COYNE Electrical School

CHICAGO ~~ ILLINOIS

ESTABLISHED 1899

RADIO

Elementary Principles
High Frequency Energy, Radio Waves
Modulation, Transmission and Reception
Antennas, Tuning, Receivers
Vacuum Tubes
Detectors, Amplifiers, and Oscillators
Principles, Characteristics, Applications
Receiver Circuits, R. F. and A. F. Amplifiers
Transformer, Resistance and Impedance Coupling
Regeneration, Neutrodynes, Superheterodynes
Power Amplification, Volume Control
A. C. Receivers, Power Supply Units
Eliminators, Phones, Speakers
Set Building and Wiring
Testing and Servicing

RADIO

While it is one of the newest branches of electrical work, radio has, during the past very few years, grown to such a tremendous size that it offers one of the greatest fields of intensely interesting and highly profitable work for the trained electrical man.

There are many millions of radio receivers of various types in use in homes in this country alone, and new ones are being made and sold at the rate of several million per year. The installation and servicing of these sets, as well as the repairing and remodeling of older types, creates splendid opportunities for practically trained radio service men, working for dealers, or operating a business of their own with an agency for some good set, and doing service and repair work for their customers.

A great number of trained men are also required for inspection, test, and research work in the factories where these sets are made.

Radio receivers are also becoming a very popular addition to the modern automobile and, within the next few years, there will be several million of these sets sold and installed, thus creating more jobs for the service man.

At this point we wish to emphasize that the field of radio service work is one of the most profitable branches of work that the trained radio man can take up, and offers more numerous opportunities in most any part of the country than do some other branches of radio.

There are also many splendid opportunities for radio operators in broadcasting stations, commercial land stations, aboard ships, on passenger aircraft, at airports, etc. These jobs provide very fascinating work and pay good salaries to properly trained men who operate, adjust, and service the transmitting equipment, and in some cases send code messages where radio telegraph is used.

Modern hotels and apartment buildings are very often equipped with elaborate radio service to all of the rooms, and require a vast system of wiring, outlets, controls, and amplifiers which must be installed and then maintained and serviced by properly trained radio men.

Public address systems with their powerful amplifiers and huge speakers are becoming very common and are extensively used in schools, auditoriums, theatres, and other public buildings, and at outdoor sports and exhibits.

Installing, operating, and servicing this equipment creates another profitable field for radio men.

Talking picture equipment in movie studios and in the thousands of theatres throughout the country also use radio amplifiers, microphones, speakers, etc., similar to radio equipment, and any man with a good knowledge of practical electricity and radio can easily understand and handle this equipment.

Then there is the much newer field of television, which is growing and developing at a tremendous rate, and creating an enormous demand for service men with a good knowledge of radio amplifiers and equipment, and a knowledge of the operating principles, care, and adjustment of television apparatus. This branch offers some of the most fascinating and profitable work in the radio field, and men who get a good understanding of this equipment and get started in this branch at the present time have open to them the same marvelous opportunities that men commencing in the radio field ten years ago had.

Keep well in mind that radio is not an altogether separate subject from electricity, but is merely another application of electricity to a different use, and in circuits using high frequency alternating current as well as direct current.

Your general knowledge of electricity and electrical equipment obtained this far in your course, and the study of this set combined with the careful study of the radio material covered in this section, and the shop practice you can obtain in the Radio Department, should qualify you very well for most any branch of radio work that you might care to undertake. In fact you will be much better qualified because of your general knowledge of electricity than anyone could be by taking only special radio training which did not include general ground work of the laws, principles, and applications of electricity.

It is not the purpose of this Section to cover a great deal of design theory or highly technical problems, but instead it will cover the general nature and principles of radio transmission and reception; and the operation, care, and servicing of radio receivers and amplifiers in particular.

In addition to the opportunities offered in employment by various radio manufacturers and dealers, shipping organizations, commercial land stations, broadcasting stations, aviation interests, theatres, etc., remember also that radio offers some of the finest opportunities for a man who wishes to build up a small business of his own, because it requires very little capital and equipment to start a radio service shop, and your general knowledge of electricity and radio should make you very capable in selling, installing, and servicing any ordinary type of radio equipment.

Many of our graduates are operating very profitable businesses of this kind, and many others are making good money in radio as a side line from their regular employment.

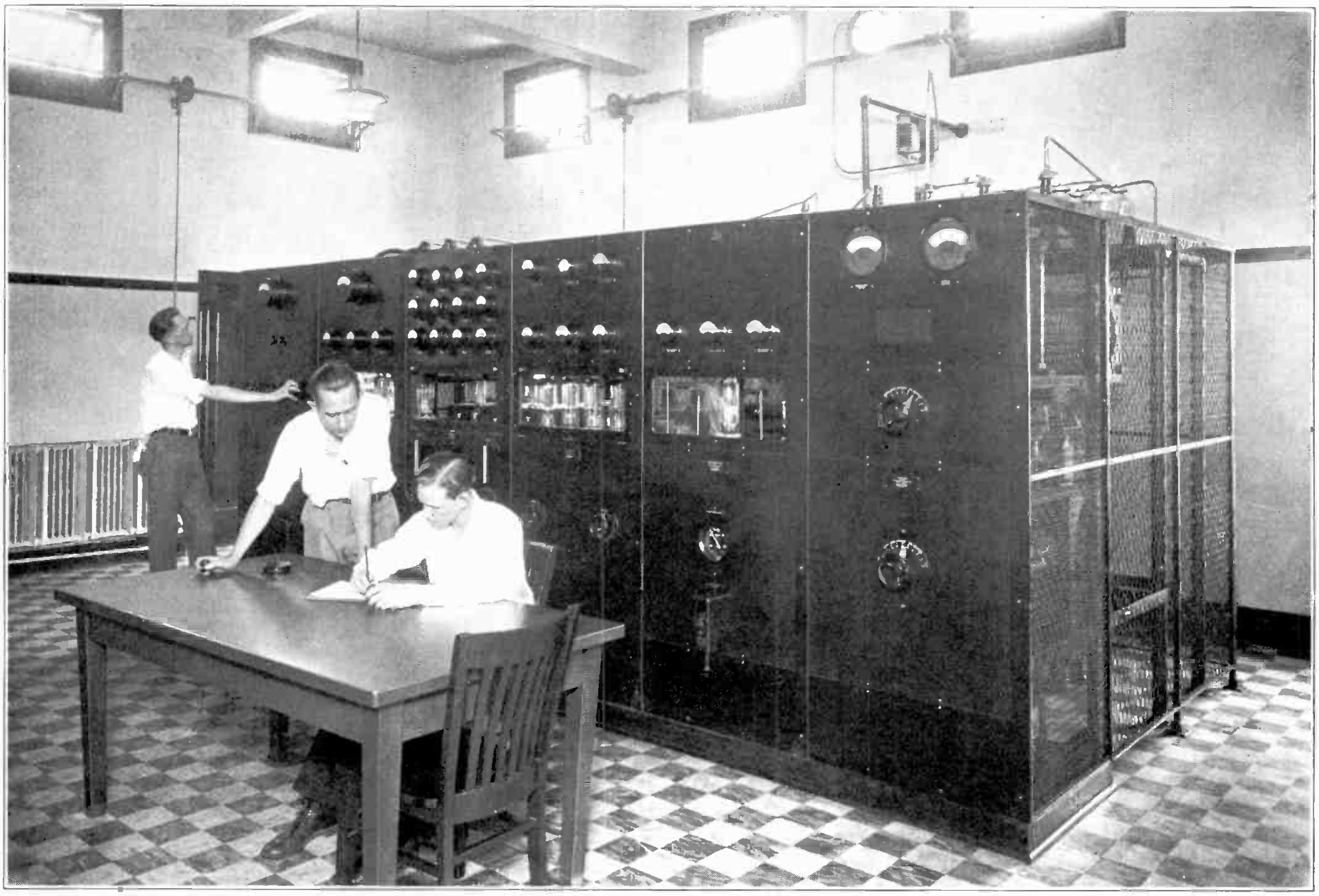


Fig. 1. This photo shows a large modern broadcast transmitter used to transmit popular programs of entertainment and educational material. (Photo courtesy of WMAQ—Daily News Station—Chicago.)

1. BRIEF HISTORY OF RADIO DEVELOPMENT

The term **Radio** is a rather new one, developed within the past ten or twelve years, and applies particularly to the general radiation or broadcasting of messages and radio entertainment and education, the word itself coming from the word **radiate.**

Before 1920 when radio broadcasting began to get its start the term **wireless** was used almost entirely with reference to such equipment.

The first known attempts at wireless communication were made by Professor Steinheil of Munich, Germany, in about 1837. Approximately thirty years later, between 1860 and 1870, a famous mathematician in England named Maxwell proved by theoretical analysis and calculations that wireless communication was possible, but Maxwell did not put his ideas into practical operation.

The next development along this line was made by Heinrich Hertz of Germany, who within a few more years discovered and established the various laws of electric wave transmission, or transmission of energy through the atmosphere without wires. The laws established by Hertz are still used and found dependable today, so Hertz is often called the founder or inventor of wireless.

Due to his early death, Hertz was unable to complete his work and put his discoveries into actual practice, but very shortly afterward Marconi successfully accomplished the first wireless communication, thus completing the work started by Hertz and also proving that such communications were possible over great distances. For this reason Marconi is also often called the father or inventor of wireless.

In early years wireless communication messages were sent from point to point by means of code signals, using the same general principles of transmission and reception as are used today, but with much cruder and more elementary types of equipment.

The first highly valuable use of wireless was to establish means of communication between ships and land stations, from one ship to another, and particularly for sending distress signals in case of a ship in trouble. This is still one of the very valuable and extensive uses of modern radio equipment.

The first transmission of wireless energy was accomplished by means of what was called a **Spark Transmitter.** These transmitters made use of a high-voltage spark or arc across a pair of adjustable electrodes, to set up high frequency current or oscillations in a local condenser and inductance coil circuit, and also in the aerial and ground circuit.

Fig. 2. Console type of radio receiver with automatic tuning feature. Thousands of these sets are in use in homes throughout the country. (Photo courtesy of Zenith Radio Corp.)

This high frequency energy in the aerial circuit sets up combined electro-static and electro-magnetic waves of energy which were transmitted a considerable distance through the air, of course becoming weaker and weaker as the distance from the transmitter is increased.

An ordinary telegraph key was used to interrupt or break up this energy into dots and dashes, or code signals. These signals were then picked up at a distance by another aerial and detected by means of a **coherer,** or device somewhat similar to the crystal detectors with which many of you are familiar.

The coherer consisted of a small tube of insulating material filled with small particles or filings of

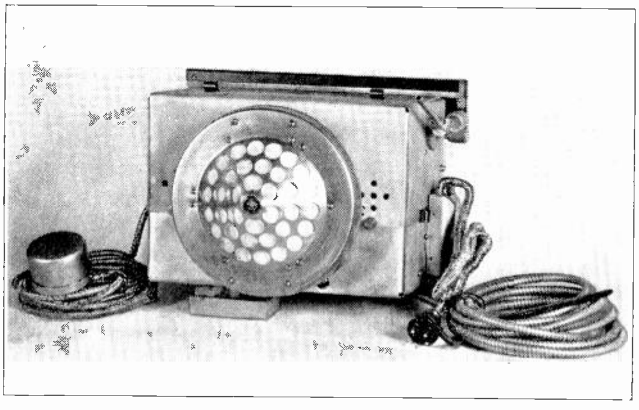


Fig. 3. Automobile radio with shielded conductors for preventing inductive interference from the car ignition system. Millions of automobiles will soon be equipped with radios of this or similar types. (Photo courtesy of American Bosch Magneto Corp.)

iron or magnetic material, which had a tendency to draw and cling together when current impulses were passed through them, thus increasing and decreasing the resistance of a local battery and headphone circuit in which they were connected.

In this manner the very feeble signals picked up by the aerial and applied to the coherer caused its resistance to vary and produce a sort of valve action, which set up current impulses from the local battery through the headphones, thus making audible signals. Fig. 7 shows a sketch of an early device of this type.

In this figure small metal plates "C" and "C1" are used for the radiating and collecting system instead of using aerials and grounds. A simple set up of this type will actually send enough energy through a space of 5 to 50 feet to operate a bell by means of a sensitive relay. Signals can be heard in headphones a much greater distance.

With this type of wireless transmitting and receiving equipment signals could be successfully transmitted and received only a very short distance.

A little later the **crystal detector** came into use and, being much more sensitive to feeble electric impulses, made possible the detection of signals over distances of quite a few miles.

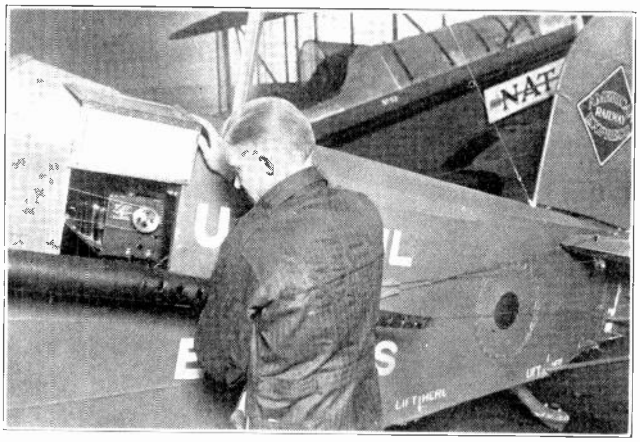


Fig. 4. This view shows a radio receiver installed in a mail plane, for use in receiving weather reports and instructions from ground stations. (Photo courtesy of National Air Transport Co.)

In the early part of this twentieth century came the invention of the **vacuum tube,** and its development and perfection made possible wireless telephony or voice transmission in addition to code signals. The vacuum tube also made possible broadcasting and reception of radio entertainment and education as we know it today.

It was not until about 1920 that this means of radio transmission and reception became popular for the purpose of entertainment, thus making a general demand for radio equipment in the homes throughout the country, and making much more efficient and popular the equipment used for sending commercial messages and radio telephone conversations.

2. WAVE FORM ENERGY

As radio signals are transmitted through space by energy in wave form, it is very important in beginning the study of radio to first obtain a general knowledge of wave form energy and how it is produced and transmitted.

Almost everyone has seen waves in water, set up by wind or by dropping some object into it. These waves represent traveling energy as can be observed from the way they will bob a small boat up and down, or even rock a large steamer. The small circular waves set up by dropping a stone in a pond, and which radiate outward in all directions from the source gradually dying out in the distance, are very illustrative of the nature of radio waves set up by a transmitting antenna.

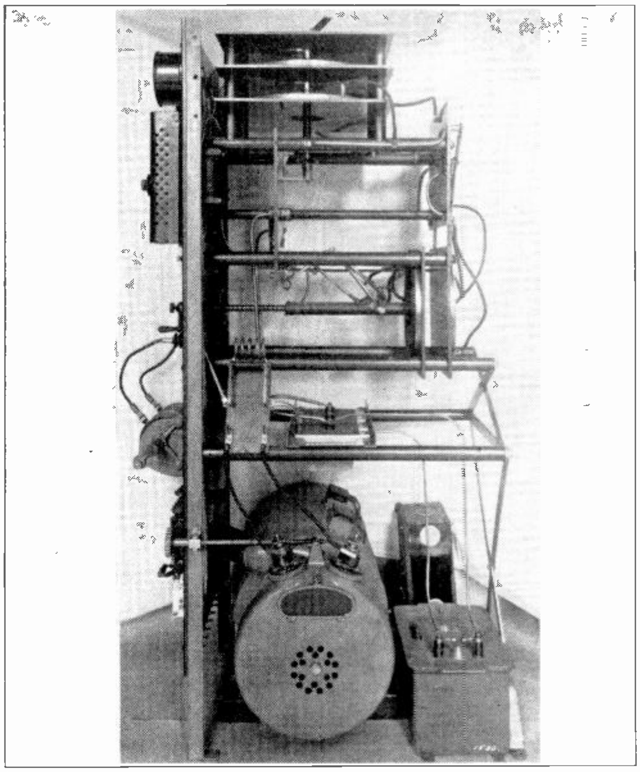


Fig. 5. Side view of a spark transmitter such as formerly used very extensively in ship radio installations. (Photo courtesy of Radiomarine Corp. of America.)

Let us next consider sound waves which although invisible are very common, and which you already know something about from explanations in an earlier section on telephones.

You will recall that sound is also energy in the form of air waves, and is created by anything that sets up vibration of the air. See Figures 108 and 109 in the Telephone Section.

Air waves or vibrations ranging between 16 and 15,000 per second create audible sounds, or sounds which can be heard by the average human ear. So all frequencies between 16 per second and 15,000 per second are called **Audio Frequencies.**

A very interesting and important fact to note about sound waves is the manner in which certain objects will vibrate in tune with them if their natural rate of vibration happens to be the same as the frequency of the sound waves.

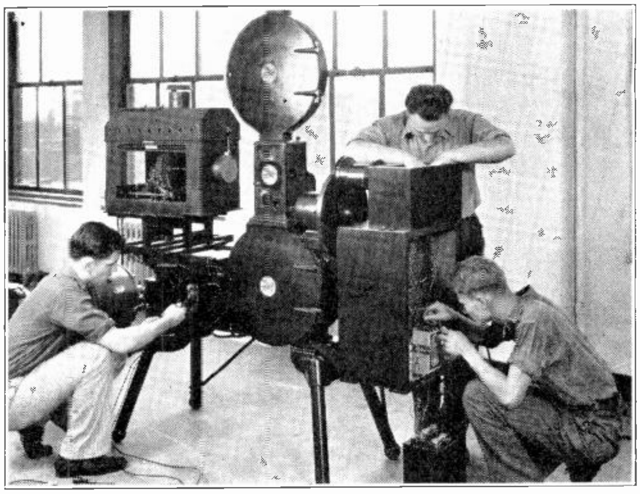


Fig. 6. Film scanning machine of a television transmitter. This machine makes possible the transmission of a talking picture which can be received in the home with radio and television receivers.

This can be readily demonstrated with a pair of tuning forks of the same pitch. Striking one fork will set up audible vibrations of the other one some distance away, by the energy radiated through the air.

This same thing is often noticed in connection with the strings of a piano or some other instrument, or even a tin pan, vibrating very noticeably when sounds of the proper pitch or frequency strike them. This principle of tuning is somewhat similar to the action of radio energy between the transmitting and receiving equipment.

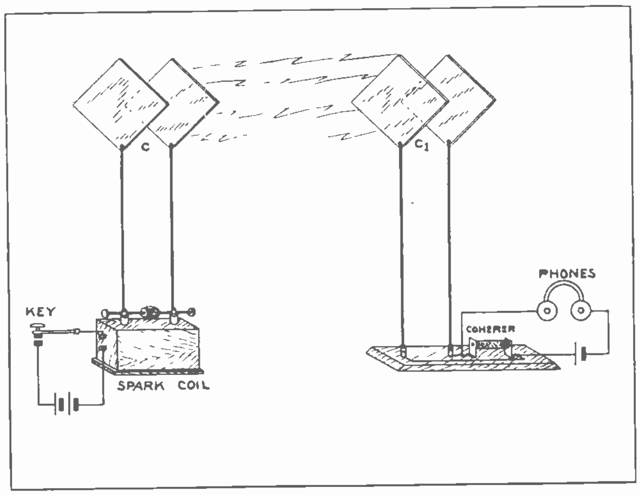


Fig. 7. Diagram of an elementary type radio transmitter. The spark coil on the left radiates from its antenna plates, energy that is received by the coherer and phones on the right.

Now if sound consists of air waves or vibrations, and will travel through the air, it is easy to see that air must be a conductor of sound.

Sound travels through air at a speed of about 1100 feet per second. Water will also conduct sound and various solids will carry sound more or less according to their nature.

At the rate sound travels through air we can readily see that it would be impractical for long distance communication, because of the time it would take the sound to travel any great distance.

The time required for a sound echo to return from a distant hill or building well illustrates this. You have probably also noticed the fact that thunder is often heard considerably later than the distant flash of lightning is seen, due to the fact that the sound travels so much slower than light.

3. RADIO ENERGY OR WAVES. NATURE AND SPEED

Radio energy instead of being in the form of air waves is supposed to consist of electro-magnetic and electro-static waves set up around conductors by the high frequency currents flowing in them. These radio waves are thrown off into space in all directions, and for great distances if the electrical energy used is sufficient. See Fig. 8 which roughly illustrates radio waves traveling from a transmitter antenna in all directions to be picked up by various receiver antennas.

Radio waves travel through all substances and all space, even where no air is present. So we find that air, which is the conductor of sound waves, is not the carrier of radio energy.

Radio waves are said to be set up in the **ether**, which exists in all space and materials.

Radio waves cannot be insulated by any known material, although they can be shielded or lead around certain spaces with metal shields. Large steel buildings often shield their interiors and certain spaces near them in this manner. Natural mineral deposits and hills often produce shielding effects on radio energy also.

Radio waves travel at a speed many thousands of times faster than sound waves—186,000 miles per second, or 300,000,000 meters per second, which is the same as the speed of light and electricity.

At this rate a radio signal will travel about 7 times around the earth in one second, or from New York to San Francisco in a time period so short it is usually not worth considering.

4. FREQUENCY AND WAVE LENGTH

Radio waves are much higher in frequency than sound or audio frequency waves. Frequencies above 16,000 cycles per second and up to many millions of cycles per second are known as **Radio Frequencies.** Above this range are the various light frequencies.

The radio waves used in ordinary broadcast work range from about 500,000 to 1,500,000 cycles per second.

Fig. 9 shows a comparison of the frequency of sound and radio waves, the upper curve representing a simple sound wave of 5,000 cycles per second, which is quite high frequency in the sound range; and the lower curve representing a constant radio wave of 100,000 cycles frequency, which is in the lower range of radio frequencies.

Radio waves are set up around transmitting antennas by passing through the antenna wires alternating current such as you are already familiar with, except of much higher frequency.

In addition to referring to radio waves by their frequency, they are also classified according to **wave length.**

The length of each wave produced by a cycle of the radio frequency current can be accurately measured or calculated.

Radio wave lengths are expressed in meters, and one meter is equal to 39.37 inches. The length of one wave can be measured either from the crest of one wave to the crest of the next of the same polarity as at A in Fig. 9, or from the start to the finish of a wave as at B in this same figure.

When the frequency of radio energy is known, the wave length can be easily calculated by dividing the distance in meters which the waves travel in one second, by the frequency or number of waves per second.

For each cycle of current applied to the transmitting aerial there will be one complete wave radiated from it.

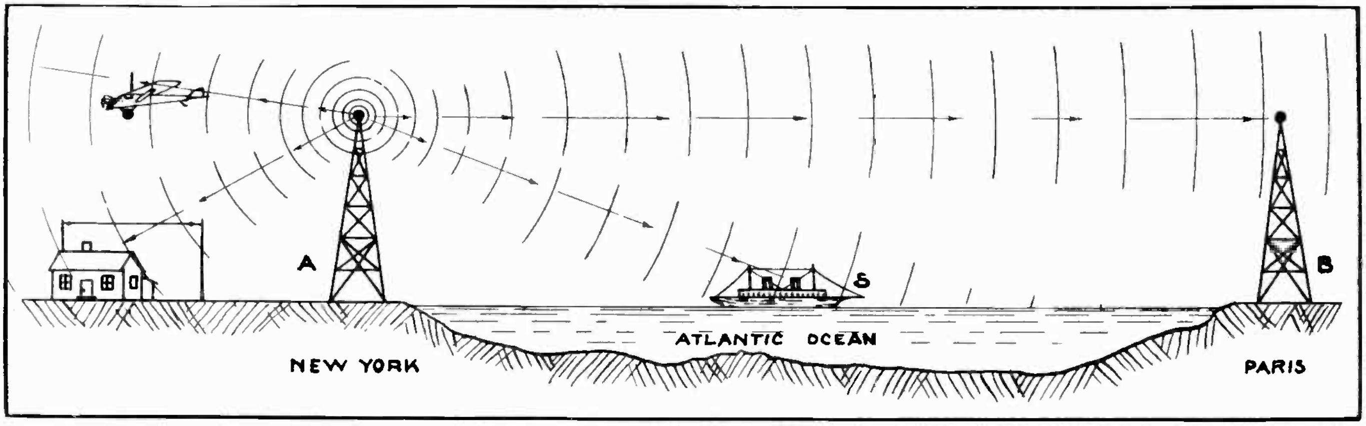


Fig. 8. Diagram illustrating the manner in which radio waves are thrown off in all directions from a transmitting antenna. These waves can be received by a number of different aerials at various distances from the transmitter as shown in the sketch.

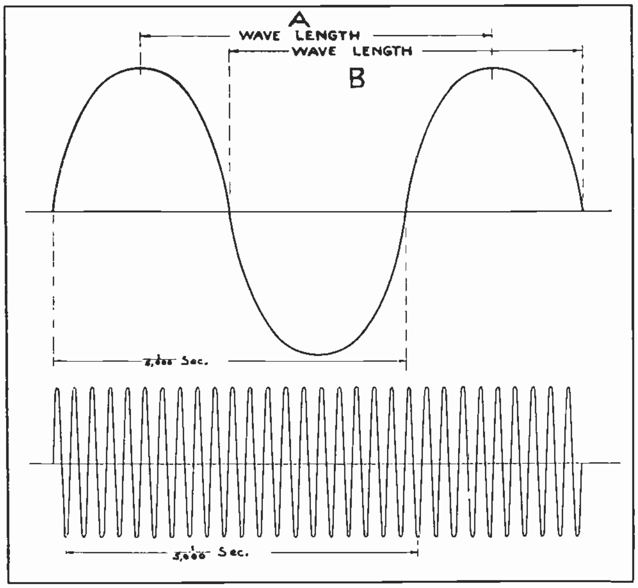


Fig. 9. The above two sets of curves roughly illustrate the difference between the frequency of sound waves and that of radio waves. The contrast between ordinary 60 cycle alternating current and the radio waves would be still greater.

Therefore

$$\text{Wave length in meters} = \frac{300{,}000{,}000}{f}$$

in which

300,000,000 = speed of wave travel in meters per second, f = frequency of current in cycles per second.

For example a station transmitting at a frequency of 1,000,000 cycles will have a wave length of

$$\frac{300{,}000{,}000}{1{,}000{,}000} \text{ or } 300 \text{ meters.}$$

Checking the ordinary broadcast frequencies of 500,000 to 1,500,000 cycles in this manner will show that they cover a wave band of 200 to 600 meters.

This formula can also be transposed and used to find the frequency of a station when the wave length is known, as follows:

$$f = \frac{300{,}000{,}000}{\text{wave length in meters}}$$

For example if a certain station is using a wave length of 400 meters, the frequency will be

$$f = \frac{300{,}000{,}000}{400}, \text{ or } 750{,}000 \text{ cycles or } 750 \text{ kilo-cycles.}$$

One kilo-cycle being 1,000 cycles.

5. SOURCES OF HIGH FREQUENCY ENERGY

We have mentioned that radio waves are set up at the transmitter aerial by the flow of high frequency current in the aerial circuit.

