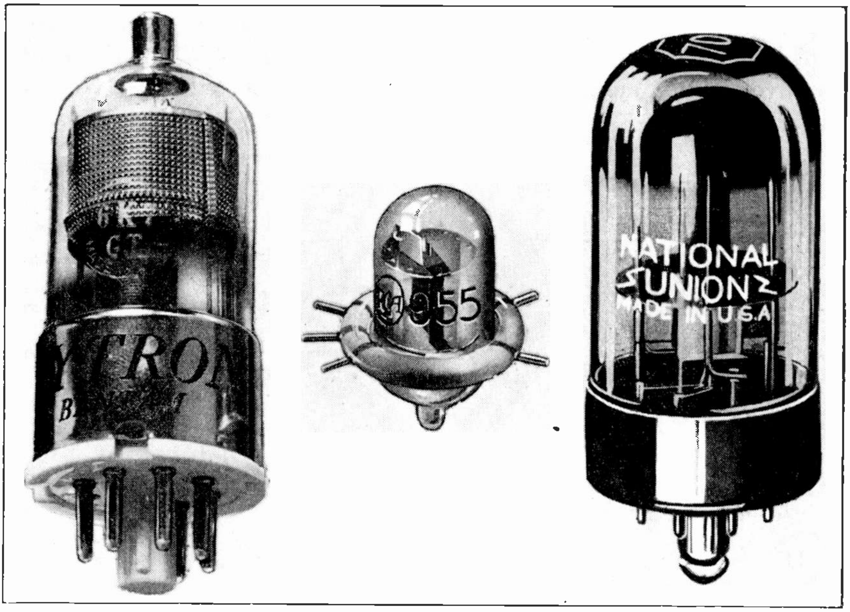


Interesting radio tube information: ***A*** **and** ***B*****—top and bottom views of a typical wafer type 4-prong socket used with glass tubes;** ***C*****—molded bakelite socket for glass tubes, designed for mounting either above or below the chassis;** ***D*****—top cap clip for metal tube; a similar but slightly larger clip is used for glass tubes.** ***E*****—an old tube, the first to appear with a filament designed for A.C. use; filament connections are made to the two side pins on the bakelite top cap. This tube is known either as the McCullough or the Kellogg tube.** ***F*****—Another form of wafer socket for glass tubes.**

relative positions as do the prongs of the corresponding tube bases). Octal tube bases and sockets are not interchangeable with the older type bases and sockets.

Locating Filament Prongs. In 4, 6, and 7-prong tube standard bases, those two prongs having the highest and lowest numbers are made larger than the others, to insure that the tube is always inserted in its socket in the correct position; for example, pins 1 and 4 of a 4-prong tube would be larger than the others; these thicker prongs are always connected to the filament. In the standard 5-prong tube, all pins are of the same diameter but are so arranged that there is only one way of inserting the tube; pins 1 and 5, the filament prongs, are always close together and directly opposite a single pin. The positions of the filament prongs in octal tubes varies with different tubes, so it is generally necessary to refer to a tube chart for accurate information.

Locating Prong No. 1. By remembering that the R.M.A. numbering system always progresses *counter-clockwise* when *looking down* on the top of the *tube socket,* you can locate any prong. You know how to find the filament prongs in standard base tubes; since one of these will be numbered *1* and the other will have the highest number for a given tube, that filament prong (on the top of the socket) which is in a counter-clockwise direction from the other filament prong will be *1.* In octal tubes, prong *1* is always in the counter-clockwise direction from the aligning slot as you look down on the octal tube socket.



Courtesy Hytron Corp., RCA Mfg. Co., Inc., and National Union Radio Corp.

Typical bantam tube (left), acorn tube (center) and loktal tube (right), all shown approximately actual size.

Top Cap Connection. Some tubes have an additional terminal in the form of a metal cap at the top of the glass or metal envelope, in addition to the prongs or pins. This cap is shown as a box outside of the tube circle in the schematic diagrams at *E, G, H* and *J* in Fig. *14.* Connections are made to this cap (usually called the *top cap*) by a top cap clip. A flexible wire lead connects this clip directly to some part in the chassis of the radio apparatus; the clip must naturally be removed before the tube can be removed from its socket.