You are already familiar with the nature of alternating current from your study in your shop course and in earlier sections of this reference set. You will recall that alternating voltage is generated by A. C. generators or alternators at the common frequency of 60 cycles per second for power and lighting purposes. Also that this alternating voltage causes current to flow back and forth through the circuits, setting up a constantly changing and reversing magnetic field around the conductors.

Keep these simple facts well in mind as you study radio and remember that the currents used in radio transmission are simply alternating currents of much higher frequency.

While low frequency current in conductors sets up changing magnetic flux around them, and this flux will induce energy in other conductors or coils even several feet away, high frequency currents seem to throw off or radiate their magnetic and static energy much more efficiently, and much farther into the atmosphere.

Radio signals sent out with only a few kilowatts of this high frequency energy are often received on the opposite side of the earth.

Ordinary A. C. generators can not be used to produce radio frequency currents, because they cannot be practically designed with enough poles, or operated at high enough speeds to generate the very high frequencies required.

Radio frequency currents can be produced by means of **Special Oscillating Circuits** in spark or arc transmitters, by special design **Inductor Type Alternators**, or by **oscillating circuits using power vacuum tubes.** The last method is the one used in most modern code transmitters and in all broadcast stations.

6. SPARK TRANSMITTER PRINCIPLES

Spark transmitters are becoming obsolete because of their low efficiency and poor tuning characteristics, but the principles of the oscillating circuit used in these transmitters are both very interesting and valuable in getting an understanding of radio energy and circuits.

Fig. 10 shows the parts and circuits of a simple spark transmitter, and the method of producing high frequency radio energy with this equipment is as follows:

Ordinary low voltage, low frequency A. C. is supplied from a light or power circuit to the primary winding of the power transformer "A", which steps the voltage up to 15,000 volts or more. As this secondary voltage rises up toward maximum value during each alternation it charges the high voltage condenser "C" storing electrical energy in it. Let us assume the polarity to be as shown by the arrows and positive and negative signs for the alternation we are considering.

A quenched spark gap "S.G." consisting of a number of metal plates to form several small gaps in series, is connected in series with the condenser and the inductance coil "L", to complete a closed oscillating circuit.

If this spark gap is properly adjusted, when the voltage from the transformer secondary rises about to its maximum for an alternation, the gap will

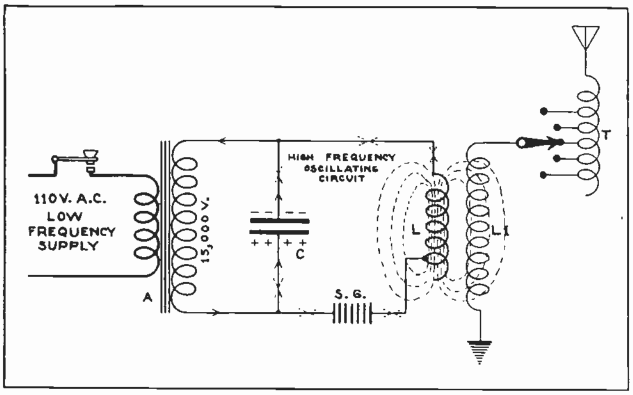


Fig. 10. Diagram of a simple spark transmitter showing the low frequency, oscillating, and antenna circuits.

break down or discharge. As soon as an arc or spark is formed at the gap its resistance is greatly reduced, allowing the condenser to discharge its energy with a rush, through the coil L and around to the negative side of the condenser.

During the condenser discharge the heavy current flowing through coil L builds up a strong magnetic field around it. When the condenser is discharged and its current dies out this flux collapses and induces a voltage in coil L that tends to keep the current flowing in the same direction, thus charging the condenser again with polarity opposite to what it was on the first charge.

As soon as the flux around coil L collapses and its induced voltage dies, and before the spark can completely die out at the gap the condenser discharges right back again in the opposite direction, and once more charges up from the magnetic energy stored in the coil during discharge.

This action continues at very high frequency, the current surging back and forth from several to a few dozen times for each primary charge the condenser is given at the peak of each low frequency alternation from the secondary of the power transformer.

Of course each succeeding oscillation is lower in voltage and power, due to the resistance losses in the closed oscillating circuit and in the spark gap, so with a certain adjustment the series of high frequency oscillations will just about die out by the time the condenser receives its next charge from the low frequency current.

The frequency of the oscillations set up in such a circuit depend principally on the inductance of coil L and the capacity of condenser C, and to some extent upon the resistance of the circuit. An increase of either the inductance or capacity reduces the frequency and increases the wave length.

The high frequency energy produced by such a spark transmitter is called **"Damped"** energy due to the "dying out" or **attenuation** of each series of oscillations.

Fig. 11-A shows a curve representing one train of oscillations produced in this manner. Fig. 11-B shows a curve of the oscillations set up by a circuit in which a quenched gap is used and so adjusted as to quench out or stop the spark sooner, without allowing the condenser to discharge down to such a low voltage.

If a key is used in the primary circuit of the transformer to make and break the circuit and thus cut up the current flow into dots and dashes, the oscillating circuit will produce short and long series of wave trains, as shown in Fig. 11-C.

As the flux around coil L in Fig. 10, builds up and collapses for each oscillation of current it of course cuts across the secondary L1 in the antenna circuit and induces voltage in this coil which causes current to flow in the antenna circuit and set up radio signals.

The adjustable coil T is the antenna tuning inductance for changing the wave length of the transmitter. This will be more fully explained later.

7. INDUCTION TYPE ALTERNATORS

The form of damped wave energy produced by a spark transmitter gives a rather broad or harsh sounding note to the signals received, because of the variations in value or **amplitude** of the oscillations in each wave train or group.

Special high frequency alternators of the inductor type previously mentioned, produce high frequency current of constant value as shown by the curve at "A" in Fig. 12.

Because this constant value energy is generated continuously by such an alternator when in operation, it is commonly called **continuous wave** or C. W. energy.

Continuous wave energy when used for radio telegraphy produces a much purer and clearer signal note than does the irregular or varying amplitude energy of a spark transmitter, and the C. W. is much sharper in its tuning.

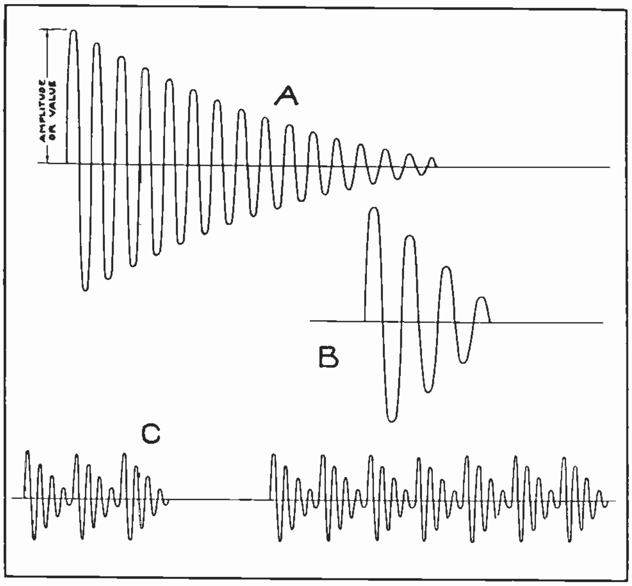


Fig. 11. Curves illustrating the nature of damped wave signals from a spark transmitter. Note how the oscillations die out at the end of each wave train.

The inductor type alternator is often called an Alexanderson alternator after the name of its inventor.

These machines can be made to produce alternating current with radio frequencies as high as 100,000 cycles per second. These waves are of course too high in frequency to produce an audible note or signal themselves, but if a rotary interrupter or "chopper" is used to break the high frequency circuit from 500 to 1,000 times per second, a clear musical note or signal will be produced. Fig. 12 "B" shows a curve representing the high frequency wave interrupted at audio frequency by the chopper.

If a key is then used to make and break the high frequency supply from the generator, these audio frequency groups of waves can then be sent out in the form of dots and dashes, as illustrated by the smaller curves at "C" in Fig. 12.

Another method of making the high frequency waves audible, without the use of a chopper, is to use a regenerative receiver which generates oscillations of its own, and which is tuned to heterodyne with the received waves and thus set up an audible beat note.

High frequency alternators are not used as a source of radio energy in modern radio stations on account of their high cost and difficulty of operation, but their principles are very interesting and valuable to know in connection with other radio equipment.

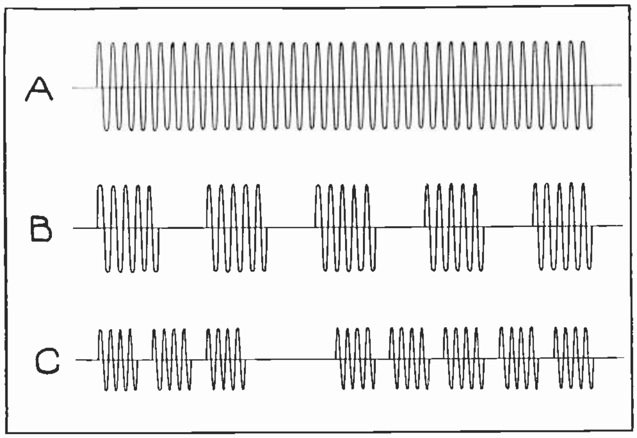


Fig. 12. Curves illustrating the nature of continuous wave (C W) and intermittent continuous wave (I C W) radio signals.

8. CONSTRUCTION AND OPERATING PRINCIPLES

Fig. 13 is a diagram showing the circuits and principles of one of these machines. The core "C" has two windings, one the field winding F, which is excited by D. C. and sets up a strong magnetic flux through the core and between the pole pieces P and P1; and the armature windings A and A1 in which the high frequency current is induced by increasing and decreasing the flux through the core.

A high speed rotor wheel or disk "R" carries a row of iron plugs or projections around its outer edge, and as the wheel rotates these iron plugs passing rapidly between the pole pieces cause the flux in the core to vary. When a piece of iron is between the pole pieces the magnetic reluctance of the core circuit is lower and the flux set up by coil F is much greater. When the iron piece passes out from between the poles the air gap is much greater and the flux is materially reduced.

This rapid change in the magnetic flux causes its lines to cut across the armature coils A and A1 and induce very high frequency A. C. voltage in them.

For example in one machine of this type the rotor carries 300 teeth or projections and revolves at 20,000 R. P. M., thus producing 300 × 20,000 or 6,000,000 cycles per minute; or 6,000,000 ÷ 60 = 100,000 cycles per second.

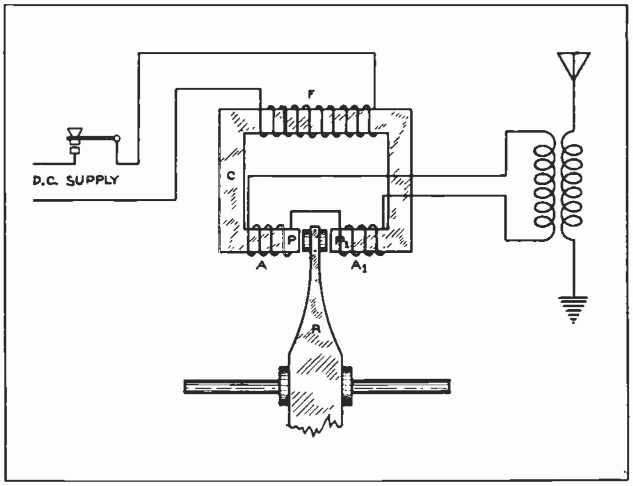


Fig. 13. Diagram illustrating the principles of a high frequency alternator for producing radio frequency energy in earlier types of transmitters.

The same results can be produced in these machines by using a steel disk rotor with slots or holes cut in is edge, to form teeth or sections of magnetic material alternating with non-magnetic spaces or sections. This construction is better than using the plugs or projections because it has less air friction or resistance at high speeds. The openings are generally filled in with brass or other non-magnetic material to make a smooth surface and further reduce air resistance.

The larger machines of this type have regular round stator frames in which both the armature and field coils are located, and as the rotor teeth pass by the coil slots the field flux is varied, thus inducing voltage in the stationary armature coils.

By making and breaking the field circuit and interrupting the excitation for a generator of this type, the high frequency output of the armature coils can be cut up into signals for radio telegraph messages. Or the C. W. output can be modulated by a telephone transmitter and voice, and this energy used for radio telephone transmission.

9. VACUUM TUBE OSCILLATORS

By far the most common method of producing pure continuous wave, high frequency energy for modern radio transmitters is by means of a vacuum tube used as an oscillator, or rather as a valve in a circuit in which it sets up oscillations.

Vacuum tube oscillator systems for radio transmitters are much more economical and efficient than the other sources of high frequency so far mentioned. They can be adjusted to produce almost any desired frequency, and they produce a pure continuous wave that is quite ideal for either radio telephone or telegraph use, and which can be very sharply tuned, thus minimizing interference and making it possible to cover great distances with comparatively small amounts of energy.

Vacuum tube oscillators use high voltage direct current from D. C. generators, rectifiers, or batteries, and convert it into high frequency A. C.

To understand how this is accomplished one must first observe the construction and operating principle of the tube itself. As vacuum tubes are not only used for oscillators but are also the heart of most all modern radio equipment, you should study very carefully the following general explanation of this device as an oscillator, and also the more detailed material which is given later on tubes for other uses.

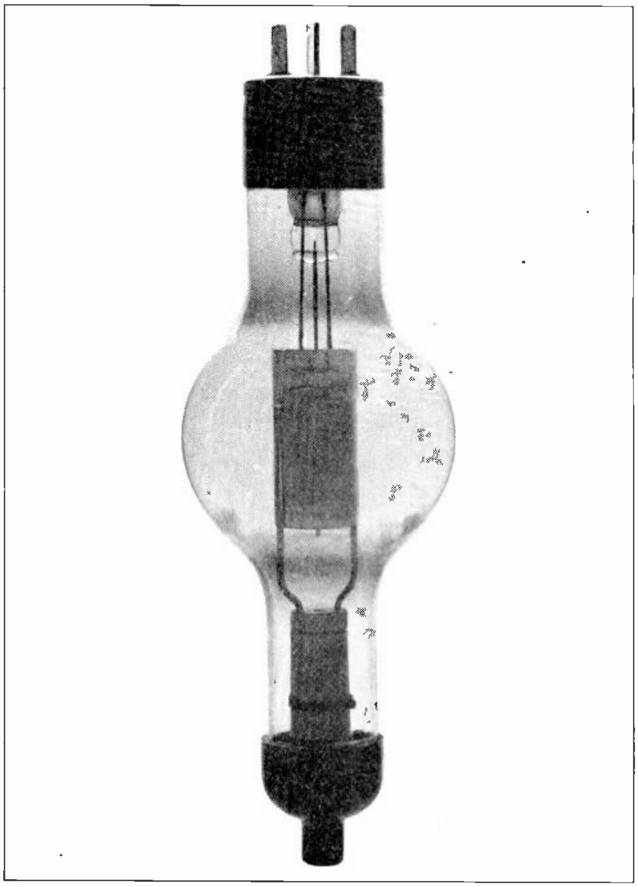


Fig. 14. Photo of a large vacuum tube such as commonly used in radio transmitters.

Almost everyone has seen ordinary vacuum tubes such as used in radio receivers, and knows that they consist of an evacuated glass bulb containing several internal parts or elements sealed inside, and provided with terminals or connecting prongs to the outside of the insulating base.

Many of these small tubes can be used as oscillators, but for radio transmitters larger tubes are generally used, as they will handle more power. Fig. 14 shows one type of power tube used in radio transmitters.

In the common three element tubes the internal parts or elements are the **Filament, Grid,** and **Plate.**

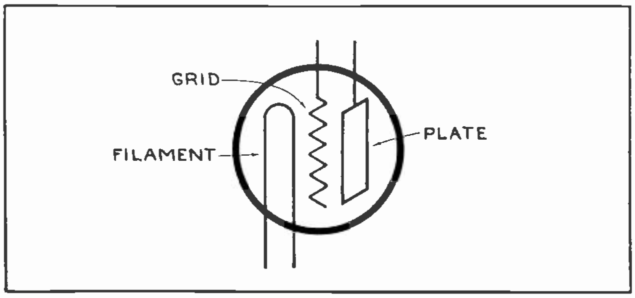


Fig. 15 Sketch of the symbol commonly used for representing a three element vacuum tube in radio diagrams.

Fig. 15 shows the common symbol used for representing a tube in circuit diagrams. On the left is the **filament** or electron emitting element, in the center is the **grid** or control element which acts as a shutter to regulate the flow of electrons, and on the right is the **plate** or anode which is supplied with voltage from a D. C. source. In Fig. 14 the metal plate can be seen in the center of the bulb with its terminal brought out of the metal cap or tip on the bottom of the tube. The plate is in the form of a slightly flattened or oval cylinder and the grid and filament are inside it. Their leads are brought out at the top of this tube.

We do not need to go into much detail in regard to the construction or characteristics of vacuum tubes at this point, to enable us to understand their use as oscillators or producers of radio frequency energy.

10. OPERATION

Fig. 16 shows a tube connected in a simple circuit with the necessary devices for setting up high frequency oscillations. By referring frequently to this sketch it will be easy for you to understand the following explanation of the action of the tube as a valve, and its function as an oscillator.

When the filament is heated by current from the low voltage battery "A", it throws off or emits **negative electrons** by the millions. These little electrons are strongly attracted by the plate which is charged positively by its connection to the positive terminal of the high voltage battery "B". This stream of electrons from the filament to the plate actually constitutes a flow of current according to the electron theory. But considering the more

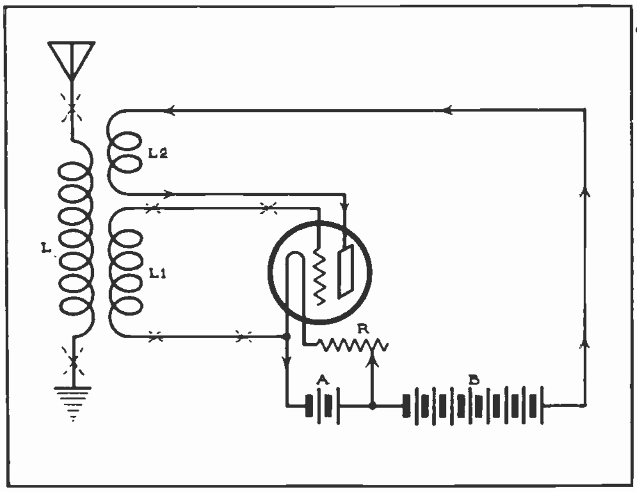


Fig. 16. Diagram of a simple vacuum tube oscillator circuit for producing radio frequency energy. Study this sketch carefully while reading the accompanying explanation.

common understanding of current flow, in a direction from the positive terminal of the battery or source, through the wires and back to the negative terminal, let us simply say that the electron stream completes the circuit by bridging the gap between the plate and filament.

Current then flows as shown by the solid arrows, from the "B" battery through the plate coil L2, to the plate, through the electron stream from plate to filament, and then back to the negative of the "B" battery.

As long as the filament is heated and emitting electrons some plate current will flow from the "B" battery, and **this current will vary directly with any change in the number of electrons passing between filament and plate,** the current increasing as the electrons are increased and decreasing as they are decreased. As long as there is no change of voltage on the grid the number of electrons does not change and this plate current remains at a certain normal value.

When the filament circuit is first closed and as the filament heats up and starts to emit electrons, the plate current starts to build up. As this current through coil L2 increases, the magnetic field set up by this coil expands and cuts across the grid coil L1, inducing a voltage in it.

If this grid coil is properly connected so that the lead attached to the grid becomes positive at this instant, this positive voltage applied to the grid causes it to attract more electrons from the filament, and thus increases the plate current to considerably more than normal. This current can only increase to a certain amount because of the limited amount of electrons which can be emitted by the filament.

When the plate current stops increasing the flux around coil L2 stops expanding and stops inducing voltage in the grid coil L1. This allows the grid potential to fall back to normal, so the grid attracts less electrons and allows the plate current to decrease.

As soon as the plate current starts to decrease the flux around coil L2 starts to collapse and cuts across coil L1 in the opposite direction to what it did at first. This induces voltage of opposite direction and charges the grid with negative polarity. So we see that alternating current is set up in the grid circuit as shown by the small dotted crosses.

As the grid becomes negative, it repels the negative electrons from the filament and decreases the number that reach the plate, thereby reducing the plate current still further.

The plate current of course cannot fall below zero value so when it finally stops decreasing the flux around coil L2 stops collapsing, and stops inducing voltage in the grid coil to make the grid negative, and this allows the grid to return to normal or zero potential.

As the grid becomes less negatively charged, the electrons from filament to plate once more start to increase and the plate current starts to build up again as previously explained.

This reversing action or cycle keeps on repeating, and as the pulsating current in coil L2 causes its flux to expand and collapse across L1, it induces alternating current in the grid circuit as shown by the small dotted crosses. It also does the same to the antenna coil L, thus setting up high frequency alternating current in the antenna circuit, as shown by the large dotted crosses.

The frequency of these oscillations depends on the inductance of the coils as this inductance determines the length of time required for the current and flux to build up to full value in each direction. As these coils usually consist of only a few turns and have no iron cores their inductance is low enough to allow very rapid oscillations, or frequencies, ranging up to millions of cycles per second in some cases.

A variable condenser can be connected across either the grid coil L1, or plate coil L2, and also used to vary the frequency of the oscillations as desired.

11. ARC TRANSMITTERS

Direct current arcs are also used to produce radio frequency energy in certain types of commercial transmitters.

Arc transmitters are supplied with direct current from a D. C. generator or rotary converter, and this current is used to maintain an arc between two electrodes, one of which is carbon and one copper.

These electrodes are mounted inside a chamber in which an atmosphere of hydrogen is maintained by vaporizing and decomposing alcohol which is allowed to drip into the heated chamber.

In some arc transmitters a powerful electromagnet or blow out coil is located near the electrodes to keep repeatedly and rapidly "blowing out" the arc. See Fig. 17-A.

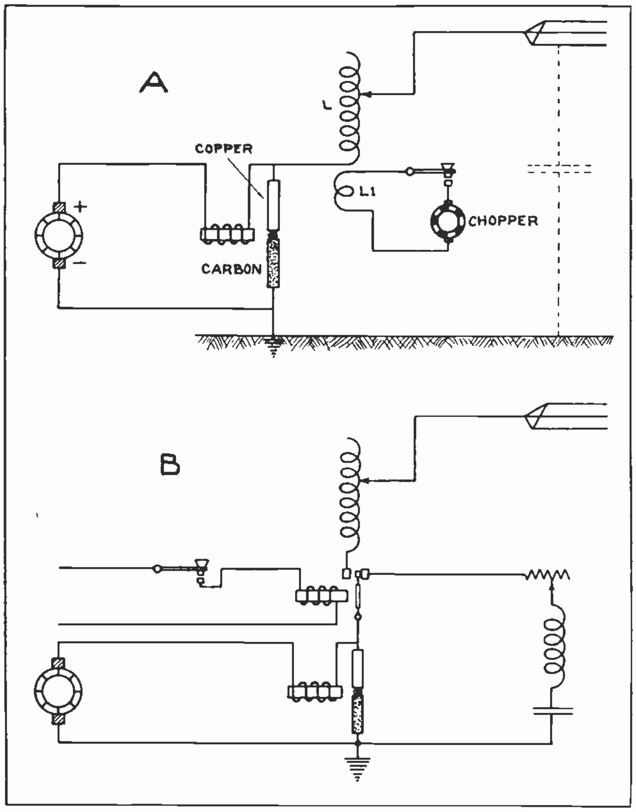


Fig. 17. Two simple sketches of arc type radio transmitters, using different methods of controlling the antenna current for code signalling.

As long as an arc of this type is operating in a circuit with inductance and capacity, it sets up continuous high frequency oscillations in the antenna circuit. This is due to an interchange of energy between the inductance and condenser varying the voltage at the arc, and the action is somewhat similar to that in spark transmitter circuits, except that with arcs the energy is undamped, or C. W.

In Fig. 17 the condenser effect is obtained from the capacity between the aerial and ground as shown by the dotted lines. This effect will be more fully explained later.

The antenna tuning coil L, serves both as an inductance to store magnetic energy for interchange with the condenser and thus set up oscillations, and also to adjust the frequency and wave length of the transmitter.

The high frequency waves emitted by an arc transmitter would not be audible at the receiver unless varied at audio frequency in some manner, or heterodyned by a regenerative receiver.

To provide an audible note a chopper is often used as shown in Fig. 17-A, to vary the frequency of the antenna current at regular audio frequency intervals. When the key is closed it allows the chopper to rapidly and repeatedly short circuit the little coil L1. Each time this coil is shorted, current is induced in it from the flux of coil L, and the reaction between the fields of these two coils then slightly changes the inductance of the antenna circuit and thus changes the frequency of the emitted wave.

Another method sometimes used is to leave the antenna circuit open normally, and only close it by means of a key or relay just during the signal intervals, as shown in Fig. 17-B.

During the periods the key is not closed and the antenna circuit is open, the oscillations from the arc are maintained through a shunt circuit consisting of a variable resistance, an inductance and a condenser, which are connected in series with each other and then across the arc as shown in Fig. 17-B.

12. SIGNALLING AND MODULATION

Now that we have learned the various methods of setting up radio frequency current or oscillations in various transmitters, let us find out how the signals are impressed on these high frequency **Carrier Waves,** and conveyed by them in leaving the transmitter.

We have already learned that the high frequency carrier wave necessary for radio transmission is not audible to the human ear, except in the case of spark transmitters where the damped wave trains have audio frequency variations in their amplitude. We have also learned that with C. W. or continuous wave radio energy, the carrier can be made audible for code signals by means of a chopper or by the beat note from a regenerative receiver.

Then for telegraph signals it is only necessary to send this signal energy out in proper code impulses or dots and dashes to form the various letters. This is done by means of a key placed in the circuit so that it will control the power to the antenna, either directly, or by means of a relay in the case of large transmitters.

In order to send voice or music however, it is necessary to impress the audio frequency sound waves on the radio frequency carrier waves, in such a manner that they will vary or control the volume or amplitude of the carrier wave directly with the volume and frequency variations of the sound. This is known as **Modulation** of the carrier wave, by the voice or music waves.

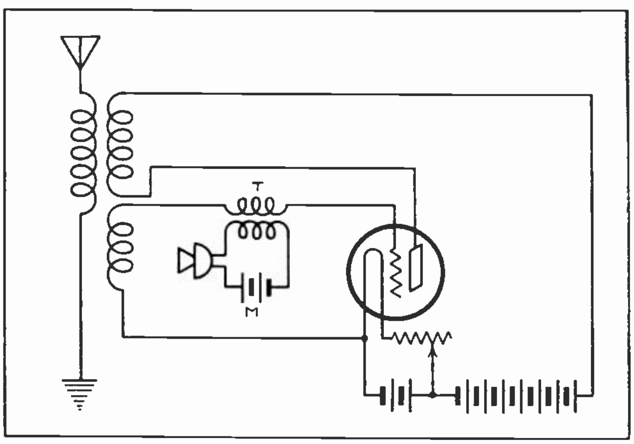


Fig. 18. Diagram showing how a telephone transmitter or microphone can be coupled to an oscillator circuit of a simple radio transmitter, to modulate the carrier wave with the audio frequency voice energy.

Modulation can be effected by coupling a telephone transmitter or microphone into the radio transmitter circuit so that it controls or varies the output of high frequency.

Fig. 18 shows a simple low power radio telephone transmitter circuit with one oscillator tube, and with a microphone coupled to the grid circuit by means of a **Microphone Coupling Transformer "T".**

The operation of a telephone transmitter or microphone has been explained thoroughly in this Reference Set, in an earlier section on telephones. It may be well for you to briefly review pages 2 to 5 of that section now.

You will recall that the microphone controls or varies the current from a battery, in impulses that correspond exactly in value and frequency to the sound waves striking the diaphragm

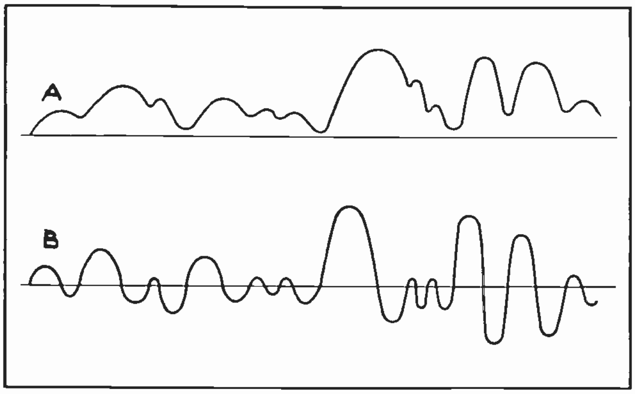


Fig. 19. The curve at A illustrates the nature of the pulsating current set up in the circuit of a microphone. At B is shown the curve for the alternating current of varying value which is induced in the secondary winding of a microphone coupling transformer.

In Fig. 18 you will note that the microphone is connected in series with a microphone battery "M", and the primary of the coupling transformer. Therefore, the pulsating current set up through this primary coil when voice or music waves strike the microphone diaphragm, induces alternating current of corresponding value and frequency in the secondary coil, which is connected in series with the grid circuit of the oscillator tube. Fig. 19-A and B show curves representing the pulsating D. C. of the microphone circuit, and the varying value A. C. which will be induced by them in the secondary of the coupling transformer. Now you will remember that any change in the grid voltage of a vacuum tube causes a corresponding change in the plate current. So as the microphone transformer supplies alternating voltage of varying value and frequency to the grid of this tube the plate current will vary accordingly. If the tube is already oscillating and delivering a radio frequency carrier current to the antenna, these audio frequency variations impressed on the radio frequency waves will cause them to vary in value: the variations being at audio frequency and corresponding to the original sound waves at the microphone. Fig. 20 shows a modulated carrier wave on which the value or amplitude of the high frequency waves has been varied by impressing the audio frequency energy upon it.

This modulated wave is what reaches the antenna and is sent out through space to reproduce voice and music at the distant receivers.

13. THE ANTENNA CIRCUIT

Now that we know the nature of the energy used in radio transmission and how it is produced, we will next want to know how this modulated wave or energy is radiated or thrown out into space from the transmitter.

You probably know of course that this is done with an **Aerial** or **Antenna,** but you may have wondered how current can flow in the antenna as it is not a complete metallic circuit.

When high frequency alternating voltage supplied by the transmitter is applied to the antenna circuit, either by direct connection or by induction to the antenna coil, current does actually flow due to the condenser or capacity effect between the antenna and ground. This current is measurable with special high frequency ammeters of the hot wire or other types. In large high power transmitting stations the antenna current may be over 100 amperes.

From explanations given of condensers in earlier sections you already know that a condenser consists of two or more conductors or conducting surfaces or plates, separated by insulation of some kind.

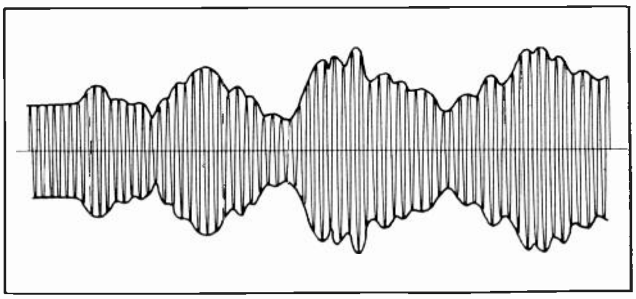


Fig. 20. Curve showing a high frequency carrier wave modulated or varied in value by the audio frequency voice waves.

Transmitting aerials for medium or long wave stations usually consist of one or more long wires, supported horizontally or parallel to the earth's surface. If several parallel wires are used, they are all connected together to form a network. These wires are attached to their supporting poles or towers by high voltage insulators, and are further insulated from the earth by the air between the aerial and the ground.

This construction forms a simple condenser as shown in Fig. 21. The dotted lines simply show that the aerial acts as one plate, the earth as the other, and the air as the dielectric of the condenser.

14. CURRENT FLOW IN ANTENNAS

You have already learned that when D. C. voltage is applied to a condenser it will charge the condenser with one plate or group of plates positive, and the other plate or group negative. We also

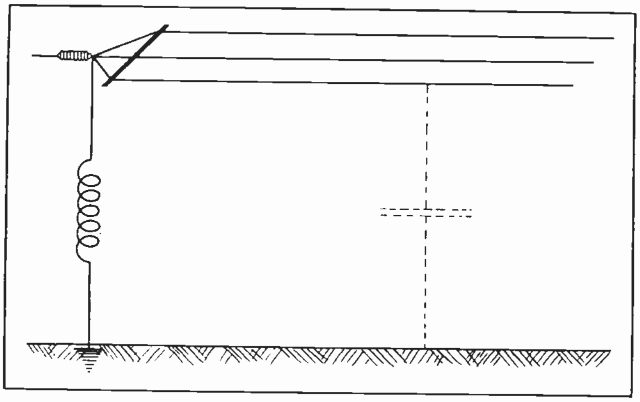


Fig. 21. Sketch showing the antenna circuit of a radio transmitter, completed by capacity to earth.

know that while the condenser is being charged current flows into it, even though it does not pass through the condenser dielectric.

Then when the applied voltage is removed and the condenser shorted or merely left connected in a closed circuit, it will discharge and cause current to flow out of it in the opposite direction to that of the charging current.

A condenser can be charged in either direction by simply reversing the polarity of the applied voltage.

We have also learned that if alternating voltage is applied to a condenser by connecting it in an A. C. circuit, alternating current will flow in the condenser leads as the condenser charges and discharges with the rise and fall of the applied voltage during each alternation. See Fig. 22. **The amount of charging current that will flow to a condenser depends directly upon the voltage and frequency of**

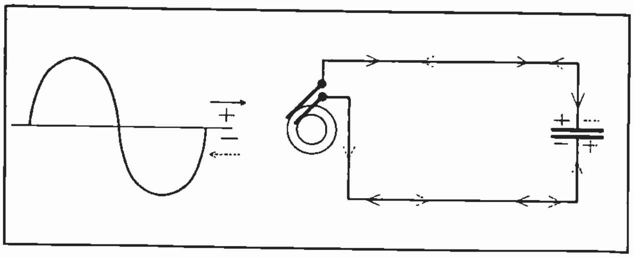


Fig. 22. On the left is shown a curve for one cycle of alternating current. On the right is shown the manner in which the alternations charge a condenser and set up current flow in its circuit.

the A. C. energy applied, as well as upon the size or capacity of the condenser.

As radio transmitters supply extremely high frequency to the antenna circuit, and usually at several thousand volts potential, considerable current will flow, even though the actual capacity between the aerial and ground may not be very great in micro-farads.

As the high voltage, high frequency current flows in the antenna of a transmitter each cycle sets up a complete electro magnetic wave, and also a complete electrostatic wave around the antenna.

These waves travel through space, earth and other objects with the speed of light, and when they strike or cut across a receiving aerial they induce very feeble voltages in it.

Transmitting aerials are not always horizontal, some being merely a vertical wire. There is sufficient capacity between a long vertical wire and the earth, however, to allow current to flow in such antenna circuits. Fig. 23 shows an illustration of electro-static waves leaving a vertical antenna. The magnetic waves are not shown in this sketch.

It is very important that transmitting antenna circuits, including their ground connections be of low resistance, in order to avoid resistance losses as much as possible. Due to the skin effect or tendency of high frequency currents to follow close to the outer surface of a conductor, rather large conductors are often used in transmitting antennas.

15. TUNING AND RESONANCE

We have already learned that a variable inductance or condenser can be used to change the frequency or oscillation period of a transmitter oscillating circuit.

The same is true of the antenna circuit and as the length of this circuit, including the antenna, lead in wire, and ground lead, determines the amount of inductance and capacity of the circuit, it should be made of the proper length for the wave length of the station.

In addition to making this circuit the proper length, variable inductance coils and variable condensers are used to tune the antenna circuit to the frequency of the energy produced by the transmitter.

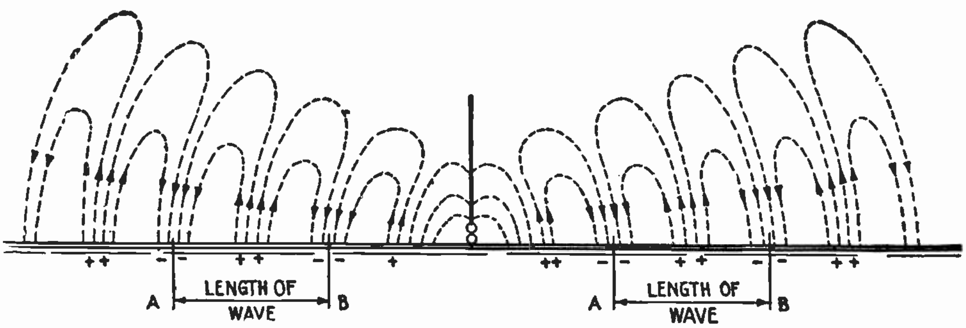


Fig. 23. This diagram shows the manner in which electro-static waves are assumed to radiate in all directions from a vertical radio transmitting aerial.

When the open antenna circuit is adjusted to the same natural frequency as that of the closed oscillating circuit of the transmitter, the two are said to be in **resonance** with each other.

Proper tuning of the antenna circuit enables maximum current to flow and produces best results and efficiency with a transmitter.

Tuning of radio transmitters has another very great advantage, in that it makes possible the sending of signals at one certain wave length, which can be received by receivers that are also tuned to that wave length, without interfering with other stations that are operating on different wave lengths. This makes possible the operation of many transmitting stations at the same time without confusion, and also makes possible the selection of the desired station by the receiver. More about tuning and tuning devices will be given later.

16. TYPES OF ANTENNAS

As already explained, a radio **Antenna** or aerial consists of one or more elevated wires, connected to the radio transmitter or receiver by means of a **lead-in wire**, running from the near end of the antenna to the equipment. And as previously mentioned, a ground lead and connection is practically always included as part of the antenna circuit.

Antennas are generally made of bare copper or bronze wires, as these have good conductivity, and the bronze wires also have good strength.

Insulated wires are often used for receiving antennas, as the insulation does not stop the passage of the radio waves which cut across the wire to induce energy in them.

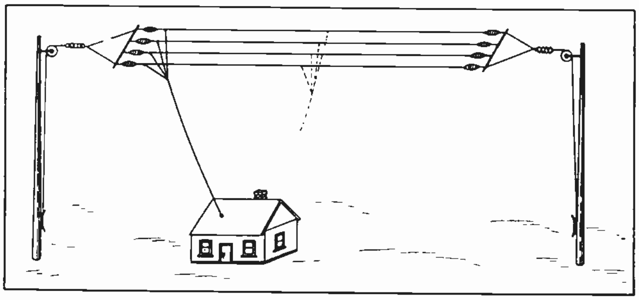


Fig. 24. The above sketch shows a flat top, L type antenna. The dotted lines show where the lead-in would be connected for a T type antenna.

All antennas and lead-in wires should however, be well insulated from their supports, from any adjacent objects, and from ground. This is particularly important with transmitting antennas which are often supplied with very high voltage, sometimes ranging as high as 5,000 to 10,000 volts in large high-powered broadcast or commercial land stations.

Glass, porcelain and composition insulators of suspension, pillar, and bushing types, are used for insulating antennas and lead-in wires.

There are several common types of antennas in use for radio transmission. Some of these are the **Vertical Wire** or **Hertz Antenna,** the **Flat Top Inverted "L" type, "T" type, Cage type, Fan type** and **Umbrella type.** Each of these types has certain advantages for various uses. The **Verticle Wire Antenna** is one of the simplest of all, and consists merely of a straight vertical wire suspended from some support or wire overhead and from which it is insulated, or in some cases supported on the side of a vertical wood pole or mast. Antennas of this type are mostly used in short wave transmission.

The **Flat Top Inverted L Antenna** is one of the most commonly used both on land and ship stations, because it is both efficient and convenient to install. Fig. 24 shows an antenna of this type, supported between two tall masts, above the transmitter building.

These antennas generally consist of from two to four parallel wires spaced about 2 to 3 feet apart, and attached by means of insulators to spreaders at each end. The spreaders are also often insulated again from the supporting cable used to draw the antenna up and hold it in place.

The ends of the parallel wires are all fastened together as shown and connected to the lead-in cable, which should be of the same carrying capacity or area as all of the antenna wires.

With the lead-in wire attached to the end of such an antenna, it is called an inverted L, from its shape or appearance. If the lead-in wire is attached to the center of the flat top section as shown by the dotted lines in Fig. 24, the antenna is then called a "T" type. Flat top antennas of this type are often fitted with tie ropes attached to the ends of the spreaders by means of insulators, and fastened down to the pole or tower, to help prevent the antenna from swaying in the wind. Very much swaying is objectionable as it tends to change the wave length of the antenna, as it moves nearer to or farther from the ground, thus changing its capacity.

Inverted L antennas are particularly convenient for use on ships, and are also commonly used on broadcast stations and commercial land stations.

These antennas are somewhat **directional,** that is, they transmit or receive over a greater range in a direction opposite to that in which their free ends point.

In some cases just one large cable is used as an inverted "L" type aerial with quite good results.

The T type antenna usually has a slightly lower wave length than an L type of the same dimensions, because the T type is in effect the same as two shorter antennas connected in parallel. Therefore, the capacity remains about the same but the inductance is somewhat less than that of L type antennas.

Fig. 25 shows a **Cage type** antenna which is sometimes used for transmitting stations. These antennas consist of a number of parallel wires held in the form of a tube or cage by hoop-like spacers of micarta or other insulating material. The wires are all brought together at one end of the horizontal cage, and then often continued down in the form of a much smaller cage for the lead-in.

Cage antennas are very simple to construct and are not so much effected by wind as flat top antennas are.

The top view in Fig. 26 shows a **Fan Type** antenna in which a number of wires are suspended from the horizontal wire between two masts or towers. The bottom ends of all these wires are brought together to the lead-in wire or cable. Antennas of this type are quite efficient and are used in certain localities.

The lower view in Fig. 26 shows an **Umbrella Type** antenna, consisting of a number of wires spread out like spokes of a wheel around one center mast. The tops of these wires are all connected together to the lead-in wire, and their top and bottom ends are insulated from the mast and earth. The lower insulators are generally located some distance up from the ground to give the antenna the proper effective height from earth. Antennas of this type are well adapted to military use and for other portable or temporary transmitters, as only one center pole is needed and it is held erect by the antenna wires themselves acting as guys.

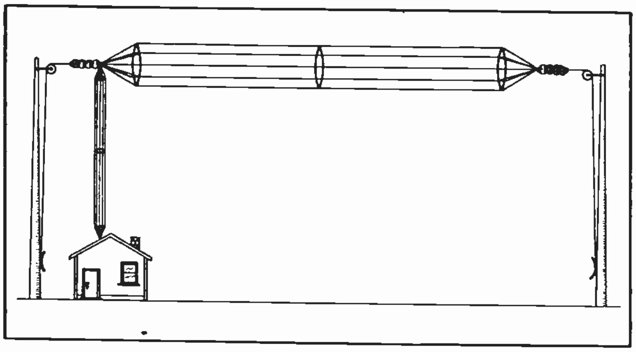


Fig. 25. This diagram shows the construction of a cage type antenna with a cage lead-in.

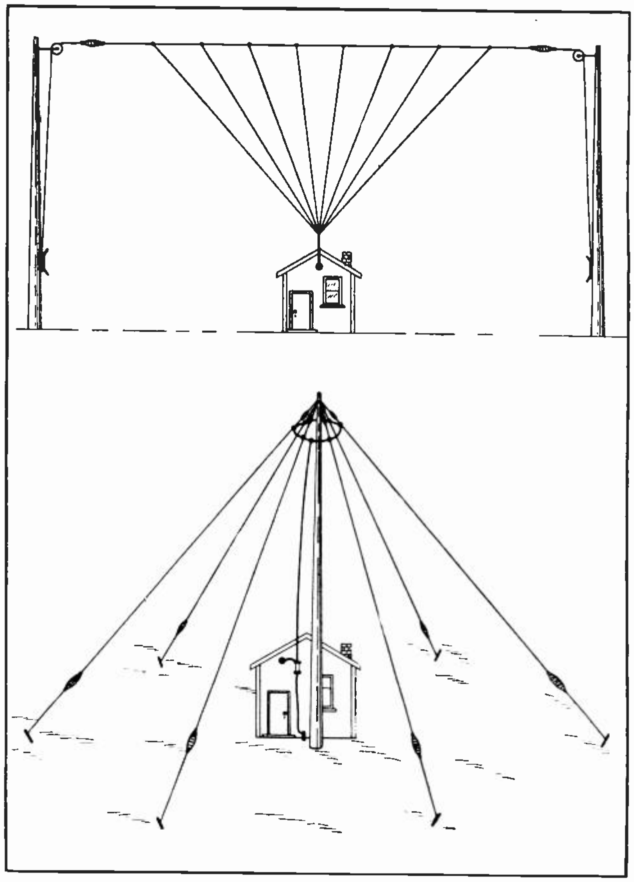


Fig. 26. The sketch at the top shows a fan type antenna and the lower sketch shows an antenna of the umbrella type.

17. ANTENNA HEIGHT AND LENGTH

In general the greater the height of a transmitting antenna, the greater its radiating efficiency or range, and they should always be high enough to be well above any nearby trees, buildings, hills, etc., if possible.

It is not practical to build them too high, however, as their supports will then cost too much, and the capacity between the antenna and its supports becomes too great on the extremely high ones.

The length of an antenna depends upon the wave length of the energy it is to handle, and upon the conditions or location. The length should be chosen so that the antenna will have a natural or fundamental wave length as near as possible to that of the transmitted energy.

When it is not possible to use an antenna of the proper length it can be "loaded" with extra inductance in the form of a coil, to increase its natural wave length; or it may have a condenser connected in it to decrease the wave length.

The natural or fundamental wave length of an antenna can be calculated by means of the following formula, if the capacity and inductance are known

$4 \times V \times L \times C =$ wave length in meters

in which

V = velocity of radio waves in meters per second
L = Antenna inductance in Henry's
C = " capacity in Farads.

A simpler method of calculating the approximate wave length is as follows: for a 4 wire flat top L antenna with, wires spaced about 2½ feet apart, multiply the entire length in feet, including the lead-in, by about 4.5. For "T" type antennas multiply the length of one end of the flat top and the lead-in by 5.

The height of an antenna also influences its wave length, both by changing its capacity to earth and by changing the length of the lead-in wire.

For example a 4 wire, inverted "L" type antenna with a flat top 50 feet long usually has a natural wave length of about 95 meters at 30 ft. height, 134 meters at 60 ft. height, and 186 meters at 100 ft. height.

The same type of antenna with a flat top 100 feet long has a wave length of about 159 meters for 30 ft. height, 200 meters for 60 ft. height, and 252 meters for 100 ft. height.

Flat top antennas of the "T" type have somewhat lower wave length for the same dimensions, as can be seen by comparing the following figures with those just given for "L" types.

A 4 wire "T" type antenna with a flat top 50 feet long has a wave length of about 70 meters for 30 ft. height, 117 meters for 60 ft. height, and 173 meters for 100 ft. height.

This "T" type antenna with a flat top 100 feet long has a wave length of about 106 meters for 30 ft. height, 154 meters for 60 ft. height, and 211 meters for 100 ft. height.

If the flat top is lengthened to 200 ft., its wave length will then be about 178 meters at 30 ft. height, 229 meters for 60 ft. height, and 291 meters for 100 ft. height.

Transmitting antennas range from 75 to 300 feet long for broadcast and ship work, up to over a mile in length for some of the very long wave commercial stations.

18. GROUNDS AND COUNTERPOISE

All connections in antenna circuits should be well made and soldered to keep the resistance as low as possible.

It is very important, particularly with transmitting aerials to have good low resistance ground connections, as the current flows through this connection to the earth side of the condenser the same as it does through the lead-in cable to the antenna side.

Good ground connections can be made by driving a long, perforated, galvanized pipe into the ground and pouring salt water into it, to soak through the holes into the soil; or by burying large copper plates or a network of copper wire. Sometimes a water piping system can be used for a ground.

Where it is difficult to obtain a good ground because of soil conditions, or for example in cases where a transmitter is located on top of a tall building, a special wire network known as a **Counterpoise** is often used beneath the regular antenna, and a few feet above ground or the roof. The ground lead is attached to this counterpoise which serves as the other plate of the aerial circuit condenser. Fig. 27 shows two methods of arranging counterpoise wires.

In some radio stations the same antenna is used both for transmitting and receiving, by using a change over switch to connect the lead-in wire either to the transmitter or receiver as desired. Generally, however, a separate antenna is used for receiving.

19. RECEIVING ANTENNAS

In homes and places where radio is only received and not transmitted, receiving antennas of much simpler construction than those just described, are used.

Receiving aerials do not need to handle much current and so generally consist of just one small wire about No. 12 or 14 B & S gauge, and of the proper length for desired results.

Either solid or stranded copper or bronze wire are very good for receiving antennas.

With early forms of radio receivers such as crystal sets, where all of the energy to operate the headphones came from the antenna, or even with sets using only one or two tubes, long, high receiving aerials were needed to pick up sufficient induced voltage to give good signals. But with modern multiple tube sets and the great amount of amplification they accomplish, very little receiving aerial is needed.

It is well to remember, however, that the higher a receiving aerial is located and the more free it is kept from surrounding trees, buildings, or other tall objects, the more energy it will usually receive. Also remember that increasing the length of a receiving antenna increases the energy it will pick up; of course keeping in mind that the antenna should not be so long that its natural wave length is much greater than that of the energy to be received.

In rural communities and certain out of the way places which are a long distance from any radio station, long, high, outdoor antennas may still be required or be an advantage.

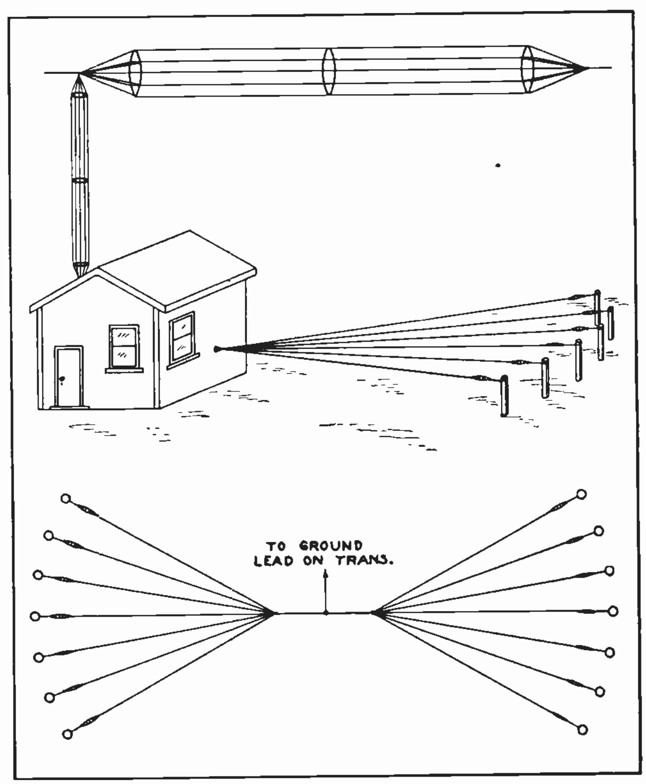


Fig. 27. The upper sketch shows the manner in which a group of wires forming a counterpoise can be used underneath an antenna to take the place of the ground connection. The lower sketch shows a counterpoise which can be used with a T type aerial.

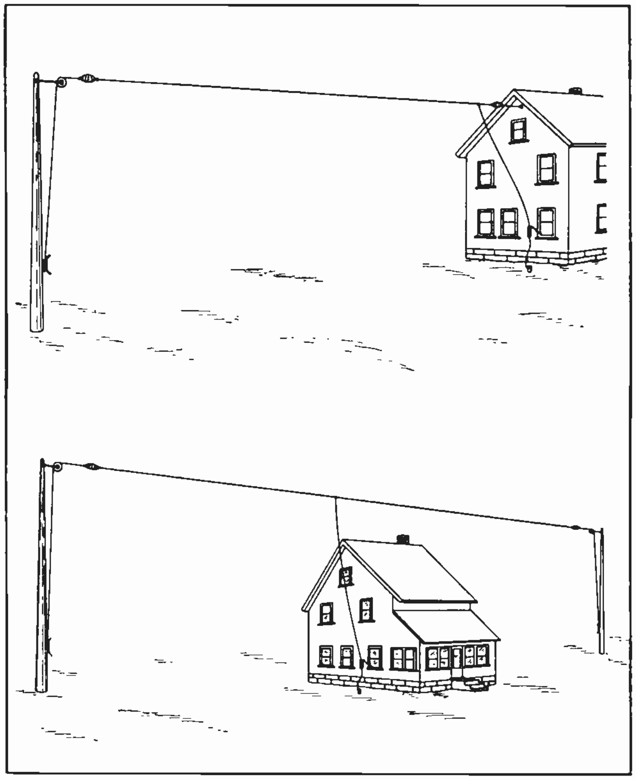


Fig. 28. The above sketches show L type and T type receiving antennas of single wire construction.

20. INSTALLATION OF RECEIVING ANTENNAS

Fig. 28 shows two methods of installing such aerials. The wire can often be stretched between two buildings or from a tall tree to a building and thus save the trouble of erecting masts or poles.

Antennas should not be drawn up tight enough to place excessive strain on the wires or fastenings, but they should be tight enough to prevent excessive swaying in the wind, as this varies their wave length and interferes with sharp tuning. Sometimes a coil spring at one end, or a weight on a rope over a pulley, can be used to keep an antenna tight when a mast or tree to which it is attached moves with the wind.

Remember that inverted "L" type aerials such as shown in the top sketch in Fig. 28, are quite directional and receive better from a direction opposite to that in which the free end points.