Glass and Metal Tube Envelopes. Metal tubes are a comparatively recent development, and therefore embody the latest scientific and engineering practices; in this respect they are better than the older type of glass tube, but this does not mean that metal tubes are basically any different from tubes having glass envelopes.

Metal tubes do, however, have certain special advantages over glass tubes. The air can be more completely removed from a metal tube, because here it is possible to heat the envelope almost to a red heat in order to drive off any gases which may be lodged in the envelope or other elements of the tube. This would clearly be impossible in a glass tube, for glass melts at a fairly low temperature. Metal radiates heat far more readily than does glass; thus, although the outside of a metal tube becomes very hot at times, the internal parts are cooler than they would be if a glass envelope were used. The envelope of a metal tube serves as a very good shield, eliminating the need for the metal jackets which are sometimes used around glass tubes. Incidentally, this shield or envelope in a metal tube is nearly always connected to pin No. 1 on the base.

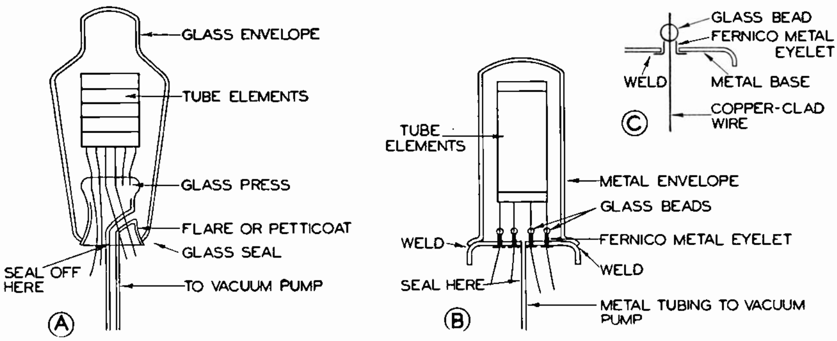
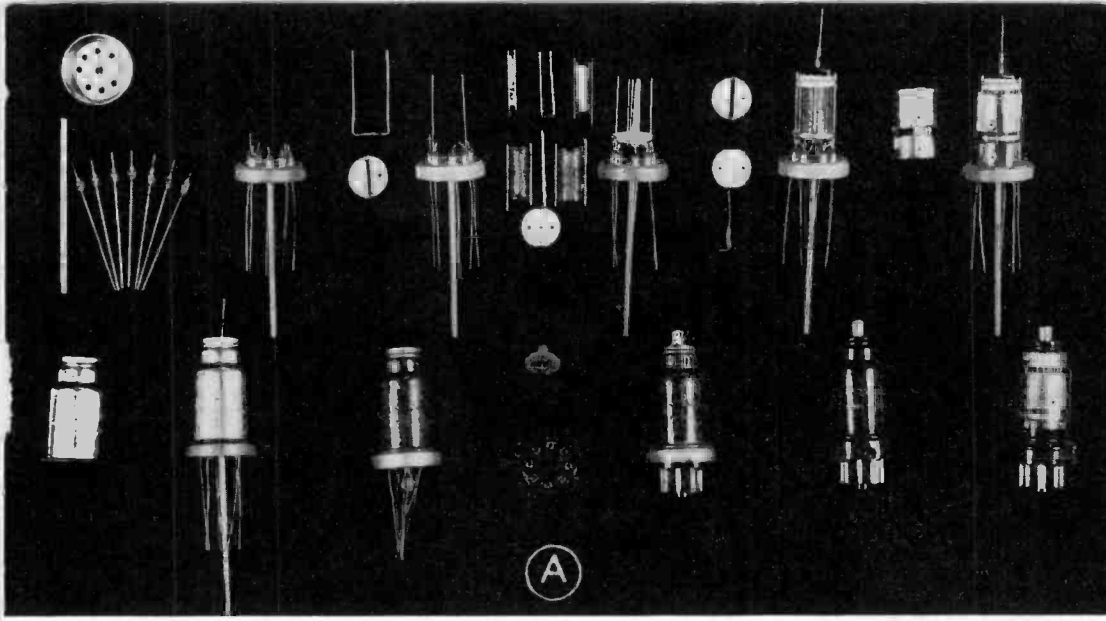