It is very important to have good low resistance soldered connections in a receiving antenna, because the received energy is so extremely small that there is not much to waste or lose. When we realize that the voltage induced by a radio signal in an ordinary receiving aerial may be less than 1 microvolt, or $\frac{1}{1,000,000}$ volt, we can readily see the necessity of having good aerial and ground connections.

Joints or splices that are not soldered allow corrosion to creep in between the wires or parts, and in time build up a very high resistance film that may reduce the signal strength to less than $\frac{1}{10}$ its former value when the splice was new.

A good ground connection often makes it possible to dispense with a very long antenna or to avoid the trouble and cost of installing one in the first place.

In houses or buildings equipped with piping, the pipes usually make a very good ground for a receiver. A cold water pipe is generally best as they are almost sure to be well grounded, and to form a complete metallic circuit to ground. Some steam or gas pipes are equipped with insulating joints at certain places, which prevent them from being a good ground.

With powerful multi-tube receivers located near to broadcast stations, very often a short piece of insulated wire about 10 to 30 feet long, laid under the rug or along a moulding is all the antenna required, and some sets will operate fairly well with no antenna at all.

It is well to keep in mind that longer antennas than necessary will generally pick up a lot of unnecessary static and interference, and that shorter antennas are more selective and make it much easier to tune out local stations if one desires.

Generally an outdoor aerial 50 to 150 feet long is suitable for receiving distant stations even with medium cost sets, and an indoor aerial much shorter is best for receiving local stations, or even distant ones if the receiver is a good one of 5 tubes or more.

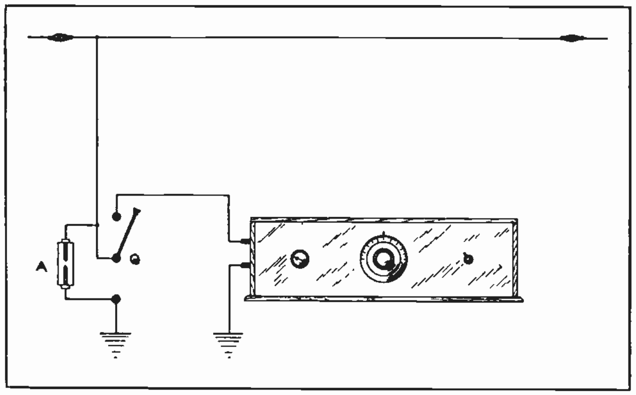


Fig. 29. This diagram shows the method of connecting a lightning arrester and a grounding switch to the lead-in of a radio receiver.

21. PROTECTION FROM LIGHTNING AND HIGH VOLTAGE LINES

All outdoor antennas should always be equipped with some form of lightning arrester, to ground any severe static charges and prevent them passing through the set and possibly damaging it or injuring operators.

On small receiving antennas these arresters usually consist of a simple needle gap arrangement connected between the lead-in wire and ground. On large, high transmitting antennas a more rugged arrester is required to safely handle the very high voltage atmospheric charges picked up, as well as possible direct lightning strokes.

A ground switch is also often used to connect the antenna direct to earth in case of electrical storms, or whenever the antenna is not in use. Fig. 29 shows a sketch of the connections for both a ground switch at G and a lightning arrester at A.

Antennas should never be erected over or directly beneath high voltage power lines, because of the danger of accidental contact in case either should break and fall across the other. Antennas that are near to power lines should be erected at right angles to them and **not parallel** to them, as this will help to prevent interference hum from induction of 60 cycle energy, and may also prevent induction of sufficient voltage to be dangerous, as might be possible with parallel wires.

22. LEAD-IN WIRES AND SPECIAL ANTENNAS

Antenna lead-in wires are often insulated, although they can just as well be bare if they do not touch parts of the building or if they are properly supported on pillar type insulators. Lead-ins should be well insulated where they enter the buildings, by means of good insulation on the wire or some form of insulating tube for receiving aerials; and by means of heavy glass, porcelain, or composition insulator bushings for transmitting aerials.

Lead-in wires should always be at least as large as the aerial wire, or with an area equal to all aerial wires in parallel where a number of wires are used. Remember that the length of lead-in wires should be added to that of the antenna proper, when calculating the effective length or natural wave length of the antenna. That is, with the exception of certain special types of transmitting aerials. Long ground leads will also affect the wave length of the antenna circuit.

Where a fairly long antenna is required and it is difficult or objectionable to erect an outdoor one, a long insulated wire, or a bare wire supported on insulators, can often be strung in an attic, keeping it as far as possible from any piping or electric wires.

Aerials located inside of steel frame buildings, buildings of steel reinforced masonry, or those using metal lath will generally not pick up much radio energy, as the steel work provides a definite shielding effect, and tends to ground or shunt the radio waves around the aerial.

Automobile radio receivers generally use a copper wire or screen located in the car top, or a metal plate under a running board for the antenna; and use the metal frame of the car for a ground. In this case we know the car frame is insulated from earth by the rubber tires, but its mass of metal serves as a sort of counterpoise or condenser type aerial even without any actual connection to earth.

Airplane transmitters and receivers generally use a trailing wire which can be reeled in, or a short wire or metal mast attached to the wings or fuselage for the antenna, and use the metal frame of the plane for the ground connection.

23. LOOP ANTENNAS

Loop antennas consisting of several rather large turns of wire are often used with portable radio equipment and in some home type receivers.

Loop aerials have a distinct advantage of being very directional, and are therefore a great help in receiving certain stations and keeping out interference from other powerful nearby stations, by simply turning the loop so that its edge or plane is in line with the station desired. Loops receive signals much better from either direction in line with their flat plane, than they do from stations located in a direction out from either side of the loop.

Loop aerials require no ground connections, as one end of the loop generally connects to the antenna terminal, and the other end to the ground terminal of the set.

Receivers designed for operation with a loop generally have it connected direct to the grid and filament terminals, thus eliminating the usual antenna coil and radio frequency transformer ahead of the first tube or stage.

The top sketch in Fig. 30 shows a loop connected in this manner to the first stage of a receiver, and the lower sketch shows how a receiver can be adapted for use either with a loop or with an antenna and ground, by means of a simple change-over switch "S".

With the switch in its present position on the upper contact the antenna coil or radio frequency transformer T is cut out, and the grid circuit is

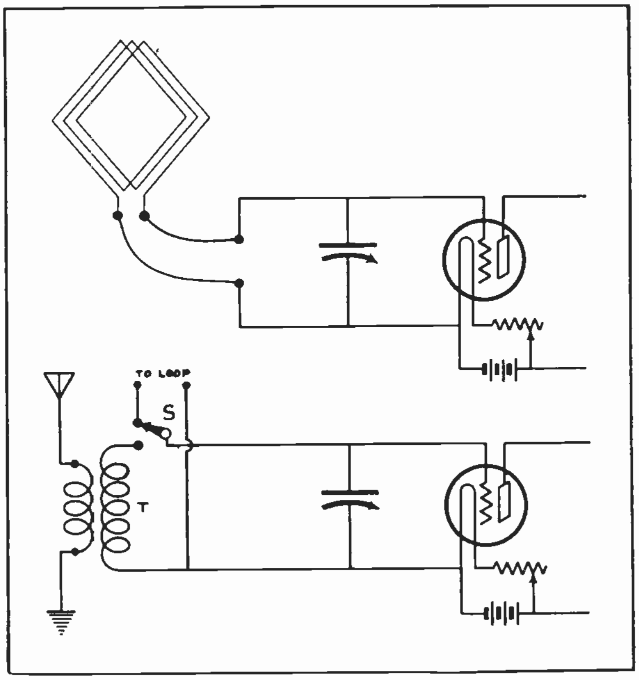


Fig. 30. The top sketch shows a loop aerial connected directly to the grid circuit of a vacuum-tube receiver. The lower sketch shows how a receiver can be adapted for use with either a loop or an aerial and ground.

connected to the loop terminals. With the switch moved to the lower contact the loop circuit is disconnected and the antenna coupling coil is connected to the grid of the tube.

The sharply directional characteristics of the loop aerial make it a very valuable device as a direction finder or interference locator. By rotating a loop while listening to a certain station or interference, the direction of the station or source of interference can be determined quite accurately by observing the position of the loop where the signal is loudest.

By use of specially constructed rotary loops with pointers and scales, observations can be made at various places around a transmitter or source of radio interference, and its location determined almost exactly by noting where the lines of direction of the different tests cross or focus.

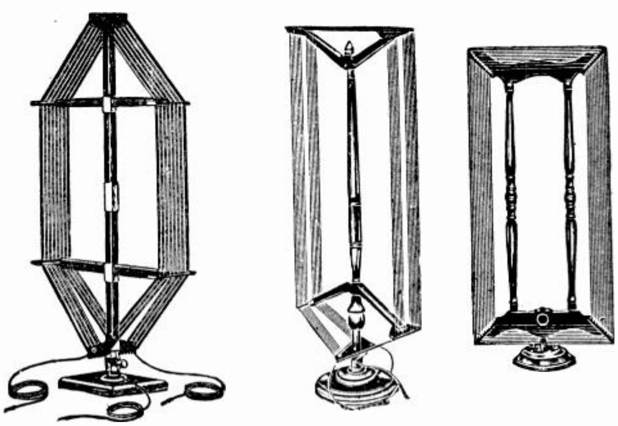


Fig. 30-A. Several different types of loop antennas for use with radio receivers. By rotating these loops directional reception can be accomplished.

The natural wave length of loop antennas depends upon the number of turns and the length of each turn, or size of the loop. It also depends somewhat upon the spacing of the turns. This spacing generally ranges from ½ to 1 inch between turns, although some loops for reception of very long wave lengths may have a number of slots ½ to 1 inch apart, with from 2 to 10 turns in each slot.

The wave length of a loop antenna can be increased by connecting a condenser across its terminals as shown in Fig. 30. By means of a variable condenser the wave length can be varied and the loop tuned to any wave length within its range.

A 4 foot loop with one turn can be used for wave lengths up to 180 meters with a .001 mfd. variable condenser in parallel, or up to 310 meters with a variable condenser of .003 mfd. capacity.

With 3 turns, a loop of this size can be used for wave lengths up to 400 or 675 meters according to which of the condensers is used, and with 6 turns its range is increased to 710 or 1200 meters according to the condenser used.

Many loops for indoor use are made about 2 ft. high, with from 6 to 20 turns, and used with a .00035 variable condenser.

24. RADIO RECEPTION AND TUNING

Now that we have a general understanding of how radio energy is produced and transmitted through space, let us see how this energy and the signals it conveys can be picked out of the atmosphere at will, and even to the extent of selecting just the signals we wish to receive.

You have already learned how the modulated high frequency waves of magnetic and static energy are radiated out through space by the transmitting antennas, and how receiving antennas are constructed to collect enough of this energy to operate receiving sets.

In an earlier section it was thoroughly explained how electro-magnetic waves or lines of force induce voltages in conductors when these lines cut across them, and if you will recall the principles of transformer action, you can readily understand how the waves radiated from a transmitting antenna induce feeble voltages in receiving antennas. Just think of the transmitting antenna as a sort of primary conductor which radiates its field great distances through space because of the nature of the high frequency energy it uses, and then think of the receiving antennas as secondary conductors in which secondary currents are induced.

Because of the great distance which usually separates the receiving and transmitting antennas the induced voltage in the receiving antenna will be extremely small or feeble. As previously mentioned this voltage is often less than one micro-volt, or $\frac{1}{1,000,000}$ of a volt.

Nevertheless this induced energy will be of exactly the same frequency as the energy at the transmitter from which the signal is coming, and it will also vary in value just exactly as the transmitted wave does when modulated by voice or audio frequency signal notes.

In this manner the energy flowing in a receiving antenna duplicates faithfully all of the conditions or characteristics of that at the transmitter, only on a much smaller scale. So now if we can make this received energy reproduce an audible sound, this sound will be a faithful reproduction of that used at the transmitter and impressed electrically on the carrier wave.

Before we consider the construction and operation of the receiver itself, however, it will be well to emphasize the fact that the very feeble amounts of energy received in radio work must be handled with extreme care, and by devices and circuits of very critical and exact design and connection, in order not to lose much of this small amount of energy, and to get the results desired from it.

While low resistance is very important, we have already learned that counter voltage of self induction and impedance in A. C. circuits, play a much greater part than resistance does in the control of alternating currents. This is particularly true when dealing with the extremely high frequency currents used in radio work.

For example, we find that receiving antennas and receiving set circuits must be **tuned** just right or have just the right amount of inductance and capacity in order to get any appreciable current of a certain radio frequency to flow in them.

This can perhaps be understood more easily if we recall the operation of the oscillating circuit used with a spark transmitter. In this circuit you will remember the frequency or rate of oscillation of the current was determined by the size of the condenser and the inductance coil, and the length of time required to charge the condenser, and the time required for the flux around the inductance coil to build up and collapse during each alteration.

If these factors can absolutely control the frequency of the energy generated in a transmitter oscillating circuit where very high voltages are applied, it is easy to see how they will also control the building up of high frequency currents in receiving circuits where the induced voltages are so very small.

If the capacity and inductance of a receiving antenna circuit are just right they will allow the induced voltage of a certain frequency to establish current which can oscillate freely in the circuit. If the capacity and inductance or the natural frequency of the circuit are not right for a certain frequency, current will not build up under feeble induced voltage of that frequency.

Of course this same circuit would allow current to build up at some other frequency for which its tuning happens to be just right, if some other station is sending waves of that frequency.

Another illustration of this tuning effect is in the vibration of a tuning fork to only those sound waves of its own natural frequency; or the response of certain reeds of a vibrating reed frequency indicator to the magnetic pull of alternating current of that same frequency. We also know that in order to keep a heavy pendulum swinging freely with the smallest possible pushes or impulses, these impulses must come at just the right time, according to the natural frequency or swing of the pendulum, so that they will aid the strokes of the pendulum.

This rather particular or "choosy" nature of radio frequency energy is a very valuable characteristic, as it is only through this feature that we are able to operate a large number of radio stations on different wave lengths at the same time, and yet select any one we wish to receive by simply tuning our receiver circuit by changing its inductance or capacity.

In other words it enables us to adjust a receiver so that a station of the desired frequency will be able to induce sufficient energy in the circuit to produce audible signals. Other stations of different frequencies may be able to induce a very little energy in the circuit also, but not enough to interfere with the desired signal, if the receiver is a good one and capable of sharp tuning.

This tuning of a receiving circuit is of course accomplished by changing either the amount of inductance or capacity, generally the latter.

Increasing either the inductance or capacity of a circuit increases its natural wave length. Decreasing the inductance or capacity will decrease the natural wave length of a circuit.

25. VARIABLE INDUCTANCE TUNERS

A method of tuning which was quite extensively used in earlier types of receivers, and is still used in transmitters and on some styles of receivers, consists of using a variable inductance such as shown at A in Fig. 31.

This form of variable inductance uses a **tapped coil "P"**, as the antenna coil or primary of the coupling transformer of the set. By shifting the rotating switch arm, turns can be cut in or out of the coil, thus increasing or decreasing the inductance and natural wave length.

Inductance coils of the smaller sizes for radio receivers are commonly wound in a single layer on a tube or cylinder of fibre or bakelite. Those with a large number of turns are often specially wound so that the turns are criss-crossed at a slight angle, in what is called honeycomb formation. This reduces the distributed capacity effect between turns. If the turns of large coils are all wound parallel and tight together, this capacity effect often becomes considerable at the very high frequencies carried by the coils. Some simple small coils of single layer winding have the turns spaced apart a short distance. Inductances for tuning vary from about 1 micro-henry $\left(\frac{1}{1{,}000{,}000}\right)$, to 125 millihenrys (.125 henry).

At B in Fig. 31 is illustrated another method of inductance tuning using a device known as the **Vario-Coupler,** consisting of a stationary coil S and a smaller coil M which is located inside or very near to the open end of the larger stationary coil.

When the turns of the movable coil are parallel to those of the stationary one, the induction or

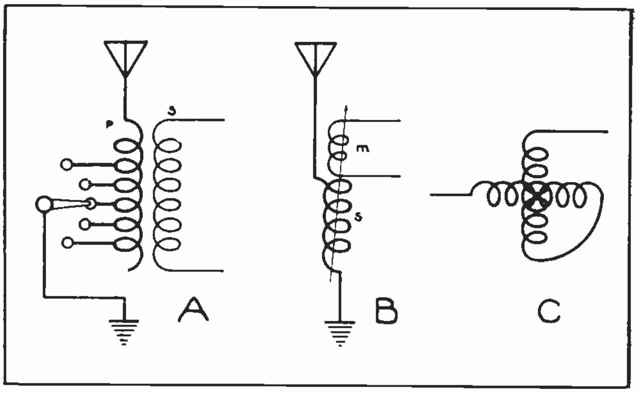


Fig. 31. The above three sketches show different methods of tuning radio circuits with variable inductances.

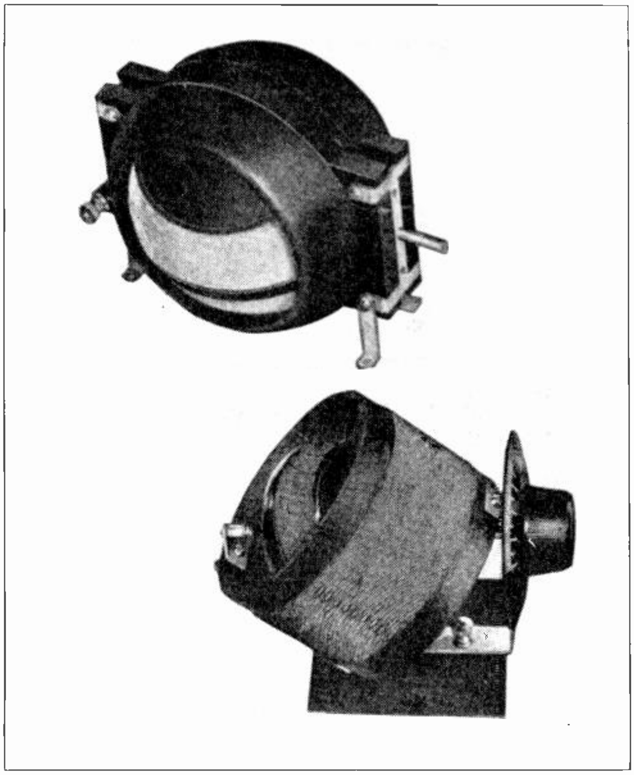


Fig. 31-D. Two types of variometers or variable inductances, such as formerly used very extensively in tuning radio receivers.

transfer of energy between them is maximum. When the movable coil is turned at right angles to the stationary one, the induction between them is almost zero. This rotation of the one coil not only varies the amount of energy it will absorb from the primary coil, but also changes the inductance of coil S by the reaction between its flux and that of the movable secondary coil.

Vario-couplers of this type provide a very smooth means of tuning a set because of the stepless change in inductance and coupling as the rotor coil is slowly turned.

Some such couplers also have taps on the primary coil for further changes in the inductance.

The slender arrow through the two coils indicates that they are coupled together inductively and variably. A number of different methods have been developed for varying the coupling between primary and secondary coils of this type, some of which are still in use in modern receivers.

Primary and secondary tuning coil units such as shown at A and B in Fig. 31 are really **Coupling Transformers** to inductively couple the antenna circuit to the rest of the receiver circuit, and are commonly called R. F. or radio frequency transformers.

One distinct advantage of being able to change the coupling between the primary and secondary coils of these transformers, is that moving them farther apart greatly increases the **selectivity** or sharpness of tuning of the set. Even though this separation of the coils loses some of the energy or volume, it makes it much easier to separate nearby stations when tuning.

When the coils are close together they are said to be **close coupled,** and this makes broader tuning. When the coils are widely separated, they are said to be **loose coupled,** and effect sharper tuning.

At C in Fig. 31 is shown still another method of varying inductance in a circuit, by using one coil which rotates within another slightly larger one, and connecting the two in series. This device is known as a **Variometer,** and is connected in series with the circuit to be tuned.

When the inner coil is in a certain parallel position inside the stationary one, its flux coincides with that of the stationary coil thus setting up a strong magnetic field around all the turns, and increasing the inductance of the unit. When the small coil is rotated 90 degrees to a position at right angles to the larger one, its flux neither aids or opposes that of the other coil very much, and the field is about normal around both, thereby reducing the inductance to a little less than it was at first. When the small coil is rotated 180 degrees to the exact opposite parallel position to what it was at first, its flux will oppose and largely neutralize that of

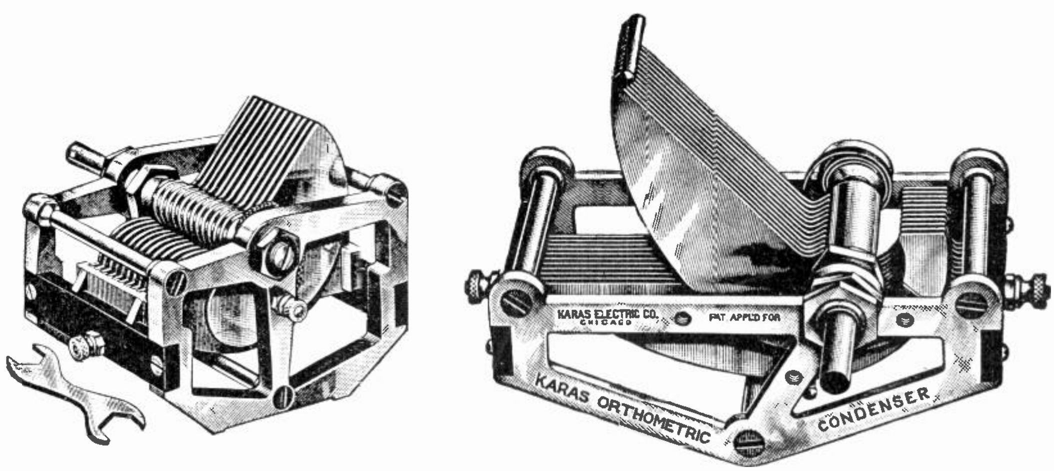


Fig. 32. Variable condensers, such as commonly used for tuning the circuits of radio receivers to the desired wave length. These condensers each have one set of stationary plates and one set of movable plates by which their capacity can be varied.

the stationary coil, thus weakening the total field around them both and greatly reducing the inductance of the unit.

Variometers of this type are not used as much in modern receivers as they formerly were. Fig. 31 shows two types of variometers such as were used extensively in earlier types of radio sets.

Some radio receivers use a set of changeable inductance coils known as **plug-in coils, or honeycomb coils** which can be conveniently interchanged for making definite changes of considerable amounts in wave length.

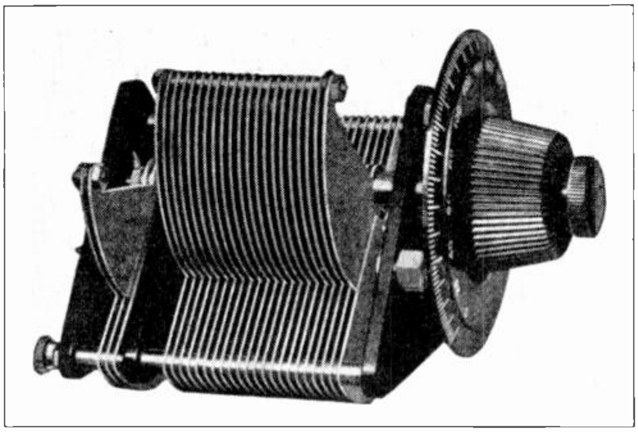


Fig. 33. Variable condenser, with vernier adjustment or small section operated by a separate knob on the tuning dial.

26. VARIABLE CONDENSERS FOR TUNING

Another very efficient and convenient device for tuning radio circuits is the variable condenser, two of which are shown in Fig. 32.

These condensers consist of a set of stationary plates and a set of rotary or movable plates, closely spaced and separated from each other only by air.

When the rotary plates are fully meshed between the stationary ones the capacity of the condenser is at its maximum, as the greatest possible area is active. When the rotary plates are entirely removed from between the stationary ones the condenser capacity is at its minimum, as only their edges are then exposed to each other.

By rotating the movable plates of such a condenser slowly, very fine and smooth changes can be made in the tuning of the circuits in which they are connected.

The plates are generally made of aluminum or brass, with the rotary ones mounted on a shaft and both sets mounted in a metal supporting frame, for convenient attachment to the panel or frame of a radio set.

The greater the number of plates used the greater the capacity and tuning variation or range, and the coarser the adjustment for a given movement. The less the number of plates the smaller is the capacity and the finer the adjustment for a given movement.

Some variable condensers are made with only three plates, two stationary and one rotary, for very fine adjustments. These are called **Vernier condensers.**

Convenient tuning knobs and graduated dials are generally attached to the shaft of the rotary elements. Some of these controls have a reducing gear or mechanism to enable slower movement and finer tuning with the condenser. Fig. 33 shows an earlier type of variable condenser which has the main element and also a smaller vernier element, and is equipped with the dial and knob.

Variable condensers are rated in micro-farads, a unit with which you are already familiar from an earlier section on A. C. They are sometimes rated by their maximum capacity such as .001 mfd., and sometimes by their range of capacity, as .000045 to .0005 mfd. Variable condensers are commonly made in sizes ranging from .000025 to .001 mfd. maximum capacities, one of the most common sizes being the standard .00035 mfd. condenser used in ordinary receivers. Condensers are also made with different plate spacings for high or low voltage circuits, and are used both in radio transmitters and receivers. Fig. 34 shows three common methods of connecting variable condensers for tuning radio circuits. The first two shown at A and B are often used in transmitters but are seldom used in modern receivers. The method shown at C being most generally used in modern receivers.

With the condenser connected as at A, in series with the antenna capacity, the total capacity and the wave length of the circuit are reduced; as you will recall from your previous study of condensers that connecting them in series reduces the voltage across each and thereby reduces their effective capacity.

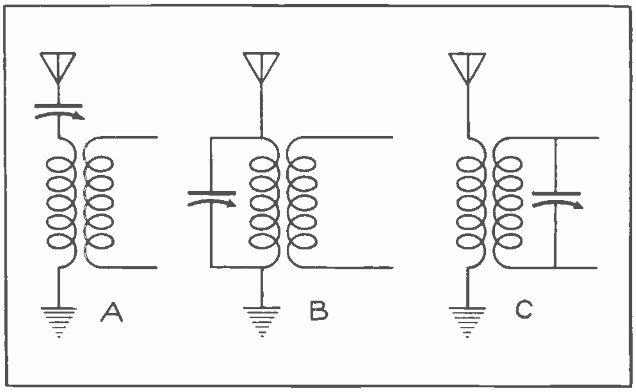


Fig. 34. Sketches showing three different methods of connecting variable condensers for tuning radio circuits.

When the condenser is connected in parallel with the inductance as shown at B, it increases the total capacity and thereby increases the wave length of the circuit.

When the condenser is connected across the secondary of the radio frequency transformer or tuner as shown at C, it tunes the secondary directly and also tunes the primary or antenna circuit indirectly, by inductive coupling between the coils. This method provides one of the smoothest and best methods of tuning and is therefore extensively used in radio receivers.

(NOTE)—Remember that adding inductance or capacity increases the wave length of a circuit. Connecting a condenser in series with the antenna or with a coil reduces the capacity and wave length of the circuit, and connecting the condenser in parallel with a coil increases the capacity and wave length.

27. RADIO RECEIVERS AND DETECTORS

While the tuning elements are absolutely essential to a radio receiver, the detector or device which makes it possible to hear or see the signals received, is often considered to be the heart of a receiver.

We have mentioned both hearing and seeing the signals because in addition to hearing code signals, voice and music with headphones or loud speaker, some commercial radio receivers print the code marks or symbols directly on a paper tape or ribbon as they come in. Television devices also convert the received energy directly into visual pictures or material, and transmission of still pictures or photos by radio is another process in which the energy received is converted directly into visible form.

As previously explained the transmitted radio energy or carrier wave is much too high in frequency to be audible to the human ear. Even after modulation by audio frequency currents the signal energy or current induced in the receiving aerial circuit, is alternating current of such high frequency that the diaphragms of the headphones cannot respond to it, because even their slight inertia prevents them from vibrating at such high speed.

We find, however, that if we convert this high frequency alternating current into pulsating D. C. with the same variations in value as the modulated A. C. has, then the phone diaphragms can respond, as the pull set up on them by the pulsating D. C. through their magnet coils is all in one direction, and simply varying in strength.

This is the job or function of the detector, **to rectify the received high frequency current into pulsating D. C.** There are two common devices used for this purpose, namely, the crystal detector and the vacuum tube. The coherer mentioned earlier in this section was one of the earliest devices used as a detector, but is entirely absolete now.

Crystal detectors were very extensively used for a number of years and were a great improvement over coherers. Crystals have certain disadvantages such as a lack of any appreciable amplifying ability and a need for frequent adjustment, so during the past few years they have been almost entirely replaced by vacuum tube detectors.

Crystals are still used along with tubes, however, in a few special types of sets, in certain experimental equipment, and are also carried as emergency equipment in certain stations, so we will very briefly cover their use and principles at this point.

Before we explain the function of crystals, however, it will be well for you to carefully observe and become generally familiar with the list of commonly used symbols shown in Fig. 36. These symbols will be used in the following diagrams of radio equipment, and are the standard ones used in representing various radio devices and parts in all ordinary diagrams and blueprints in magazines and text books, and those furnished by manufacturers on their equipment.

So in order to be able to easily trace and read these diagrams and thereby understand the equipment they represent, you should learn to recognize each of these symbols and know what it means.

28. CRYSTAL DETECTORS

As previously mentioned, the function of a radio detector is to rectify the high frequency alternating current received.

There are a number of crystals which have more or less of this property when current is passed through them. One of the most commonly used is the Galena crystal, which is a natural crystal formation of sulphide of lead, and is found in lead mines. Zincite, bornite, and silicon crystals are also used in some cases. Carborundum crystals are also used in circuits with a low voltage battery.

Fig. 37 shows a photo of a piece of galena crystal in a mounting or holder, and Fig. 38 shows a sketch of a mounted crystal at A, and at B a complete crystal mounting with its feeler contact or adjustable cat-whisker, which is used to explore the surface of the crystal for sensitive spots.

When a crystal such as galena is connected in an A. C. circuit, it will allow current to pass through it quite freely in one direction, and will almost entirely prevent its flow in the opposite direction. This is illustrated by the relative size of the current arrows on the wires leading to the crystal at A in Fig. 38.

This rectifier action is thought to be due to either electro-chemical or electro-thermal action between the layers within the crystal structure, or at the point of contact between the tip of the cat-whisker wire and the crystal surface.

29. ACTION OF CRYSTAL DETECTOR IN A RECEIVER CIRCUIT

Fig. 39 shows a method of connecting a crystal and a pair of headphones to a tuning coil to form a simple radio detector or receiver.

When the high frequency waves of a damped wave signal for example, strike against the receiving antenna of such a circuit, they induce alternating voltages in the antenna. This voltage tends to set up in the tuning coil, during each wave train, an alternating current such as illustrated by the curve at A in Fig. 40.

The voltage drop across the coil L in Fig. 39 will cause part of the current to flow through the crystal and headphones.

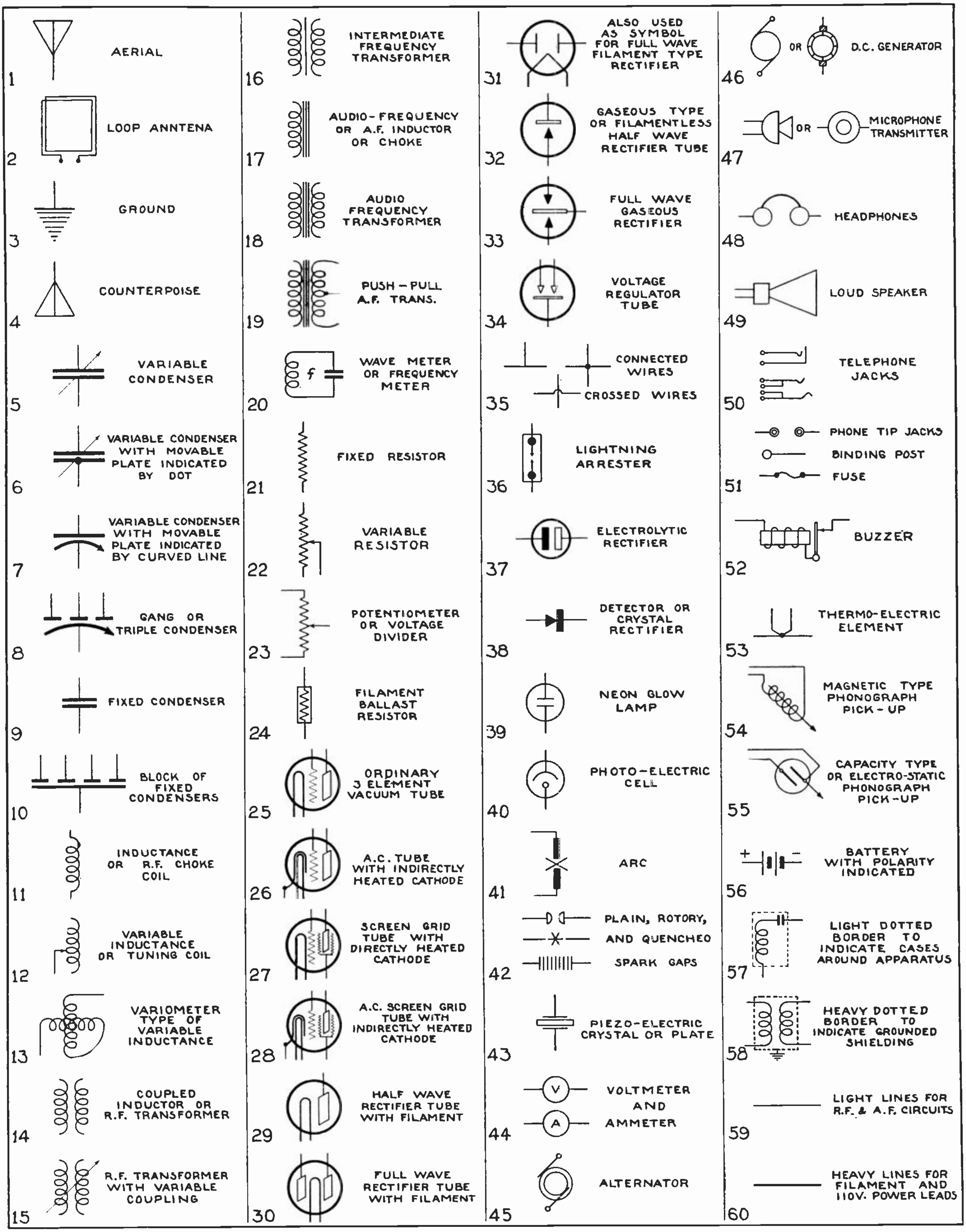


Fig. 36. This chart shows the most commonly used symbols for representing radio devices and parts in circuit diagrams. Examine each symbol carefully so that you can recognize any of them in radio diagrams from now on.

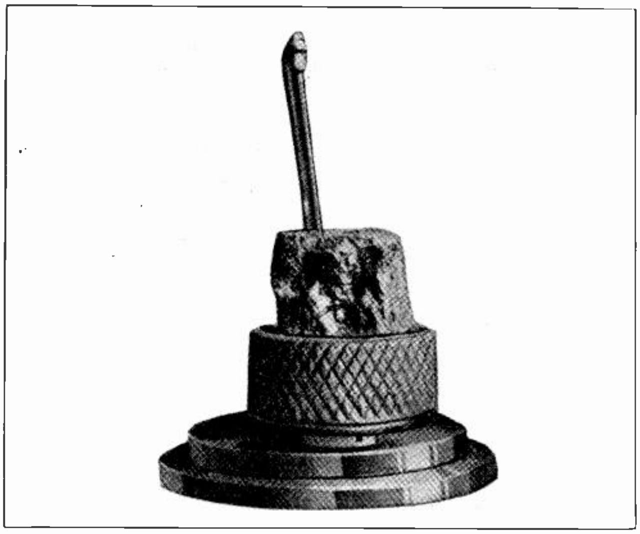


Fig. 37. Photo of a detector crystal fastened in its mounting. Such crystals as this were formerly used very extensively in radio receivers.

If the crystal were left out the high frequency current would not produce any sound at the phones, because it could not flow to any appreciable extent through the high impedance of the phone coils which are wound on iron cores. Even if the current did get through the coils in any useful amount the phone diaphragms could not vibrate at such high frequency, nor could the human ear hear it if they did.

With the crystal in the circuit as shown in Fig. 39, however, the current is allowed to flow through it and the phones in only one direction, and is practically all cut off in the reverse direction. This is illustrated by the curves at B in Fig. 40.

Thus practically all that gets through the phones is pulsating D. C. or current in one direction. The current through the phones does not vary with, or follow, each of the high frequency pulsations of these rectified groups, but due to the impedance of the phone coils the current builds up to a sort of average value, in the form of one pulsation for each group or wave train, as illustrated by the large dotted curves at C in Fig. 40.

These longer and slower current impulses through the phone magnets, all in one direction, cause the diaphragms to be attracted and released or vibrated at audio frequency, thus setting up audible signals.

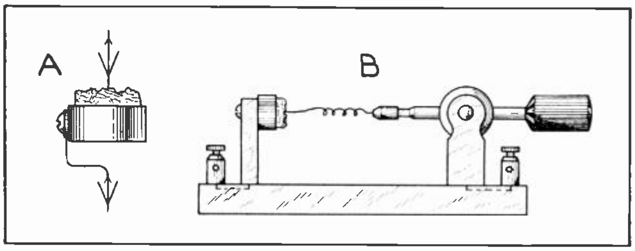


Fig. 38. The sketch at A shows a crystal and illustrates the rectifier effect on the current passing through it. At B is shown a complete crystal mounting with the crystal and cat whisker in place.

The same general action takes place with modulated C. W. energy of voice or music reception. The crystal rectifies the energy to high frequency pulsating D. C. by cutting of the flow in one direction. Then the impedance of the phones causes the unidirectional voltage pulsations to build up current through the phone magnets, which does not vary much with each high frequency impulse, but varies or pulsates with the slower variations in value which are due to the audio frequency modulation of the waves, as was shown at C in Fig. 40.

So we find that detection, or the change from radio frequency energy to audio frequency, takes place as a result of **the combined rectifying action of the crystal and the choking action of the phones.**

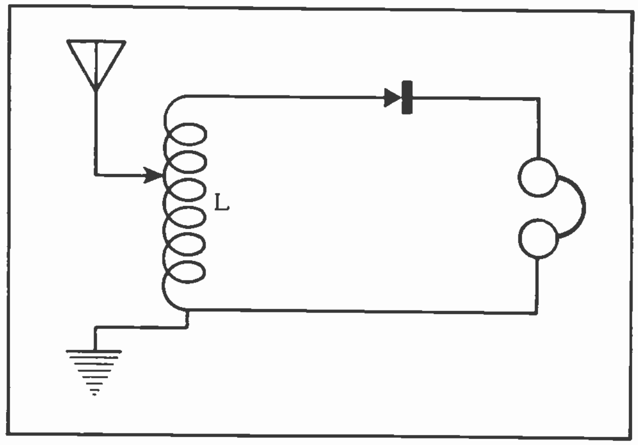


Fig. 39. This sketch shows a circuit for a simple crystal detector radio receiver.

30. AMPLIFICATION WITH CRYSTALS AND LOCAL BATTERY

Some crystals such as those made of carborundum can be used with a small amount of current from a local battery added to that from the antenna, to obtain a sort of feeble amplification of the signal, through the valve action of the crystal.

Fig. 41 shows a complete circuit diagram for a receiver of this type.

A variable condenser is used for tuning the circuit and a small fixed condenser "C" is connected across the phones and battery, to shunt or pass by them, the radio frequency current. This condenser is not large enough, however, to pass the audio frequency variations. Because of its function it is often called a **by-pass** or **bridging** condenser.

The amount of battery voltage applied to the crystal and phones is carefully adjusted for best results, by means of a high resistance rheostat or potentiometer P.

31. CARE AND USE OF DETECTOR CRYSTALS

To obtain best results from detector crystals they should be kept clean and free from dust and grease, even being careful not to get the oil from ones hands on them by careless handling. Dirty crystal surfaces can be cleaned by washing with alcohol.

When it seems difficult to locate any sensitive spots by feeling or exploring the crystal surface with the point of the cat-whisker, new spots can often be uncovered by carefully chipping away small sections or layers of the crystal.

When operating a crystal receiver, one explores the crystal with the cat-whisker while listening with the phones. When a sensitive spot is touched it will be known by a slight hissing sound in the phones. This sound is partly due to static or atmospheric disturbance.

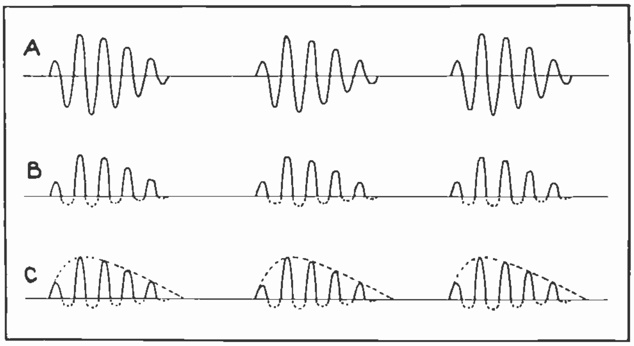


Fig. 40. The curve at A represents the alternating current induced by damped wave-trains striking an aerial. At B is shown the curve for this energy after it has been rectified into pulsating D. C. by the crystal. At C the large dotted curves illustrate how each group of pulsations supply one current impulse to the headphones.

Next adjust the tuning coil and condenser to the wave length of the desired station, tuning it in as loud and clear as possible. Then make a final adjustment of the cat-whisker, or find the spot where the signal is best.

Crystal receivers have received messages and signals from transmitters hundreds of miles distant, will produce very clear and undistorted signals, and are very cheap to construct. But they have the disadvantage of requiring frequent adjustment and being incapable of any great degree of amplifcation.

For these reasons vacuum tube receivers are much more dependable, and have replaced crystal sets almost entirely.

32. VACUUM TUBES

Before taking up vacuum tube types of radio receivers and amplifiers it will be well to get a

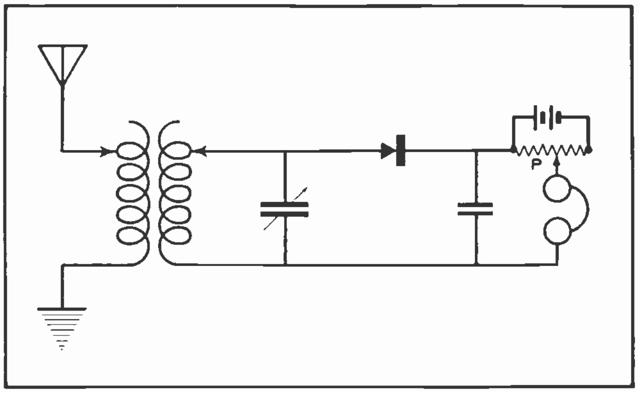


Fig. 41. Sketch of a crystal detector circuit using a battery and potentiometer for applying voltage to the crystal and obtaining slight amplification of the received signal.

thorough general understanding of vacuum tube construction, operation and characteristics, and their functions as detectors and amplifiers.

Vacuum tubes play a most important part in practically all modern radio equipment, and in fact have made possible the development of radio from the spark and crystal stage to the splendid equipment in use today. So again we wish to emphasize the value of obtaining a good understanding of these interesting devices.

You have already learned about the general construction of the common three element vacuum tubes and their function as oscillators, in articles 9 and 10 of this section, but at this point we will cover a few more details of their construction, explaining their operation in general and also their function as detectors and amplifiers.

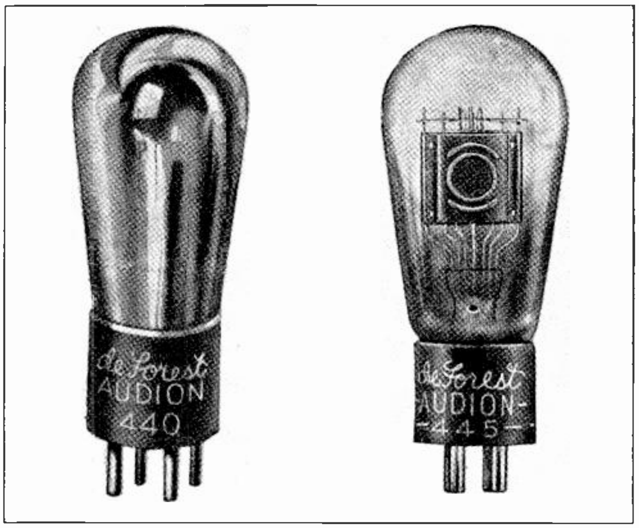


Fig. 42. Two types of vacuum tubes such as commonly used in radio receivers.

Fig. 42 shows two ordinary vacuum tubes such as are used by the millions in radio receivers. The tube on the left has the inside of its bulb covered with a silvery coating which is deposited on its inner surface in the process of manufacture, and on account of this coating we cannot see the parts inside. The tube on the right, however, has a clear bulb, and the thin pressed metal plate can be clearly seen, and some of the support wires for the filament and grid are also visible.

Note the manner in which the sealed glass bulbs are cemented into the insulating bases, through which the connection prongs project. These prongs hold the tubes in sockets and complete the circuits to the socket terminals.

33. TUBE CONSTRUCTION AND FUNCTIONS OF PARTS

You will recall that the three important elements of the tube are the filament, grid and plate. The filament being heated to throw off electrons to complete a circuit and establish current flow between the plate and filament; the plate used as a positive

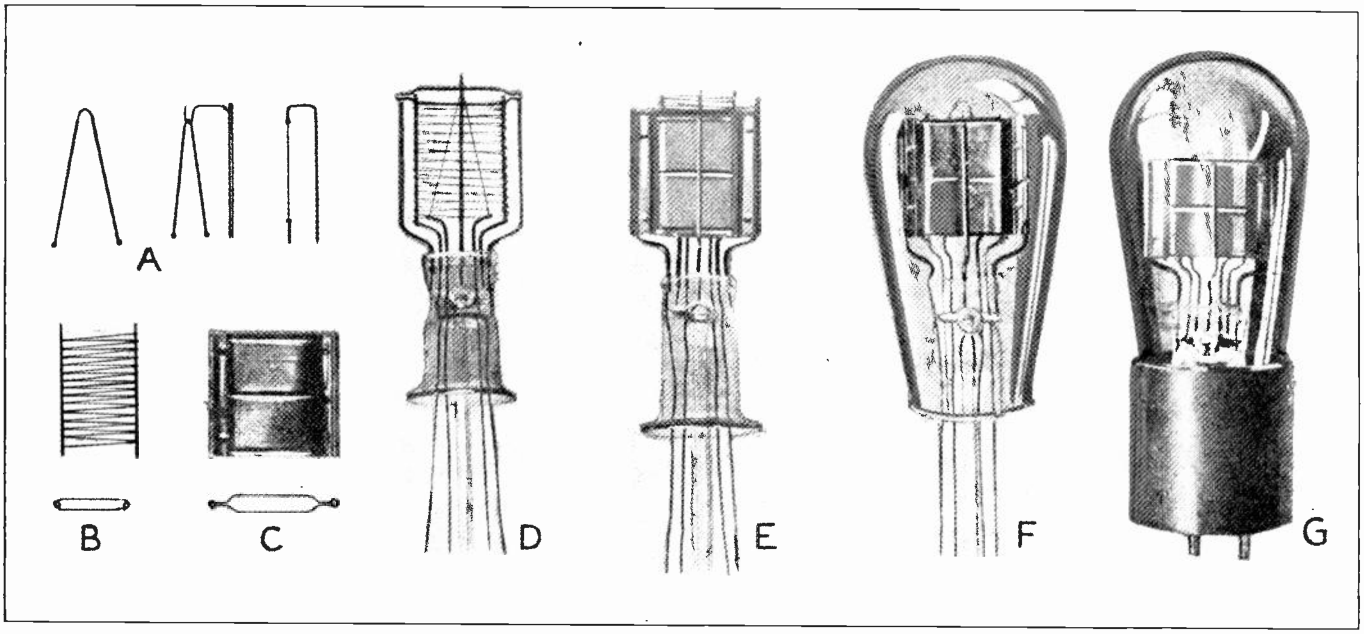


Fig. 43. The above views show the various parts of a vacuum tube and illustrate the manner in which these parts are assembled and mounted in the complete tube. Refer to these views frequently while reading the accompanying paragraphs.

electrode to supply current from the B battery; and the grid being used as a control element or shutter to regulate the electron stream and the current flow. Fig. 43 shows these various elements before they are assembled in the tube, and also shows the completed tube.

The filament is just a simple loop of high resistance tungsten or nickel wire, as shown both with and without its support at A, or in some cases just a single straight strip of this material held in place by a supporting wire, as shown by the right hand one of these filaments at A.

The tungsten filaments of later model tubes are usually treated with thorium, and the nickel wires coated with oxide, to make them emit electrons more freely at lower temperatures. This makes them much more efficient than the older types, as the ordinary small tubes with the thoriated or oxidized filaments only require about .25 ampere, or ¼ as much filament current as the older tubes. Many of these filaments operate at such low temperatures that they need only be heated to a dull cherry red, while others are operated at white heat or incandescence.

Filaments of D. C. tubes are heated by current from a low voltage "A" battery, ranging from 1½ to 6 volts, and filaments of A. C. tubes are heated by current from the low voltage secondary winding of a filament or power transformer.

Tube filaments are rather delicate and the tubes should never be roughly handled or the filament wires are likely to become broken or bent into contact with the grid. Filaments are also easily burned out if too high voltage is applied to them.

At B in Fig. 43 is shown the grid of the tube. This grid consists of a coil or spiral of fine nickel wire and is placed around the filament, between it and the plate, and supported so that it does not touch either the filament or plate. See Fig. 44. The grid support consists of two small stiff wires which have their lower ends imbedded in the glass of the tube as shown at D in Fig. 43. Here the filament and grid are both shown mounted on their support wires which have been imbedded in the top of the glass post while it was hot and soft.

As previously explained the grid, when positively or negatively charged, acts as a control or shutter to regulate the stream of electrons from the filament to the plate.

The filament electrons being negative will be attracted to the grid when it is positive, and the electron flow thereby increased. When the grid is negative it repels most of the electrons, throwing them back toward the filament, and thus greatly reducing the stream of electrons to the plate.

At C in Fig. 43 is shown the plate of the tube. This plate is made of a thin sheet of nickel, formed into a flattened or oblong tube or jacket, and when mounted it surrounds the filament and grid as shown at E in Fig. 43.

Note the wires which are attached to the filament, grid and plate, and taken down through the glass stem of the tube for connection to the tube prongs.

The plate when connected to a B battery or other source of direct current supplies current to the tube and this current is controlled by the number of electrons between the filament and plate. These electrons being controlled by the grid, the grid also controls the plate current flow.

At F is shown the glass bulb placed over the parts and ready to be melted or sealed to the base of the glass inner support, thus making the tube air tight.

Before finally sealing the bulb, it is evacuated or has the air practically all pumped out. After this process it is sealed, fitted with a bakelite base and the lead wires are connected to the prongs in this base.

In some cases a very small amount of inert gas is allowed to remain in the tube when it is evacuated, and in other cases a small quantity of alkali gas is put in the tube after the air is drawn out.

Tubes of this type with low vacuum or with gas content are often referred to as **soft tubes,** and are generally used for detectors. Tubes with higher vacuum are called **hard tubes,** and are more commonly used as amplifiers; although they are also used as detectors in some cases.

Evacuating the tubes or removing the air and oxygen from them prevents the rapid burning away or oxidization of the heated filaments, and also makes a lower resistance path for current between the plate and filament.

In certain types of modern vacuum tubes a small cup of magnesium is placed inside the tubes before sealing, and after evacuation and sealing the magnesium is exploded by means of a powerful high frequency field. The burning magnesium absorbs or consumes the small amount of gases left in the tube after evacuation. It is this process which causes the silvery deposit or coating on the inside of certain tubes.

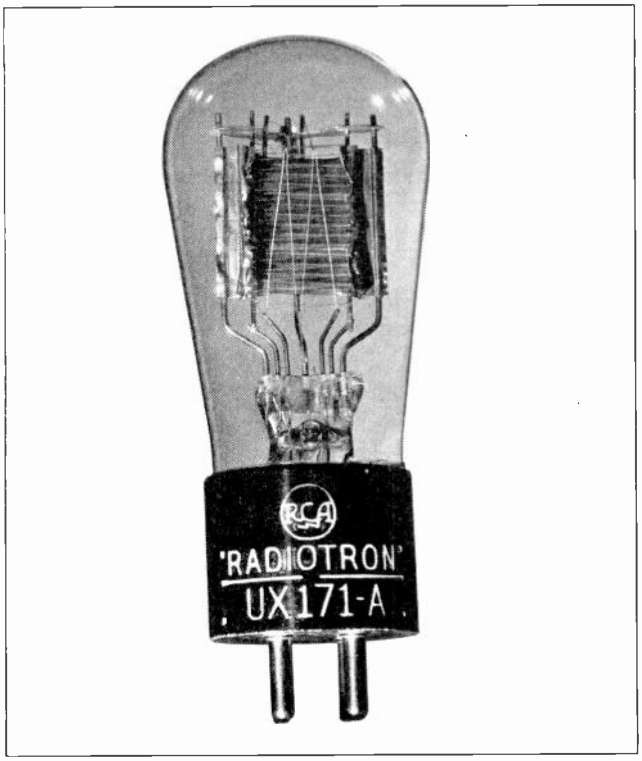


Fig. 44. Photograph of a vacuum tube with the plate opened up on one side to show the location of the grid and filament which are surrounded by the plate.

Vacuum tubes are made in different sizes and types for use as detectors, amplifiers, and oscillators in various radio equipment.

The average serviceable life of a good tube with proper treatment should be between 800 and 1,000 hours of use.