FIG. 17. **Important differences in envelope construction in glass and metal tubes are illustrated by these sketches.**

Differences in the construction of the envelopes for glass and metal tubes are shown at *A* and *B* in Fig. *17*, while the special Fernico metal seal which made possible the all-metal tube is shown in Fig. *17C*. The secret of making good glass tubes lies in using the proper metal in passing through the glass stem or press. This metal must have almost exactly the same rate of expansion and contraction with temperature as has glass, for otherwise the glass stem would crack and allow air to leak in. Special copper covered wires are used for this in radio tubes as well as in incandescent electric lamps.

Single-Ended Metal Tubes. Many of the metal tubes are now being made with the control grid lead going to one of the prongs in the base, giving what is known as a single-ended tube, because all connections are at one end. A special type of base construction is employed to shield the electrode leads and prongs from each other. Most of the tubes now used in television receivers are of the single-ended type. These tubes permit making all tube connections underneath the chassis,



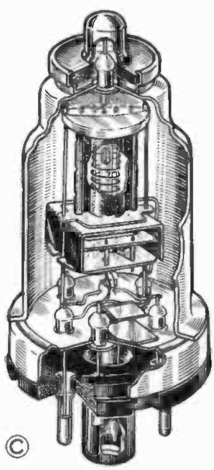
Courtesy Hygrade Sylvania Corp.

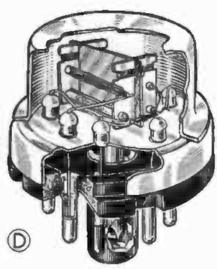
A (above). The assembly of a typical all-metal tube, the type 6A8 pentagrid converter, can be traced in the above photograph. Metal exhaust tubing and Fernico metal eyelets are welded to metal header shown at upper left, then glass beads with wire leads are threaded through eyelets and fused to them. Electrodes are welded to projecting leads, metal envelope is welded to header, tube is evacuated and sealed off, octal bakelite base and top cap are crimped into position and tube is sprayed, completing job. A completed tube with half of envelope cut away is also shown.

B (at right). This unusual drawing, giving a cut-away view of an all-metal tube, shows how connections are made to electrodes and how electrodes are mounted inside.

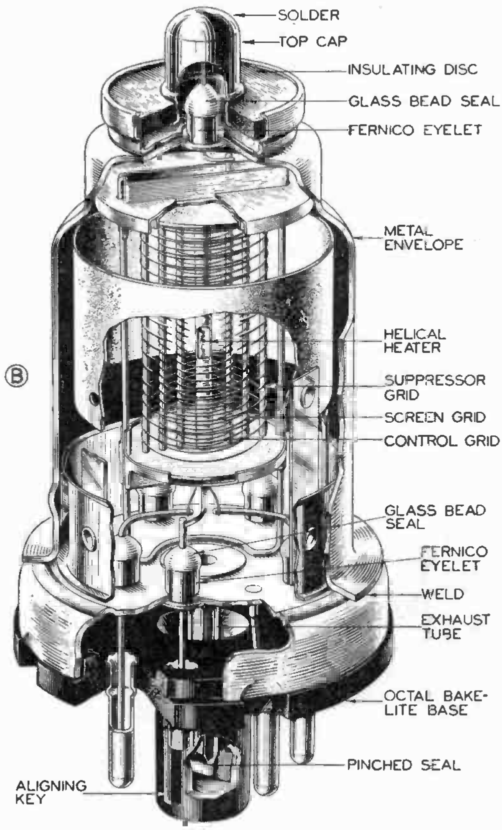
C (at left). Cut-away view showing arrangement of electrodes inside a 6Q7 all-metal duplex diode triode.

D (below). Cut-away view of 6H6 all-metal twin diode, a radio midget.





Courtesy National Union Radio Corp.



Courtesy R.C.A. Manufacturing Co., Inc.

simplifying the wiring and eliminating long leads through the chassis to tube top caps.