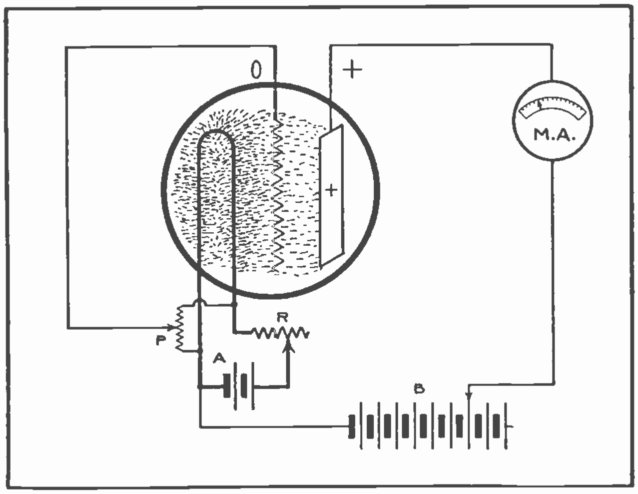


Fig. 45. This sketch illustrates the electron flow from the filament to the plate of a vacuum tube when no potential is applied to the grid. You will note that only a moderate amount of electrons are attached to the plate while the grid is in this condition.

34. OPERATION OF VACUUM TUBES

In Fig. 45 is shown a sketch of a common type of 3 element vacuum tube. The filament is connected to a low voltage battery (1½ to 6 volts) called an "A" battery, which supplies current to heat the filament.

The plate is connected to a higher voltage battery (22½ to 45 volts) called a "B" battery, which supplies a positive charge to the plate.

The grid of the tube in this case is connected to the center of a potentiometer, which is connected across the filament. This is done to allow an adjustment of the grid potential or voltage, which is obtained from either the positive or negative filament lead.

Note the three circuits thus formed. They are the **grid circuit,** consisting of the grid, grid lead, potentiometer, filament, and the gap from the filament back to the grid; the **filament circuit,** consisting of the filament, "A" battery and rheostat R; and the **plate circuit,** consisting of the plate, plate lead, milliammeter "MA", battery leads, "B" battery, one side of filament, and the gap from the filament back to the plate.

When such a tube is cold and has no current flowing through its filament, no plate current will flow as the gap between the filament and plate is too high resistance.

When the filament is heated by passing current through it **electron emission** is set up, and millions of negative electrons are thrown off around it in all directions. Some of these electrons fly across to the plate, due to the attraction of the positive plate for the negative electrons, thus completing a circuit and allowing a very small current to flow from the B battery in the plate circuit. This current can be measured in milli-amperes by the meter M A.

35. PLATE CURRENT

This current which flows in the plate circuit when no signal voltage is applied to the grid, or when the grid is at normal potential, is called the **normal plate current.** The amount of normal plate current flow will depend on the type of tube, upon the electron emission from the filament, and upon the voltage applied to the plate. It commonly ranges from 5 to 40 milliamperes in common receiving tubes.

If the plate voltage is gradually increased, it also increases the positive attraction for the negative electrons, thereby increasing the number that stream to the plate. Therefore, as the plate voltage is increased, the plate current flow will also increase, up to a certain maximum value, where it will not increase appreciably with further plate voltage increase. The reason the plate current will not increase much beyond this point is because the increased plate voltage is drawing all of the available electrons emitted by the filament. This point is called the **saturation point.**

To increase the plate current beyond this value, we would need to increase the electron emission from the filament by increasing its temperature.

Fig. 46 shows a curve which illustrates the manner in which the plate current changes with variation of plate voltage.

This curve is approximate and shows the general plate voltage, plate current characteristic of common receiving tubes, although its shape would vary a little for different types of tubes.

Note how the plate current increases quite slowly as the voltage is raised from 0 to 60 volts, and then increases very rapidly as the voltage is raised from 60 to 200. Beyond this, however, the plate current increases very little for any further voltage increase.

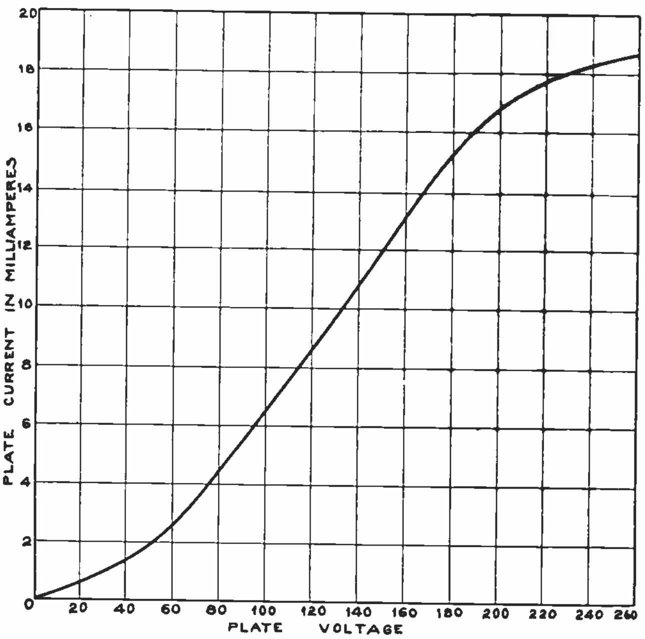


Fig. 46. Curve showing the manner in which the plate current of a vacuum tube varies with changes of the plate voltage.

By careful examination of the curve, tracing up along the 60 volt line to the point where it crosses the curve, then reading to the left along a horizontal line to the left edge of the chart, we find the first 60 volts applied to the plate will only produce about 2½ milliamperes. The next 60 volts, however, will raise the current from 2½ to about 8½ milliamperes, and the next 60 volts brings it up to about 15 milliamperes. From this point on the curve begins to level off, and the next 60 volt increase only raises the plate current from 15 to a little above 18 milliamperes.

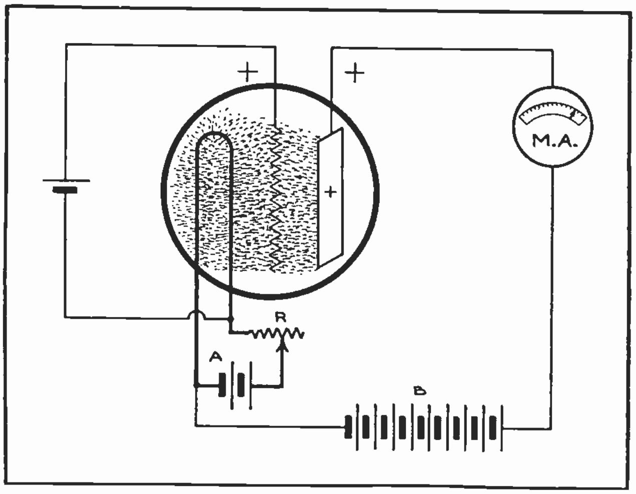


Fig. 47. This sketch shows the greatly increased flow of electrons from the filament to the plate of a vacuum tube when the grid is positively charged at very low potential.

36. CONTROL ACTION OF GRID

In Fig. 45 the grid lead of the tube is connected through a potentiometer to the filament, and the grid kept about at zero potential so it takes practically no part in the tube action or in causing the plate current. The plate current flow is simply due to the moderate amount of electrons drawn from the filament to the plate by its positive attraction.

In Fig. 47 is shown another sketch of a tube with the grid positively charged by means of a low voltage battery connected in its circuit.

In this case the grid return lead is connected to the positive filament lead to prevent the A battery from applying negative potential which would overcome the effect of the cell in the grid circuit.

When the grid is positively charged in this manner, even at very low potential, because it is close to the filament it exerts a great attractive force on the negative electrons from the filament, and causes them to stream toward it in great quantities. When these electrons reach the grid, a few strike and cling to it, but because they are then getting near to the plate which is of much greater positive potential, most of the electrons fly right on through the grid to the plate, as shown in Fig. 47. Compare the number of electrons between filament and plate in this sketch with the number in Fig. 45, where the grid is at zero voltage.

The greatly increased stream of electrons when the grid is positively charged as in Fig. 47, causes a corresponding increase in plate current, as shown by the milliammeter in the plate circuit. Compare its reading with that of the one in Fig. 45.

In Fig. 48 is shown another sketch of a tube with the grid negatively charged, by reversing the polarity of the battery cell connected in its circuit and leaving the grid return connected to the negative side of the filament. In this case the negative charge on the grid repels the negative electrons from the filament, throwing most of them back toward the filament and allowing only a very few to get through the plate.

This nearly complete shutting off of the electron stream in the gap between the filament and plate, reduces the plate current nearly to zero, as shown by the milliameter in the plate circuit in Fig. 48.

Compare very carefully figures 45, 47, and 48, until you are sure you fully understand the effect of the grid in controlling the plate current as the grid potential is varied or reversed.

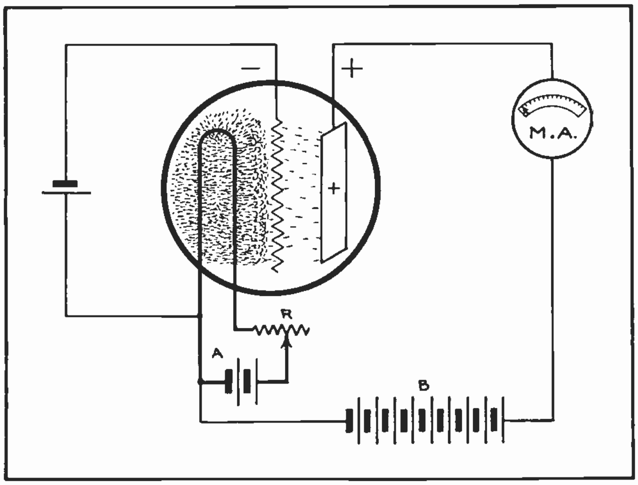


Fig. 48. The above diagram shows the manner in which the electron flow from filament to plate is almost entirely shut off when the grid of the tube is negatively charged. Compare this sketch with those in Figures 45 and 47.

37. VALVE AND DETECTOR ACTION OF TUBES

We have found that the tube acts as a very sensitive valve, with the grid controlling the current in the plate circuit. It only requires a very small change of potential on the grid to make a much greater change in the plate current. So vacuum tubes also have an amplifying function, due to the fact that a very small amount of energy on the grid, even as small as a few millionths of a watt, will release and control much greater amounts of energy from the B battery.

As the plate current is direct current supplied by the B battery, and only flows in one direction, we also find that a tube connected in such circuits will act as a **rectifier.** Or in other words, we can supply feeble **alternating voltage** to the grid circuit and have strong **direct current pulsations** set up in the plate circuit of the tube.

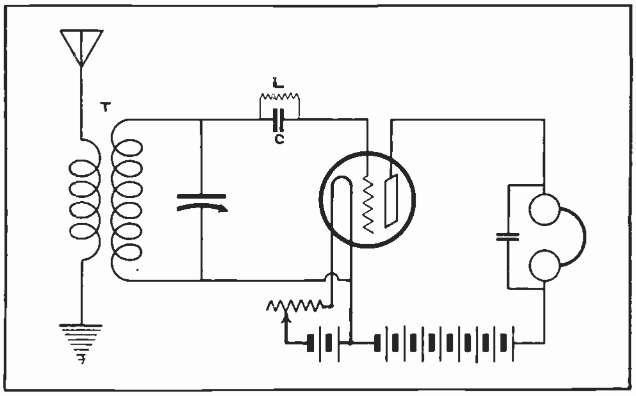


Fig. 49. Diagram of a simple single tube detector circuit using a grid leak and condenser to obtain detector action.

As explained in an earlier article, rectification of the received high frequency energy is necessary to accomplish detection and to enable the headphones to produce audible signals.

From the foregoing we find this rectification and detection can be accomplished with vacuum tubes as well as with crystals.

In Fig. 49 a vacuum tube is shown connected in a simple detector circuit for receiving radio signals. The grid circuit is connected through a grid resistance and condenser, L and C, to the secondary winding of the antenna coupling-coil or R. F. transformer T, and then back to the filament. The grid resistance and condenser will be explained later.

A variable condenser is connected across the R. F. transformer for tuning the circuit to the proper wave length. A pair of headphones and a bypass condenser are now connected in the plate circuit in place of the milliammeter shown in the previous circuits.

38. RECTIFIER ACTION

When the antenna and grid circuits are tuned to receive signals from a transmitter, high frequency A. C. is induced in the grid circuit and this alternating voltage is applied to the grid.

Each time the grid becomes negative the electron stream is diminished and the plate current reduced below normal. Each time the grid becomes positive the electrons are allowed to reach the plate in greater numbers and the plate current is greatly increased. **Thus the application of high frequency A. C. causes pulsating D. C. to flow in the plate circuit.**

If the incoming carrier wave is modulated by voice or code signals, the variations in the value of the A. C. voltage applied to the grid will cause corresponding audio frequency variations in the pulsations in the plate circuit. This in turn sets up vibration of the headphone diaphragms and reproduces the sound.

Fig. 40 showed the audio frequency pulsations resulting from rectified groups of the high frequency waves of code signals, and while these groups were rectified by a crystal detector we now find that tubes will produce the same result. Vacuum tubes are much more sensitive as detectors than crystals are, because the tubes can use such very feeble voltages on the grid to control strong impulses from the B battery through the headphones.

39. OPERATION OF DETECTOR TUBE. GRID VOLTAGE, PLATE CURRENT CURVE

The detector action of vacuum tubes can be greatly improved by taking advantage of a known characteristic of the tube and using just the right grid and plate voltages to work the tube at a certain point on its grid voltage plate current curve. At this particular point the pulsations will be more pronounced in one direction from normal plate current, thus producing greater variations in the pull on the phone diaphragms and greater signal strength.

This point of maximum effectiveness of the tube as a detector is illustrated by Fig. 50, which shows the **grid voltage, plate current curve** or characteristic of a tube. This curve shows the manner in which the plate current of a common type of detector tube will vary with changes in grid voltage.

Note that as the grid voltage is reduced from about 8 volts negative to zero potential, the plate current only increases very little, or from zero to about 1½ milliamperes. As the grid voltage swings past zero and becomes positive, the plate current

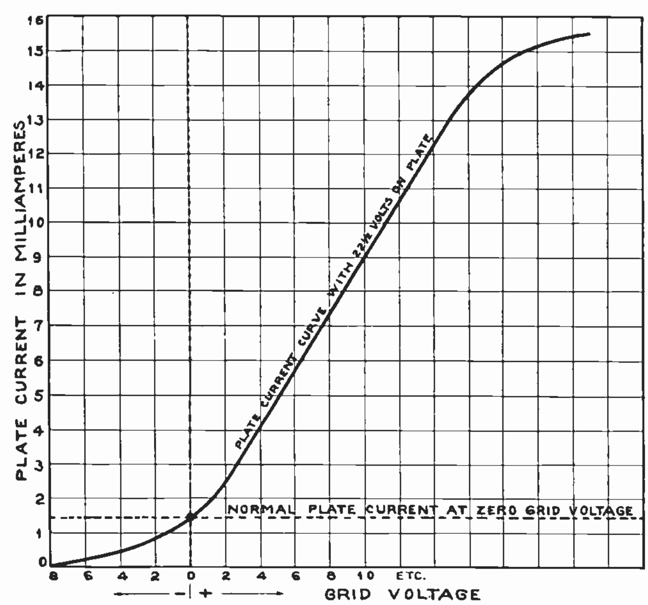


Fig. 50. The above curve shows the manner in which the plate current of a vacuum tube changes with variations of the grid voltage.

increases very rapidly for each volt of increase in positive grid potential, up to the point where it nears saturation.

By using 22½ volts on the plate of this tube, the lower knee or bend of the curve is kept about at the point of zero grid potential, as shown by the vertical dotted line crossing the curve about at this knee. The normal plate current which flows at zero grid voltage is indicated by the horizontal dotted line. Changing the plate voltage will change the shape of the curve somewhat. For example the plate voltage will cause a greater change in plate current for each volt of change in grid potential, and will cause the plate current curve to shift so that the zero grid voltage line will cross it at a point farther out in the straight portion.

If a detector tube is worked with the zero grid voltage point at the knee of the curve as shown in Fig. 50, the alternating voltage applied to the grid will cause the pulsations of plate current to rise farther above normal value than they fall below. This is illustrated in Fig. 51. Here a section of a plate current curve is shown from A to B, the alternating grid voltage curve of an incoming damped wave signal from G1 to G6, and the resulting curve of the pulsating plate current from P1 to P6.

The voltage values of the alternations applied to the grid can be determined by the figures at the tops of vertical dotted lines, and the current values of the D. C. pulsations set up in the plate circuit can be determined by the figures at the left ends of the horizontal dotted lines.

The normal plate current which flows at zero grid potential is shown by the heavy solid and dotted horizontal line. By following the vertical dotted line down from the tip of any alternation of the grid voltage to the point at which it strikes the plate current characteristic curve AB, and then following the horizontal line to the right, the plate current pulsation curve for that grid voltage is found. Then by looking to the left margin the current value of the plate pulsation or impulse can be determined.

You will note that while the positive and negative grid voltage alternations are equal in value or amplitude, the positives cause the plate current to rise about three times as far above normal as the negative cause it to fall below normal. This results in an average current increase or one long pulsation through the headphones. See the curved dotted line which indicates this.

In this diagram only three complete H. F. alternations are shown for the damped wave signal, but an actual wave group of this kind would probably consist of 12 to 30 or more oscillations, and the entire group of pulsations set up by them would be used to make up one of the audio frequency pulsations through the headphones.

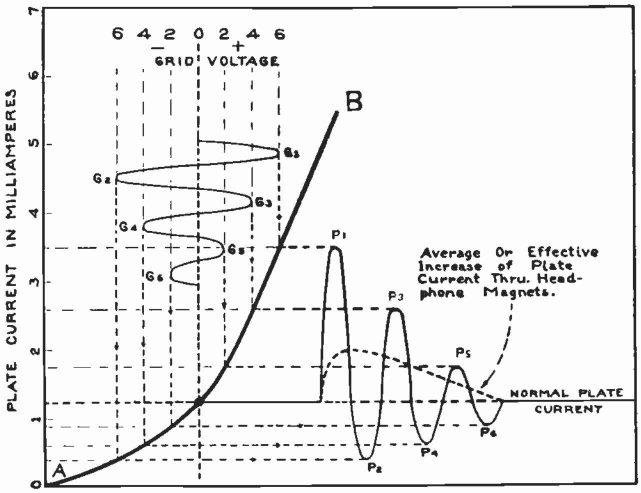


Fig. 51. Curves showing the manner in which the signal voltage of a damped wave train is applied to the grid of a tube, and is both amplified and rectified in the resulting plate current impulses. Study this action carefully in the accompanying paragraphs.

40. GRID BIAS VOLTAGE

We have already stated that a detector tube can be worked at its most efficient point, by using the proper plate voltage to bring the bend or knee of the plate current curve at about zero grid potential. This condition was shown in Fig. 51.

Another method of obtaining rectification or detector action, with maximum variations in plate current for each change of signal voltage on the grid, and thereby producing greater movement and sound from the phone diaphragms, is by giving the grid a negative bias. This means applying or keeping a negative potential on the grid at all times.

This negative potential or bias can be obtained in several different ways. One way being to connect the grid return lead to a point between the filament rheostat and the negative side of the A battery, as at X in Fig. 52 A. This causes a negative potential equal to the voltage drop in the negative side of the filament plus that in the rheostat, to be applied to the grid.

Another method is by use of a "C" battery or biasing battery as shown in Fig. 52 B. Here a low voltage battery C1 is connected in the grid return with its negative terminal toward the grid and its positive terminal to the filament lead. A small by-pass condenser C2 is often connected in parallel with this battery to allow the high frequency signal energy in the grid circuit to pass directly to the filament lead.

At C in Fig. 52 is shown a method of using a potentiometer or variable high resistance P, connected across the C battery for varying the negative biasing voltage applied to the grid. Here again the by-pass condenser C2 is used to keep the feeble signal energy from having to pass through this high resistance in order to get to the filament and complete the grid circuit.

41. GRID LEAK AND CONDENSER

At D in Fig. 52 the negative grid bias is obtained by means of a **grid condenser** and **leak**, GC and GL, which you may recall were also shown in the detector circuit in Fig. 49. These devices accomplish the biasing of the grid in the following manner:

When the tube is in operation some of the negative electrons thrown off by the filament strike the grid and cling to it, thus tending to build up a slight negative charge on the grid. If the grid return is connected to one side of the filament as is generally the case, these negative electrons will flow right back to the filament or their source. If the grid lead was not connected to anything, the electrons not being able to drain or flow off from it would soon accumulate in sufficient amount to build up a considerable negative potential on the grid, and stop practically all flow of electrons from filament to plate, by the repelling action of this negative charge on the grid.

Now if we had some way of holding just the proper amount of this negative charge on the grid and allowing the rest to escape, we could give the grid the desired negative bias in this manner. That is exactly what we do with the grid condenser and grid leak.

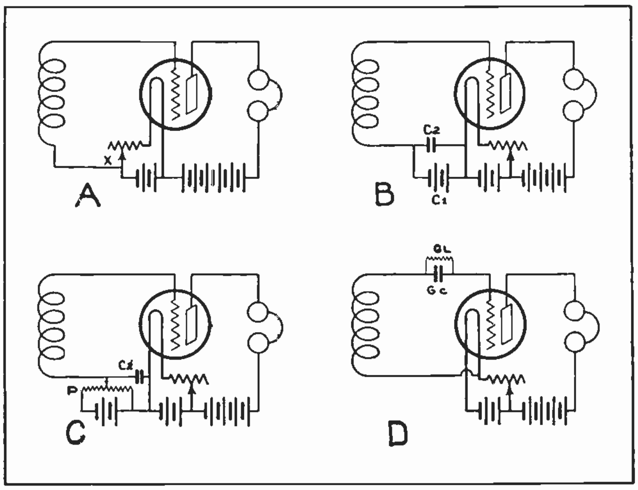


Fig. 52. The above sketches show four common methods of biasing the grid of a vacuum tube with a low negative potential.

The grid condenser, while allowing the high frequency A. C. signal energy to pass through it to the grid, will not allow the direct current flow of electrons or **grid current** to pass through it from grid to filament, around the grid circuit. Thus it acts as a blocking condenser to store up electrons and negative charge or bias on the grid.

Now to prevent this charge becoming too high we place a high resistance "leak" across the condenser to allow the excess electrons to leak back to the filament whenever the grid potential gets high enough.

By selecting the proper sizes of grid condenser and leak for various tubes or circuit conditions the detector tubes can be properly biased for operation at the best point on their curves, and maximum signal strength thus obtained at the headphones. The size of grid condenser commonly used is about .00025 microfarad (mf.), and the grid leaks vary from about .5 to 10 megohms, the 2 megohm size being the most common.

A low resistance leak allows the electrons forming the grid current to flow away from the grid more rapidly, thus maintaining lower negative potential or bias on the grid. A high resistance leak tends to hold back the electrons and grid current flow until greater negative potential is built up on the grid to force them to flow through the resistance back to the filament, and thus the higher resistance maintains a greater negative grid bias.

Too high grid leak resistance may cause the tube to become inoperative or "paralized", by storing up such a high negative potential on the grid that it stops practically all flow of electrons from filament to plate.

Early forms of grid leaks were made with an inked strip of paper held in a tube or case with contact clips at its ends. The ink formed the very high resistance path through the leak. Later forms of grid leaks consist of a thin metallized or graphite coating applied in liquid form and dried and baked on the inside of a glass tube, or on a slender insulator element in the tube.

The grid leak method of detection is more sensitive than the C battery method and is therefore best to use for very weak signals, from the antenna. The C battery method is best for handling strong signals, as there is less liability of overloading the tube. One advantage of the grid leak method is that a leak of proper resistance will automatically control or adjust the grid bias for variations in signal strength. This can be understood by applying Ohms Law. We know that the current flow through any certain resistance will be proportional to the voltage applied. So whenever the electrons tend to build up a higher negative potential on the grid, this higher potential speeds up the rate of flow through the grid leak and keeps the negative bias quite well controlled.

42. EFFECT OF NEGATIVE BIAS

Now let us see just what effect this negative bias has on the operation of a detector tube.

First of all it allows the use of much higher plate voltages, to obtain greater output from the tube and stronger signals in the headphones. Then by biasing the grid with a negative potential the incoming signal oscillations simply cause the grid potential to become more or less negative, instead of positive and negative. This in turn causes all the variations or changes in plate current to be below normal instead of part above and part below, as when the grid is operated at zero potential.

Operating the tube with a negative grid bias, or keeping the grid always at some negative potential, also prevents the grid from attracting to itself such

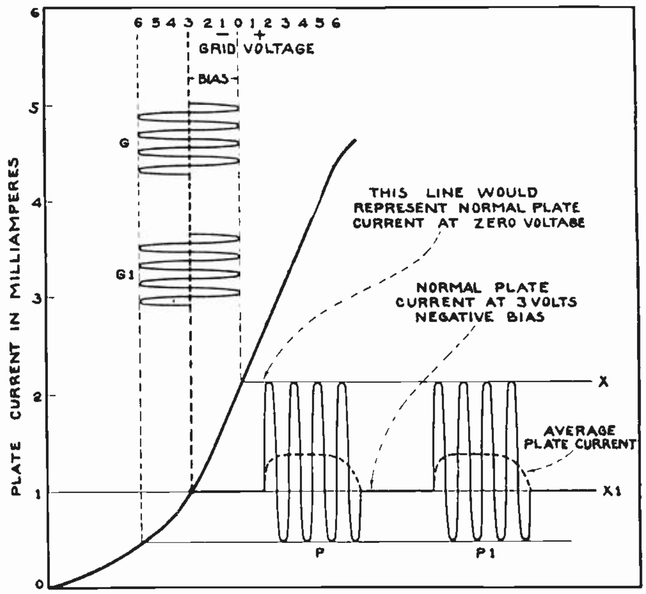


Fig. 53. These curves illustrate the rectifier or detector action obtained from a tube operating with a negative bias on the grid. This sketch shows I.C.W. signals applied to the grid, instead of damped wave signals as shown in Fig. 51.

large numbers of electrons from the filament and thereby reduces the **grid current.** Excessive grid current is very objectionable as it robs the plate circuit of some of its current thereby reducing the tube efficiency, and it also tends to cause distortion of the signals.

The manner in which a negative grid bias or potential reduces the grid current can be readily understood by keeping in mind that if the grid is always slightly negative it will not attract negative electrons to itself, even though it will allow them to pass through between the grid wires to the plate if the positive plate voltage is kept high enough to draw them on through. On the other hand, if the grid is not biased and is allowed to become positive on every other alternation of the applied signal voltage, it then attracts negative electrons to the grid wires, robbing the plate of that amount, and setting up grid current flow in the grid and filament circuit.

Fig. 53 illustrates the manner in which a constant 3 volt negative grid bias from a C battery or some DC source is used on a detector tube to work the tube at the proper point or knee of the plate current curve applied to it, which has high plate voltage.

The use of the higher plate voltage causes the plate current curve to shift over so that the point of zero grid voltage comes in the straight portion of the curve, as shown by the light dotted vertical line running down from zero. The horizontal line X would represent the normal plate current at zero grid voltage.

By using the 3 volt grid bias the working point of the grid voltage is shifted to the left of zero as shown by the heavy dotted vertical line. The normal plate current with the grid bias in use is represented by the horizontal line X1.

The curves G and G1 represent two groups of I. C. W. or interrupted continuous wave signal voltages applied to the grid. This signal voltage being alternating and of 3 volts amplitude, swings back and forth from 3 volts positive to 3 volts negative. But on account of the 3 volts bias the grid signal voltage starts at 3 volts negative and causes the grid voltage to swing from zero to 6 volts negative and back again, but never positive.

The resulting pulsations or variations in the plate current as shown by the curves P and P1, increase and decrease from about 2.2 to .4 milliamperes, but never rise above the line X or what would be the normal current at zero grid voltage.

The average plate current or the audio frequency pulsations which flow through the headphones are shown by the dotted curves.

43. EFFECT OF GRID LEAK AND CONDENSER ON SIGNAL STRENGTH

Fig. 54 illustrates approximately the operation of a tube using the grid leak and condenser method of biasing the grid. In this case the negative bias is not constant as with the C battery, but builds up during each signal group as the grid accumulates more and more electrons as each positive alternation of the signal voltage is applied to it. This causes the bias voltage to swing from zero over to negative about as shown by the dotted curve X. This is due to the negative electrons accumulating on the grid a little faster than they can leak off during the signal. Then during the idle period between groups of alternations the leak drains the grid potential down to zero again, as shown in Fig. 54 by the dotted curve X falling back to the vertical zero line each time between signal groups.

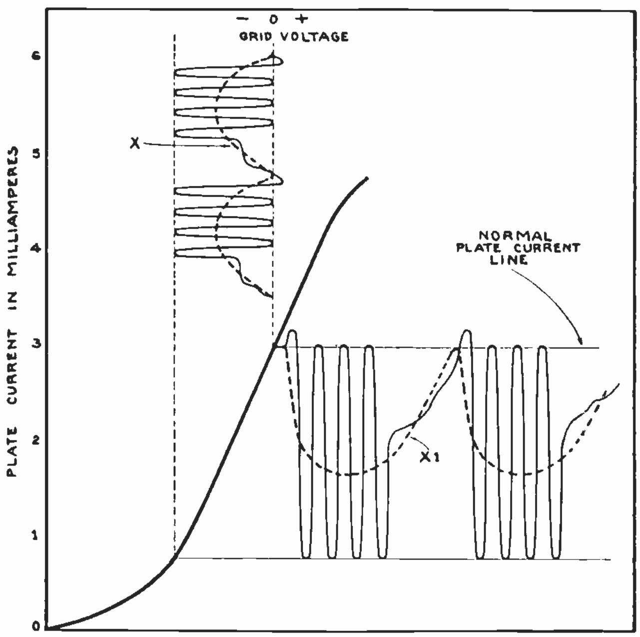


Fig. 54. Curves illustrating detector action of a tube using a grid leak and condenser to obtain maximum rectification with plate current impulses falling below the normal plate current.

However, the fact that the biasing voltage keeps practically all of the grid voltage variations on the negative side, the pulsations of plate current are practically all downward from the normal plate current. The dotted curve X1 shows the approximate average plate current, and you will note the very decided decrease from normal during each signal group. This decrease of current through the phone magnets releases their diaphragms, and then as the average current rises back toward normal between signal groups the diaphragms are again attracted, thus causing strong vibration.

You will also note that this form of bias allows the tube to be worked on a straight portion of the steeper curve above the bend or knee, thus making the full swing or change or grid voltage much more effective in producing decreases or variations in the plate current. This is one of the reasons for the extreme sensitivity of the grid condenser and leak method of detection.

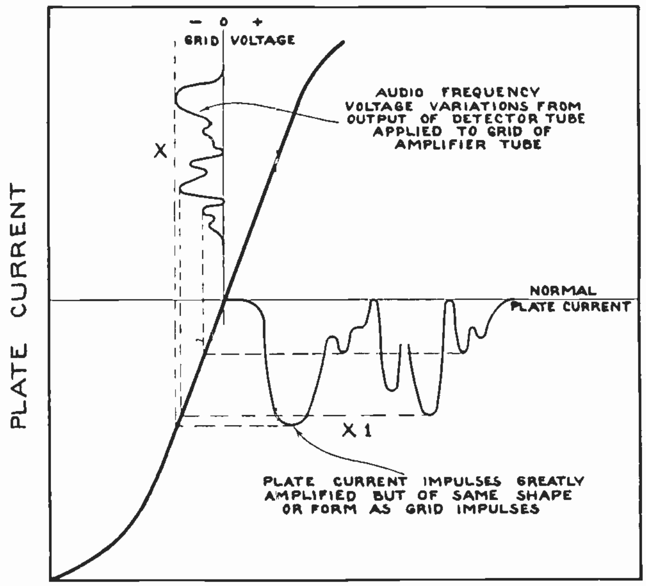


Fig. 55. Detector action illustrated with audio frequency curves of the average variations caused in the grid voltage and plate current by the voice modulation on the carrier wave.

44. VACUUM TUBES AS AMPLIFIERS

We have already learned that vacuum tubes can be used for amplifiers as well as for detectors, because of the fact that a small change in grid voltage and power will cause a much greater change in plate current and power.

For amplification we do not need to operate the tube at the knee of its curve as we do to obtain best results in rectification and detection. Instead we operate it on the straight portion of the curve so that all variations or increases and decreases of grid voltage will be amplified equally, and the waves or impulses kept unchanged in shape and merely increased in amplitude or volume.

Fig. 55 illustrates this amplifier action of a vacuum tube. The average voltage or output impulses of

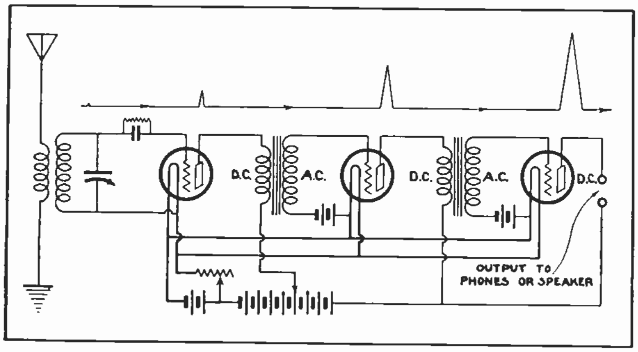


Fig. 56. Circuit diagram of a simple 3 tube receiver with one tube used as a detector and two as amplifiers. Note how the signal strength is increased by each tube.

the detector tube are applied to the grid of this amplifier tube as shown at X. These are greatly amplified in the pulsations of plate current in the amplifier tube as shown at X1, but you will note that they retain their original shape or form.

In Fig. 56 is shown a circuit by means of which the output of the detector tube is fed to the grid of an amplifier tube through an audio frequency transformer. The output of this amplifier tube is then fed to the grid or input of another tube for still further amplification if desired. This would be referred to as two stages of **Audio Frequency** amplification, as these amplifier tubes only handle the energy after it is detected and converted into A. F. pulsating D. C., by the detector tube and impedance of the first transformer primary. Each separate amplifier tube with its transformer and circuit is called one **stage** of amplification.

The peaks in the horizontal line above the circuit diagram in Fig. 56 illustrate how the signal strength is increased by the amplification effect of the detector tube and by both of the amplifier tubes.

The output of the detector tube is pulsating D. C., but by passing this through the primary of the first A. F. transformer it sets up A. C. in the secondary and in the grid circuit of the first amplifier tube.

This alternating current, however, carries the same general wave form and variations in value as the pulsating D. C., and thus conveys the signal to the grid of the amplifier tube. Here again it is amplified and rectified to pulsating D. C., and then passed on through the next A. F. transformer to the next amplifier tube, etc.

The audio frequency transformers not only serve as a means of coupling the tubes and circuits together but also serve to aid amplification by increasing the voltage on the grids of following tubes, as these transformers are generally wound with a step-up ratio of about 1 to 2 or 1 to 3.

Amplifier tubes are also used to increase the strength of the signal before it reaches the detector tube. This is called R. F. or **radio frequency** amplification as it is done before the energy is rectified and converted to audio frequency. Fig. 56-B shows the manner in which an R. F. amplifier tube increases the voltage or amplitude of the incoming R. F. signal and leaves it in the same true I. C. W. form, for rectification later in the detector tube.

45. AMPLIFICATION FACTOR

Some vacuum tubes are better amplifiers than others, depending upon their construction, and in particular upon the size and spacing of the grid wires and the distance between the grid and plate. Using small diameter grid wires, closely spaced, and placing the grid closer to the plate increases the amplifying ability of a tube.

The term **Amplification Factor** is used to express the amount of amplification that can be obtained with a certain tube. This Greek letter Mu (μ) is used as a symbol for amplification factor, and the expression "low Mu" or "high Mu" is often used in connection with amplifier tubes to express their ability as amplifiers.

The amplification factor of a tube is determined by comparing the amount of plate voltage increase required to make a certain change in plate current, with the change of grid voltage required to make the same amount of change in plate current.

For example, if a 3 volt change in grid voltage makes a change of 10 milliamperes in the plate current, and it requires a change of 30 volts on the plate to make the 10 milliamperes variation in plate current, then the amplification factor of that tube will be 30 $\div$ 3 or 10. The amplification factor of ordinary tubes such as the 201 or 301 types usually ranges from 6 to 10 although special high Mu tubes are made with amplification factors of 30 to 40 or more.

Amplifier tubes are used for **Voltage Amplification** in some parts or radio receivers, and for **Power Amplification** in other parts. Voltage amplification

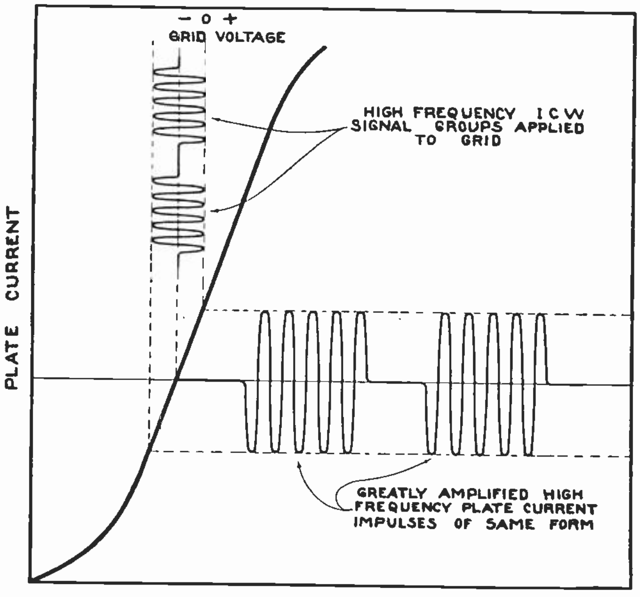


Fig. 56-B. Curves illustrating amplifier action of a vacuum tube. Note that the grid voltage impulses are greatly amplified or increased in the plate current impulses, but are kept in the same form instead of being rectified.

to merely increase the voltage on the grid of each successive tube, is commonly used in radio frequency stages and in the first audio frequency stages, while power amplification which increases both voltage and current is used in the final audio frequency stages.

For very sensitive detectors special soft, low vacuum or gas filled tubes are sometimes used, but in many sets ordinary hard or high vacuum tubes are used both for detection and amplification.

Fig. 57. Photo of power amplifier tube such as used for obtaining great amplification and handling larger amounts of plate current for producing stronger signals from radio receivers. (Photo courtesy of R. C. A. Radiotron Co., Inc.)

For power amplification larger tubes of special construction, having lower internal resistance and greater capacity in milliamperes or watts are used. These power tubes provide the energy required for operation of large loud speakers and for better reproduction of the heavy bass notes of music. Power tubes are very similar to ordinary amplifiers, except that their elements are larger, and they are designed for much higher plate voltages. Fig. 57 shows a power tube which has a capacity of 34 milliamperes plate current, or over 1.6 watts without distortion.

46. SPACE CHARGE

The cloud or stream of negative electrons which are thrown off by a tube filament into the space between the filament and plate, create a negative charge in this space. This is called the **Space Charge** in a tube.

The space charge tends to prevent free emission of electrons from the filament, as the negative charge or electron already in the space tend to repel and throw back the fresh electrons coming from the filament. The space charge is of course greatly reduced by the positively charged plate and also by the grid at any time it becomes positive, because they tend to attract the electrons, drawing them away from the filament more rapidly.

One way of further reducing the space charge is to equip a tube with an extra grid located between the regular grid and the plate, and by keeping this grid at some positive potential to aid the plate in attracting the negative electrons.

This extra grid is called a **screen grid** or **shield grid** and will be more fully described in later paragraphs.

47. INTERNAL CAPACITY EFFECT IN TUBES

There is a small amount of capacity or condenser effect between the metal elements inside a vacuum tube, as these parts being separated by gas or vacuum and supplied with varying voltages, act as plates of a small condenser.

The capacity between the grid and filament and between the plate and filament is generally about 5 M. M. F. (micro-micro-farads), or small enough so it does not interfere with the tube operation to any great extent. The capacity between the plate and grid, however, is about 8 M. M. F. in common detector and amplifier tubes, and may have a decided effect on the operation of the tube.

This capacity is extremely small when compared with most of the condensers used in radio circuits, one micro-micro-farad being only one millionth part of a micro-farad. But even this small amount of 8 M. M. F. in a tube is sufficient to create enough capacity coupling between the input and output circuits of the tube at radio frequencies, to set up a feed back from the plate or output to the grid or input circuit. This often results in bad oscillation of the circuit and howling in the phones or speaker. In other cases the capacity between the tube electrodes causes absorption of energy from the input circuit by the output circuit.

There is also a certain amount of capacity between the socket terminals and wiring of tubes to add to this undesirable coupling effect through the tube.

In order to prevent oscillation and howling, and reduced efficiency of the tube and its circuits, this tube capacity must either be neutralized in some manner, or reduced to a minimum by special construction within the tube. A method of neutralizing it by means of a small condenser outside the tube will be explained later. A method of reducing the capacity effect in newer type tubes is by the use of the extra grid or screened grid which has already been mentioned for reducing space charge.

48. SCREEN GRID TUBES

The screen grid, we have now found, will serve a double purpose of **reducing the space charge** and also **reducing the interelectrode capacity** of tubes.

Fig. 58 shows a diagram of a screen grid tube connected in one stage of a radio receiver. This sketch shows the screen grid connected to the B battery or plate current supply, at a point which will supply it with from 22 to 45 volts positive potential. It is this positive potential which causes the screen grid to attract negative electrons toward itself and toward the plate which is charged positive at 90 to 135 volts or more, and draws most of the electrons on through to itself. In this manner the screen grid helps to reduce the space charge, thereby greatly increasing the efficiency and the amplification factor of the tube.

Amplification of 30 to 60 times can be obtained with screen grid tubes, as compared with 6 to 10 times for ordinary tubes without this extra grid.

You will note in Fig. 58 that the screen grid is made in two parts one of which is between the control grid and the plate, and the other on the outside of the plate so that a complete shield is formed around the plate.

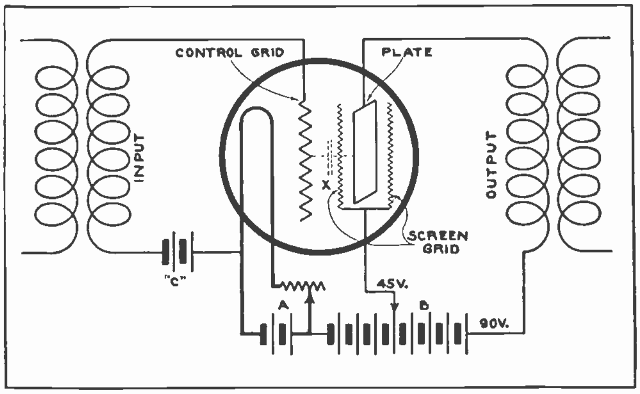


Fig. 58. Diagram of a screen-grid tube showing the connection of the screen grid, and illustrating the manner in which it reduces the capacity between the control grid and plate.

The capacity between the control grid and plate in a tube without the screen grid, would be as shown by the dotted condenser X. But when the screen grid is inserted it acts as a shield between the grid and the electrostatic field around the plate and thereby reduces the capacity effect between grid and plate to about .01 M. M. F. as compared with 8 to 10 M. M. F. in ordinary tubes.

This very great reduction of grid to plate capacity of the tube almost entirely prevents objectionable oscillation and feed back.

The inner section of the screen grid consists of a spiral of closely spaced fine wires, very much like the regular control grid. The outer shield or section of the screen grid surrounding the plate consists of a screen mesh or a perforated band of sheet metal.

Fig. 59 shows a screen grid tube with part of the outer screen and plate cut away to show the inner construction. Note the inner section of the screen grid which surrounds the filament and control grid, and is located between the control grid and the plate.

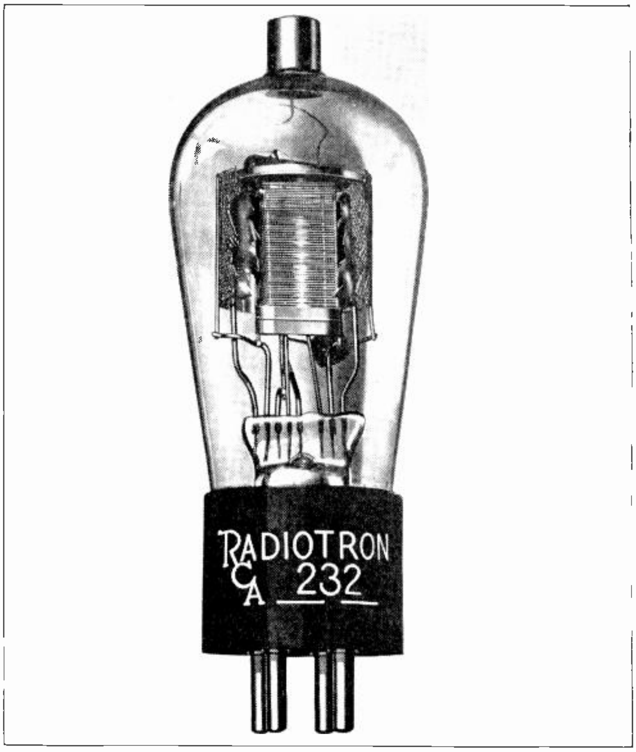


Fig. 59. This excellent photograph shows a vacuum tube with part of the outer screen grid and part of the plate removed, to clearly show the inner screen grid in its position between the control grid and plate. (Photo courtesy of R. C. A. Radiotron Co., Inc.)

The screen grid lead is brought out to the regular grid prong on the tube base, and the control grid lead on this type of tube is brought out to the small metal cap on top of the tube.

Screen grid tubes being very sensitive to outside capacity influence require good shielding from other stages and parts of the circuit. Where complete interstage shielding is not provided the tubes themselves are often equipped with grounded metal shields or hoods.

Screen grid tubes are largely used as R. F. amplifiers, although in some cases they are used as detectors.

49. PLATE RESISTANCE AND MUTUAL CONDUCTANCE

The internal resistance or plate circuit resistance of a vacuum tube depends upon several factors in the tube design, such as (a) spacing between tube elements, (b) length and area of filament, (c) filament condition-temperature and efficiency of electron emitting surface, (d) area of plate, (e) amplification factor, and (f) applied voltages.

This plate resistance of course causes a certain amount of loss in the tube, proportional to the amount of resistance. It is, therefore, desirable to keep the plate resistance as low as possible without changing the tube design in such a manner that it interferes with other desirable characteristics.

For example, a tube which is constructed with the proper spacing between grid wires and between the grid and plate, to obtain a high amplification factor, generally has a high plate resistance also.

The plate circuit resistance to D. C. can be easily determined according to Ohms law, or by dividing the plate voltage by the plate current. For example, if a certain tube has 45 volts applied to its plate and shows a plate current flow of 1.7 milliamperes or .0017 amperes, then as

$$R = \frac{Ep}{Ip}$$

the resistance will be $\frac{45}{.0017}$ or 26,470+ ohms.

Plate resistance is generally expressed in Ohms resistance to the A. C. component of the pulsating D. C. plate current, and as this value is approximately one half that of the D. C. resistance, it is easy to determine the A. C. resistance by calculating the D. C. resistance and dividing it by 2. The term **plate impedance** was formerly extensively used for A. C. resistance, but the latter term is now becoming more generally used.

As both the plate resistance and the amplification factor of a tube greatly affect its performance, the term **Mutual Conductance** which considers both of these factors, is quite generally used in expressing or comparing the values of tubes of the **same general type.**

Mutual conductance is expressed in **Micromhos,** and is found by dividing the amplification factor of a tube by its plate resistance, or

$$GM = \frac{\mu}{rp}$$

In which GM = Mutual Conductance in micromhos
μ = Mu or amplification factor
rp = plate resistance

In general, tubes with high mutual conductance are more efficient amplifiers than those of similar types having lower mutual conductance (GM). One should be sure, however, that the comparison is made between tubes of the same general type or tubes designed for the same service, and with similar characteristics in other respects. This is because tubes of a different type having more of certain other characteristics might be better under certain conditions.

50. A. C. TUBES

Early types of vacuum tubes were all developed with filaments designed for heating with D. C. from low voltage A batteries, and great quantities of D. C. operated tubes are still made for use in battery operated sets in farm homes and places where electric power supply is not yet available. Most modern radio sets for use in city homes and places where 110 volt A. C. power is available, are made with A. C. tubes, which have their filaments heated by current from the low voltage secondary of a transformer. This is a great convenience as it eliminates the necessity of the messy and bulky wet storage batteries formerly used for filament power.

A. C. tubes are of two general types known as **Filament Type** and **Heater Element Type.**

A. C. "filament type" tubes have simple filaments very much like those of D. C. tubes, except that they are generally made of a shorter and heavier wire. This enables them to hold their heat a little longer and does not allow the heat to vary so much with the rise and fall of the A. C. voltage.

In filament type A. C. tubes the filament serves as the cathode or electron emitter the same as in D. C. tubes.

In order to avoid very objectionable hum from the variations in the A. C. voltage, it is necessary to connect the grid return on these tubes to a center point on the filament, so that the voltage drop is equally balanced on each side of this connection. This is done either by using the center tap on a resistance unit connected across the filament terminals, or by use of a center tap sometimes provided on the secondary of the filament transformer. At A in Fig. 60 is a sketch showing how this connection is made to the center tap of a resistor, and the dotted lines show how it would be made to a center tap on the transformer. Use of a resistance with a variable center tap allows the grid connection to be adjusted to the point of best balance and least hum.

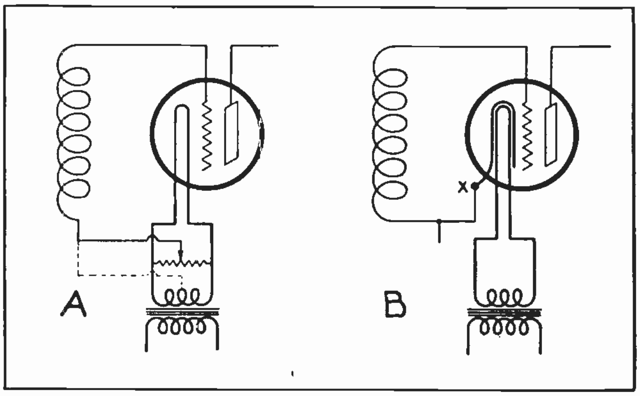


Fig. 60. At A is shown a vacuum tube using A. C. to heat the filament, and having the grid return lead connected to the center of a potentiometer. At B is shown an A. C. heater-element type tube using A. C. for the filament and having a separate cathode which is heated by the filament.

Filament type A. C. tubes are only used as amplifiers and oscillators but not for detectors, because even with the most careful selection of the neutral point for the grid return, considerable hum will be set up if they are used as detectors. Filament type A. C. tubes are generally called the "26" type as these last two numbers of the tube description number are commonly used to designate this type of tube. It is well to note at this point that the last two numbers on a tube, are the ones that usually denote its type, and the preceding letters and numbers indicate the manufacturer.

51. HEATER ELEMENT TUBES

Heater element type A. C. tubes use a small oxide coated nickel cylinder as the cathode or electron emitter, and this cathode is heated by a filament which is placed inside the cylinder but is insulated from it. In these tubes the filament serves only as the heater element and not as the cathode or electron emitter, and can therefore be made of ordinary tungsten wire.

The filament being entirely insulated from the cathode or electron emitting element practically none of the influence of the A. C. voltage variations is allowed to affect the cathode. In this manner practically all A. C. hum is eliminated.

The grid return lead on these tubes is connected to the cathode lead which is brought out to a fifth prong on the Y type, five prong bases used for these tubes. Fig. 60-B shows the connection of the grid return to the cathode lead at X. Fig. 61 shows a sketch of a heater element type A. C. tube, showing a sectional view of the elements. Note the location of the filament or heater wire inside the insulator which separates it from the cylindrical cathode. This view clearly shows how the cathode is heated by heat from the filament passing through the insulator to the cathode, and also how the insulator separates the filament and cathode electrically, thus preventing A. C. hum.

The grid and plate are also shown in sectional view in this sketch.

Fig. 61-A shows a photo of an A. C. heater element tube with part of the special mesh type plate torn away to show the grid and cathode inside.

A. C. tubes of the heater element type require from a few seconds to a half minute or more to heat up and become operative, as it takes a little time for the heat from the filament to pass through the insulating tube to the cathode. This time lag in the heat change is desirable, however, as it also works the other way, requiring a short period for the cathode to cool off, and thus making the tube less sensitive to momentary voltage variations and to the continuous variations in the A. C. voltage due to its alternations.

A. C. tubes of the heater element type are used both for detectors and amplifiers. Their filaments operate on about 2.5 volts and require about 1.75 ampere.

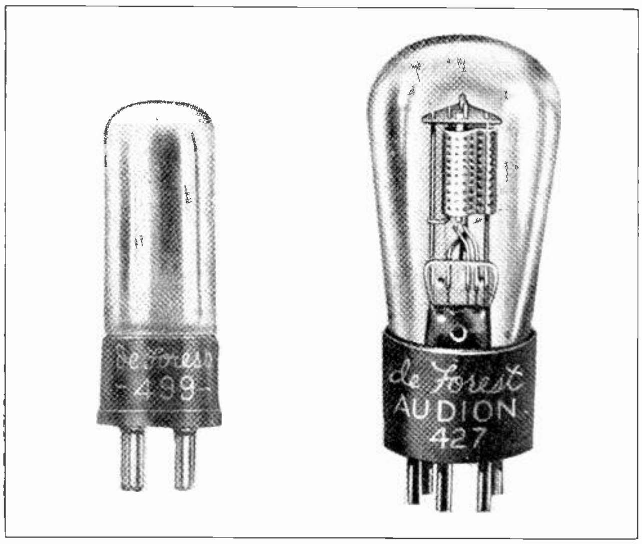


Fig. 61. Photo showing two different types of vacuum tubes for use in radio receivers. The filament of the small tube on the left can be operated on dry cells thus making it very good for use in portable sets. (Photo courtesy of DeForest Radio Co.)