Loktal Tubes. Small-sized glass tubes with a special locking plug-type guide key are known as *loktal* tubes. These are all single-ended, and the prongs are sealed into the glass base plate on which the electrodes and the glass envelope are mounted. Around the glass base is a metal shell with a metal guide key having an indentation around the lower part which snaps into a ring in the special eight-prong socket required for these tubes. Loktal tubes are used principally in compact midget a.c.-d.c. receivers and auto radios.

Bantam Tubes. A number of octal-base glass tubes are available with a midget-sized glass envelope as well as with the standard size envelope. These bantam tubes have the letters GT following the tube type number, and are intended chiefly for use in compact table-model receivers where space is at a premium.

Acorn Tubes. Special vacuum tubes having leads projecting out through a glass ring and sometimes also through the glass cap are known as *acorn* tubes. These are hardly any larger than ordinary acorns, and are used chiefly in ultra-high-frequency transmitter and receiver circuits.

TUBE NUMBERS

Since it is clearly impractical for busy radio men to describe a certain tube completely when speaking of it, each tube has been assigned a number. In the early days of radio, when only a few different types of radio tubes existed, little confusion existed even though numbers were assigned to new tubes in haphazard fashion; tubes such as the 01A, 12, 26, 71A, 45, 56, 58 and 24 are examples. Notice that these numbers give no indication of the characteristics of the tubes. As the number of different types of radio tubes increased, it became increasingly more difficult to recognize all the tubes by their numbers alone, without referring to charts. The following code, which is now standard *for all new tubes*, was developed by the R.M.A. to eliminate this confusion.

R.M.A. TUBE NUMBERING CODE

Each tube designation shall consist of a number (or digit), followed by a letter, which is in turn followed by another digit.

(a) The first numeral (or group of numerals) shall indicate the filament voltage in steps of 1 volt, using figure 1 to mean any voltage below 2.1, 2 to mean 2.1 to 2.9 volts, 3 to mean 3.0 to 3.9 volts, 4 to mean 4.0 to 4.9 volts, 117 to mean 117.0 to 117.9 volts, etc.

(b) The last numeral shall designate the number of useful elements (filament, cathodes, grids, plates, etc.) which are connected by means of wire leads to prongs or the tube cap. The filament is here counted as one element, and the envelope or shield of a metal tube is considered as one element.

(c) **The letter between the numerals shall be a serial designation which will serve to distinguish tubes having the same number of useful elements and the same filament voltage. Rectifiers will start with Z and work backward through the alphabet, while all other tubes start with A and work up through V of the alphabet. When all 26 letters of the alphabet have been used for a given combination of first and last numbers, the next 26 new tubes with these numerals will have the letter A ahead of the serial designation letter; succeeding groups of 26 tubes will have B, C, D, etc. ahead of the serial designation letter. Examples: 6AB5; 6AF6G.**

(d) **The letter S ahead of the serial designation letter (following the first numerals) indicates a single-ended tube. Example: 6SK7. The letter G following the last numeral indicates an octal-base tube having a standard glass envelope instead of a metal envelope. Example: 6Q7G. The letters GT following the last numeral indicate an octal-base tube having a bantam (extra-small) glass envelope instead of a metal envelope. Example: 6Q7GT.**

TEST QUESTIONS

Be sure to number your Answer Sheet No. 8FR-3.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In what three ways can free electrons be forced out into space from metals and metallic compounds?
2. What two electrodes must *every* electronic tube have?
3. Will electrons flow through an electronic tube when the anode is negatively charged with respect to the hot cathode?
4. Name the three types of electron-emitting materials used for cathodes in modern electronic tubes.
5. In a two-electrode tube, what prevents a positively charged anode from attracting *all of the electrons* emitted by the cathode?
6. Why are small quantities of gas used in some electronic tubes?
7. What is the purpose of the grid which is placed between the cathode and the anode of an electronic tube?
8. When the grid of a triode tube has a very large negative C bias, will the plate current be *very large*, of *normal value*, or *practically zero?*
9. Is a tube having an indirectly heated cathode called a *heater type tube* or a *filament type tube?*
10. What does the first numeral (or group of numerals) in the R.M.A. Tube Numbering Code indicate?