Fig. 61-A. Photograph of an A. C. heater-element vacuum tube with part of the plate removed to show the grid and the cathode inside of which the heater element or filament, is located. (Photo courtesy of R. C. A. Radiotron Co., Inc.)

52. TYPES OF VACUUM TUBES

Vacuum tubes for receivers are made in a wide variety of types and sizes, ranging from the little dry cell operated detectors and amplifiers up to power amplifiers capable of handling several watts.

For transmitting purposes, amplifier, modulator and oscillator tubes are commonly made in sizes ranging from 15 watts to 20,000 watts, and some special tubes have now been made to handle 200,000 watts.

On the left in Fig. 61 is shown a "99" tube of the dry cell operated tube for use in portable receiving sets or sets for use in places where A. C. power supply is not available and where storage batteries are undesirable. These tubes use less than .07 amp. at 3 volts for their filaments, so can be operated on a few dry cells for several months of ordinary use.

On the right in Fig. 61 is shown a "27" tube such as commonly used for either detector or amplifier duty. This is an A. C. tube of the heater element type.

On the left in Fig. 62 is shown a "24" tube of

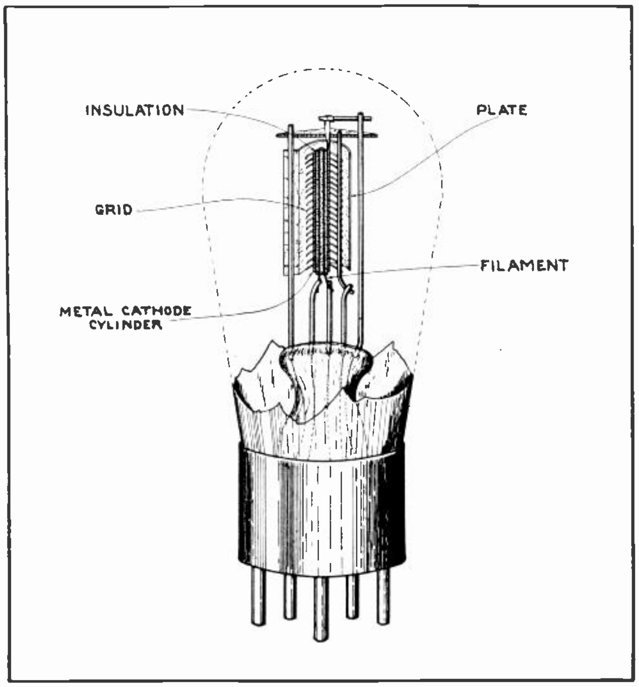


Fig. 61-B. This sketch gives a sectional view of an A. C. tube and shows the construction of the heater element, its insulator, the cathode, grid, and plate of the tube.

high Mu or high amplification factor. This is an A. C. heater element screen grid tube.

On the right in Fig. 62 is shown a "50" power amplifier tube which operates with a filament voltage of 7.5 volts, filament current of 1.25 amperes, plate voltage of 250 to 450 volts, and is capable of handling 4.6 watts of undistorted power output.

Fig. 63 shows a 15 watt transmitter tube on the left and a 50 watt tube on the right. Fig. 64 shows a 250 watt transmitter tube on the left and a 5,000 watt transmitter tube on the right. This 5,000 watt tube is water cooled by circulating cool water through the large metal jacket attached to the tube.

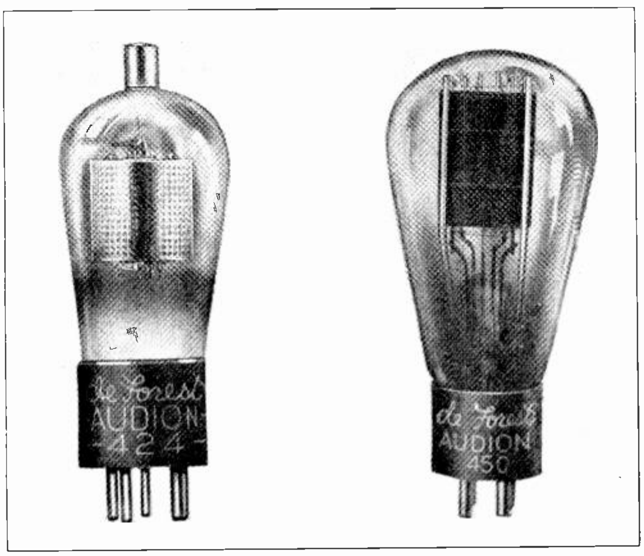


Fig. 62. On the left is shown a screen grid amplifier tube, and on the right a power amplifier tube. (Photo courtesy of DeForest Radio Co.)

In selecting or working with receiving tubes always keep in mind that the last two figures of the tube number designate the general type, and the first figure and letters denote the manufacturer. Cunningham tubes are generally known by the leters C or CX preceding their numbers, and the first figure is usually a 3, as C-301, C-327, etc.

Radio Corporation tubes are known by the letters R C A, UX, UV, or UY preceding their numbers, and the first figure is generally a 1, 2, or 8, as R C A-232, UV-199, UX-222, UX-865, etc. DeForest tubes have the name marked on the tube, and use no letters before the numbers, but the numbers generally start with the figure 4 on receiving tubes and the figure 5 on the transmitting tubes.

Regardless of whose make the tubes may be, on all those made by standard manufacturers the same last two figures always denote the same general type of tube. For example C-327, Ux-227, and 427 tubes are all detector-amplifier tubes, or tubes suitable for either detection or amplification, and they all have very similar characteristics.

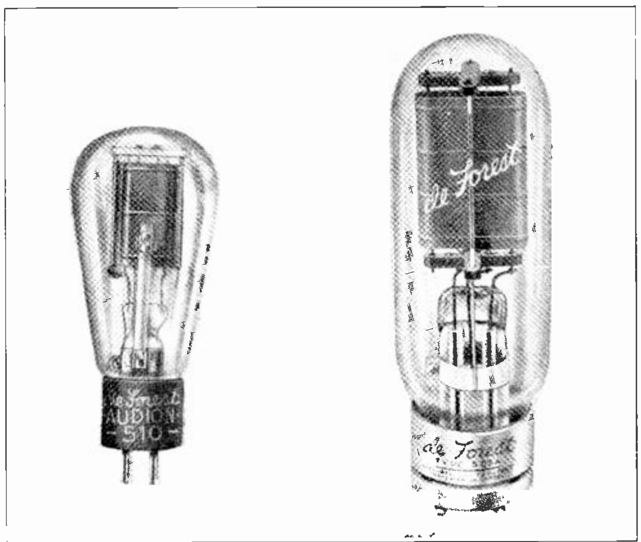


Fig. 63. This photo shows a 15 watt transmitter tube on the left, and a 50 watt transmitter tube on the right. These tubes are constructed very similarly to those for receivers except that they have larger elements spaced farther apart to handle the greater plate currents at higher voltages. (Photo courtesy of DeForest Radio Co.)

Fig. 65 is a chart giving the average characteristic of a number of the most common types of vacuum tubes used in radio receivers and in small transmitters. Study this chart very carefully noting the interesting and valuable data and information given for each tube, and if you will become familiar with the use of this chart you will find it very valuable when selecting or testing tubes for various equipment. The data given helps to select tubes with proper characteristics for the set and conditions in which they are to be used. When testing tubes one can tell whether they are in good condition or not by comparing their operation with the data given for them. This chart is also valuable when checking up on operating voltages and con-

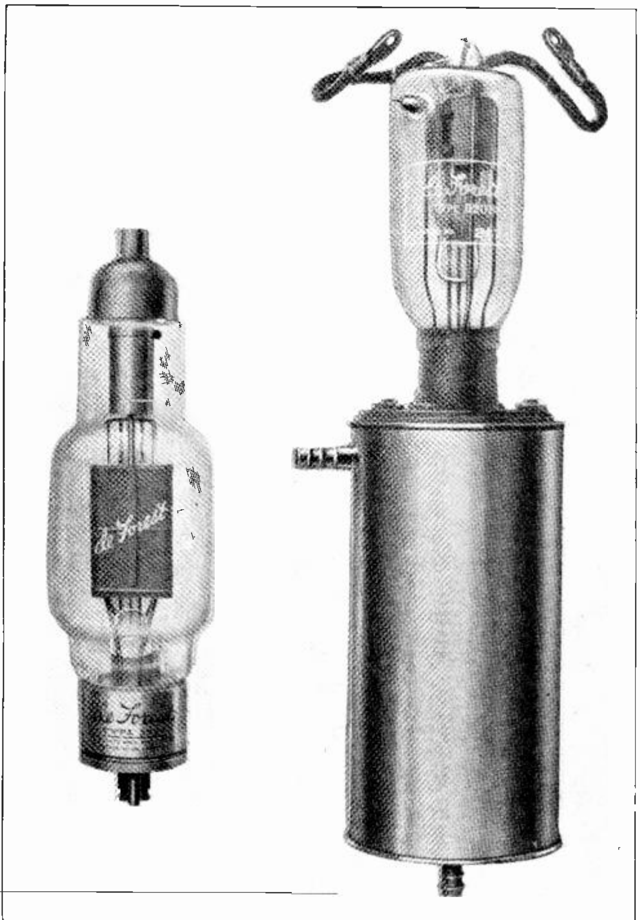


Fig. 64. The tube on the left in this photo is a 250 watt transmitter tube, and the one on the right is a water-cooled 5000 watt tube for large radio transmitters. (Photo courtesy of DeForest Radio Co.)

ditions in a set to make sure that the tubes are not being abused and to adjust the set for satisfactory efficient operation and for maximum tube life.

53. RECTIFIER AND VOLTAGE REGULATOR TUBES

Special types of vacuum tubes are also used as rectifiers in "all electric" sets for converting or rectifying A. C. to D. C. for the plate supply and grid biasing energy. Fig. 66 shows a half wave rectifier tube on the left and a full wave tube on the right.

The 481 tube on the left will give an output of 110 milliamperes, of half wave current, and the 480 tube on the right will deliver 125 milliamperes of full wave current.

The general principles of vacuum tube rectifiers have been explained in earlier sections of this reference set, pertaining to rectifiers and chargers. You will recall that here again the hot filament is used as an electron emitter to enable current to flow from plate to filament only when the plate is positive and attracts negative electrons to complete the circuit. When the plate is negative it repels the electrons and prevents the flow of current through the tube in the reverse direction. By using two plates as in the tube on the right in Fig. 66, both halves of the cycle can be rectified or passed through in one direction, current flowing first from one plate and then the other, to the filament. Fig. 67 shows another type of half wave rectifier tube a little different from the one on the left in Fig. 66, but which operates very much the same. This tube is used to obtain higher D. C. voltages than can be handled with the ones shown in Fig. 66.

Another specially designed tube is used as a ballast or voltage regulator tube in sets supplied with current from A. C. light circuits. These tubes have a fine wire anode and a large plate for a cathode, and are filled with a mixture of gasses at low pressure. When a certain voltage is applied to these electrodes the gas becomes ionized and allows current to flow from the anode to the cathode.

The valuable characteristic of these tubes is that their voltage drop remains almost constant for any value of current through them, up to their maximum load. With the tube connected in parallel with a section of the resistance which is used across the output of the B voltage supply, it tends to absorb or smooth out variations in current load drawn by the tubes in the set, thus keeping the current in the resistance uniform, and thereby keeping the voltage drop and plate voltage nearly constant.

54. REACTIVATION OF VACUUM TUBES

As mentioned before the life of good receiver tubes should be from 800 to 1,000 hours of normal use. Some tubes become inactive or very inefficient in a much shorter period, however. One should always keep in mind that the filament does not have to be burned out to make a tube useless. Tubes often fail because of a leak in the bulb and a loss of their vacuum, or after a period of service, fail because the electron emitting material has been exhausted from the surface of the filament. In other cases their electron emission may have been impaired by overloading the tubes with too high plate voltage.

In such cases tubes of the thoriated type can generally be **reactivated** or brought back to normal emission by application of carefully controlled over-voltage to their filaments.

When performing this operation the voltage should be carefully checked with a voltmeter and accurately controlled.

For ordinary reactivation about 25 to 35 percent over-voltage can be applied to the filaments for about 1 to 1½ hours, **without any plate voltage applied** during this period.

This heats the filament to a point where it boils or melts out a certain amount of the thorium from inside the metal of the wire to its outer surface, faster than the thorium is consumed by electron emission.

During normal operation of a tube the thorium consumed from the filament surface is constantly replaced by more from within the metal until the

RCA RADIOTRON AVERAGE CHARACTERISTICS CHART

DETECTORS AND AMPLIFIERS

Type	Use	Base	Max. Overall Dimensions: Height	Max. Overall Dimensions: Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes	Detection*: Plate Supply Volts	Detection*: Plate Current Milliamp.	Detection*: Grid Return Lead To	Amplification: Plate Supply Volts	Grid Bias Voltage: D. C. on Fil.	Grid Bias Voltage: A. C. on Fil.	Plate Current Milli-amp.	Screen Grid Volts	A. C. Plate Resistance Ohms	Mutual Conductance Micromhos	Voltage Amplification Factor	Ohms Load for Maximum Undistorted Output	Maximum Undistorted Output Milli-watts
WD-11	Detector or Amplifier	WD-11	4 1/8"	1 3/16"	D. C.	1.1	0.25	45	1.5	+F	90 135	4.5 10.5	— —	2.5 3.5	— —	15500 15000	425 440	6.6 6.6	15500 18000	7 35
WX-12	Detector or Amplifier	UX	4 11/16"	1 7/16"	D.C.	1.1	0.25	45	1.5	+F	90 135	4.5 10.5	— —	2.5 3.5	— —	15500 15000	425 440	6.6 6.6	15500 18000	7 35
UX-112-A	Detector or Amplifier	UX	4 11/16"	1 13/16"	D. C.	5.0	0.25	45	4.0	+F	90 135	4.5 9.0	— —	5.5 7.0	— —	5600 5300	1500 1600	8.5 8.5	5600 8700	30 120
UV-199	Detector or Amplifier	UV-199	3 1/2"	1 1/16"	D. C.	3.3	0.063	45	1.0	+F	90	4.5	—	2.5	—	15500	425	6.6	15500	7
UX-199	Detector or Amplifier	Small UX	4 1/8"	1 3/16"	D. C.	3.3	0.063	45	1.0	+F	90	4.5	—	2.5	—	15500	425	6.6	15500	7
UX-200-A	Detector	UX	4 11/16"	1 13/16"	D. C.	5.0	0.25	45	1.5	−F	Following UX-200-A Characteristics Apply Only for Detector Connection					30000	666	20	—	—
UX-201-A	Detector or Amplifier	UX	4 11/16"	1 13/16"	D. C.	5.0	0.25	45	1.5	+F	90 135	4.5 9.0	— —	2.5 3.0	— —	11000 10000	725 800	8.0 8.0	11000 20000	15 55
UX-222	Radio Freq. Amplifier	UX	5 3/8"	1 13/16"	D. C.	3.3	0.132	—	—	—	135 135	1.5 1.5	— —	1.[illegible] 3.[illegible]	45 67.5	850000 600000	350 480	300 290	— —	— —
UX-222	Audio Freq. Amplifier	UX	5 3/8"	1 13/16"	D. C.	3.3	0.132	—	—	—	180†	1.5	—	0.4	22.5	2000000	175	350	—	—
UY-224	R. F. Amp. or Detector	UY	5 1/4"	1 13/16"	A. C. or D. C.	2.5	1.75	Refer to Technical Bulletin		Cath.	180 180	1.5 3.0	1.5 3.0	4.0 4.0	75 90	400000 400000	1050 1000	420 400	— —	— —
UY-224	Audio Freq. Amplifier	UY	5 1/4"	1 13/16"	A. C. or D. C.	2.5	1.75	—	—	—	250‡	1.0	1.0	0.5	25	2000000	500	1000	—	—
UX-226	Amplifier	UX	4 11/16"	1 13/16"	A. C. or D. C.	1.5	1.05	—	—	—	90 135 180	5.0 8.0 12.5	6.0 9.0 13.5	3.8 6.3 7.4	— — —	8600 7200 7000	955 1135 1170	8.2 8.2 8.2	9800 8800 10500	30 80 180
UY-227	Detector or Amplifier	UY	4 11/16"	1 13/16"	A. C. or D. C.	2.5	1.75	45	3.5	Cath.	90 135 180	6.0 9.0 13.5	6.0 9.0 13.5	2.7 4.5 5.0	— — —	11000 9000 9000	820 1000 1000	9.0 9.0 9.0	14000 13000 18700	30 80 165
RCA-230	Detector or Amplifier	Small UX	4 1/4"	1 3/16"	D. C.	2.0	0.06	45	1.0	+F	90	4.5	—	2.0	—	12500	700	8.8	—	—
RCA-232	Radio Freq. Amplifier	UX	5 1/4"	1 13/16"	D. C.	2.0	0.06	—	—	—	135	3.0	—	1.5	67.5	800000	550	440	—	—
UX-240	Detector or Amplifier	UX	4 11/16"	1 13/16"	D. C.	5.0	0.25	135† 180†	0.3 0.4	+F	135† 180†	1.5 3.0	— —	0.2 0.2	— —	150000 150000	200 200	30 30	— —	— —

*For Grid-Bias Detection, refer to Technical Bulletins.

†Applied through plate coupling resistor of 250000 ohms.

‡Applied through plate coupling resistor of 200000 ohms.

POWER AMPLIFIERS

Type	Use	Base	Height	Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes	Detection: Plate Supply Volts	Detection: Plate Current Milliamp.	Detection: Grid Return Lead To	Plate Supply Volts	Grid Bias D. C. on Fil.	Grid Bias A. C. on Fil.	Plate Current Milli-amp.	Screen Grid Volts	A. C. Plate Resistance Ohms	Mutual Conductance Micromhos	Voltage Amplification Factor	Ohms Load for Maximum Undistorted Output	Maximum Undistorted Output Milli-watts
UX-112-A	Power Amplifier	UX	4 11/16"	1 13/16"	D. C. or A. C.	5.0	0.25	—	—	—	135 180	9.0 13.5	11.5 15.0	7.0 7.6	—	5000 5300	1600 1700	8.5 8.5	8700 10800	120 260
UX-120	Power Amplifier	Small UX	4 1/8"	1 3/16"	D. C.	3.3	0.132	—	—	—	135	22.5	—	6.5	—	6300	525	3.3	6500	110
UX-171-A	Power Amplifier	UX	4 11/16"	1 13/16"	A. C. or D. C.	5.0	0.25	—	—	—	90 135 180	16.5 27.0 40.5	19.0 29.5 43.0	12.0 17.5 20.0	— — —	2250 1960 1850	1330 1520 1620	3.0 3.0 3.0	3200 3500 5350	125 370 700
UX-210	Power Amplifier	UX	5 5/8"	2 3/16"	A. C. or D. C.	7.5	1.25	—	—	—	250 350 425	18.0 27.0 35.0	22.0 31.0 39.0	10.0 16.0 18.0	— — —	6000 5150 5000	1330 1550 1600	8.0 8.0 8.0	13000 11000 10000	400 900 1600
RCA-231	Power Amplifier	Small UX	4 1/4"	1 3/16"	D. C.	2.0	0.130	—	—	—	135	22.5	—	8.0	—	4000	875	3.5	—	170
UX-245	Power Amplifier	UX	5 5/8"	2 3/16"	A. C. or D. C.	2.5	1.5	—	—	—	180 250	33.0 48.5	34.5 50.0	25.0 34.0	— —	1900 1750	1850 2000	3.5 3.5	3500 3900	780 1600
UX-250	Power Amplifier	UX	6 1/4"	2 11/16"	A. C. or D. C.	7.5	1.25	—	—	—	250 350 400 450	41.0 59.0 66.0 80.0	45.0 63.0 70.0 84.0	28.0 45.0 55.0 55.0	— — — —	2100 1900 1800 1800	1800 2000 2100 2100	3.8 3.8 3.8 3.8	4300 4100 3670 4350	1000 2400 3400 4600

RECTIFIERS

Type	Use	Base	Height	Diam.	Filament Supply	Filament Terminal Volts	Filament Current Amperes	Ratings	Remarks
UX-280	Full-Wave Rectifier	UX	5 5/8"	2 3/16"	A. C.	5.0	2.0	1 {A. C. Voltage per Plate (Volts RMS) ... 350; D. C. Output Current (Maximum MA.) ... 125 2 {A. C. Voltage per Plate (Maximum Volts RMS.) ... 400; D. C. Output Current (Maximum MA.) ... 110	For D. C. Output Voltage delivered to filter of typical rectifier circuits, refer to Technical Bulletin.
UX-281	Half-Wave Rectifier	UX	6 1/4"	2 7/16"	A. C.	7.5	1.25	A. C. Plate Voltage (Maximum Volts RMS.) ... 700 D. C. Output Current (Maximum MA.) ... 85	For D. C. Output Voltage delivered to filter of typical rectifier circuits, refer to Technical Bulletin.

SPECIAL PURPOSE

Type	Use	Base	Height	Diam.	Description	Characteristics	
UX-874	Voltage Regulator	UX	5 5/8"	2 3/16"	Designed to keep output voltage of B-Eliminators constant when different values of "B" current are supplied.	Operating Voltage Starting Voltage Operating Current	90 Volts D. C. 125 Volts D. C. 10-50 Milliamperes
UV-876	Current Regulator (Ballast Tube)	Mogul	8"	2 1/16"	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage.	Operating Current Voltage Range	1.7 Amperes 40-60 Volts
UV-886	Current Regulator (Ballast Tube)	Mogul	8"	2 1/16"	Designed to insure constant input to power operated radio receivers despite fluctuations in line voltage.	Operating Current Voltage Range	2.05 Amperes 40-60 Volts

FOR AMATEUR AND EXPERIMENTAL TRANSMITTING USE

Type	Use*	Base	Maximum Overall Dimensions: Height	Maximum Overall Dimensions: Width	Filament Terminal Volts	Filament Current Amperes	Voltage Amp. Factor	Normal Plate Volts	Approx. Grid Bias Volts	Approx. Screen Volts	Maximum Plate Current Amperes	Maximum Plate Dissipation Watts	Normal Power Output Watts
UX-852	Oscillator or R. F. Amplifier	UX	8 3/4"	6 1/8"	10.0	3.25	12	2000	250	—	0.10	100	75
UX-865	Oscillator or R. F. Amplifier	UX	6 1/4"	2 3/16"	7.5	2.0	150	500	75	125	0.06	15	7.5
UX-866	Half-Wave Rectifier	UX	6 5/8"	2 7/16"	2.5	5.0	Maximum Peak Inverse Voltage ... 5000 Volts; Maximum Peak Plate Current ... 0.6 Ampere; Approximate Tube Voltage Drop ... 15 Volts						

Fig. 65. The above chart gives the characteristics of a large number of the most common vacuum tubes, and gives a lot of very valuable data that will be a great help in selecting vacuum tubes for various circuits and uses, and also in testing tubes in service. Characteristics and data for new tubes which are developed from time to time, can be obtained by writing to the R. C. A. Radiotron Company. The data given for any of the above tubes is very much the same as for tubes of similar type and number, made by other manufacturers. Tube characteristics charts can be obtained from other manufacturers by writing for them. (This chart courtesy of R. C. A. Radiotron Co., Inc.)

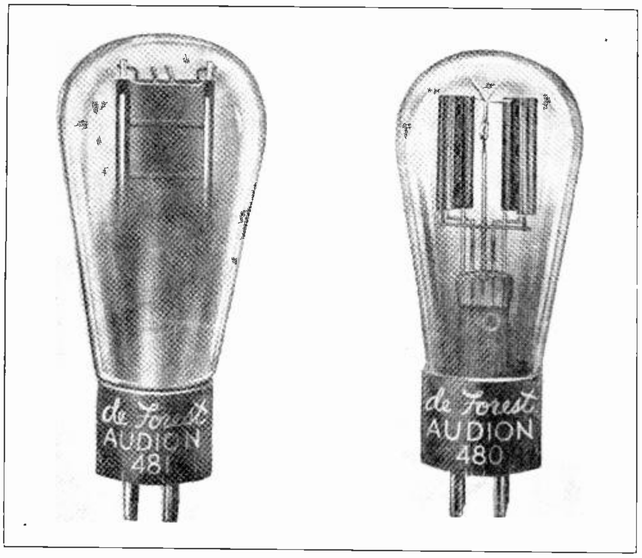


Fig. 66. On the left is shown a half-wave rectifier tube and the one on the right is a full-wave rectifier. Such tubes are used in "power packs" of A. C. receivers. (Photo courtesy of DeForest Radio Co.)

tube is worn out. If the tube is overloaded by applying excessive plate voltage it uses up the thorium on the filament surface faster than it can be replaced from within the filament metal. Thus the need for reactivation or "rejuvenation" as it is sometimes called.

If the slow reactivation just outlined doesn't succeed in bringing the tube back to normal emission and plate current at the proper filament and plate voltages, then the **flashing** process may be used.

This consists of applying from 3 to 4 times normal voltage to the filament for about 10 to 12 seconds, and then continuing for 30 minutes to an hour or more at the 25% over-voltage rate as previously explained.

By testing the tube at 30 minute intervals during the latter process it can be determined when its emission and plate current become normal again. If 2 hours reactivation treatment does not revive a tube it should be discarded.

Many common types of tubes can now be obtained at such low cost that it does not pay to spend much time trying to reactivate them.

55. GENERAL

In order to get the best service and maximum life from vacuum tubes one should see that they are operated according to the following instructions:

1. See that the filament is not operated at any higher voltage than the normal filament voltage rating, and keep the filament rheostat set as low as possible with good results. A filament voltmeter is helpful in adjusting the filament voltage.
2. Do not use high plate voltages without the proper "c" battery voltage on the grid, and never higher than the maximum plate voltage rating of the tube.
3. Always see that D. C. filament connections are made right to get proper polarity, and never reversed. Reversed polarity of the filament leads reduces the effectiveness of a tube and may cause the rheostat to be turned too high in an effort to bring the signal up to normal.
4. Do not try to operate a good tube and a bad one from the same rheostat, or the good one may be overloaded in an effort to bring the poor one up to normal.
5. If a set uses a separate rheostat to reduce the filament temperature of one or more tubes to obtain volume control, see that this rheostat is set for full volume before adjusting the filament rheostat of these tubes.
6. See that tubes are not subjected to vibration, and that they are kept tight in their sockets and ventilated sufficiently to prevent over-heating.

Vacuum tube construction, operation and characteristics have been covered quite completely in this section, and while it is not expected that you will remember all of the points covered at the first reading, if you obtain a good general understanding of vacuum tubes, and then frequently refer to this material for reference it will be extremely valuable to you, because of the importance of a good knowledge of tubes to the radio service man.

56. RECEIVING CIRCUITS

Now if you have obtained a good general knowledge of radio principles and vacuum tubes as ex-

Fig. 67. Another type of half-wave rectifier tube for use with higher voltages, such as required for the plates of power tubes. (Photo courtesy of R. C. A. Radiotron Co., Inc.)

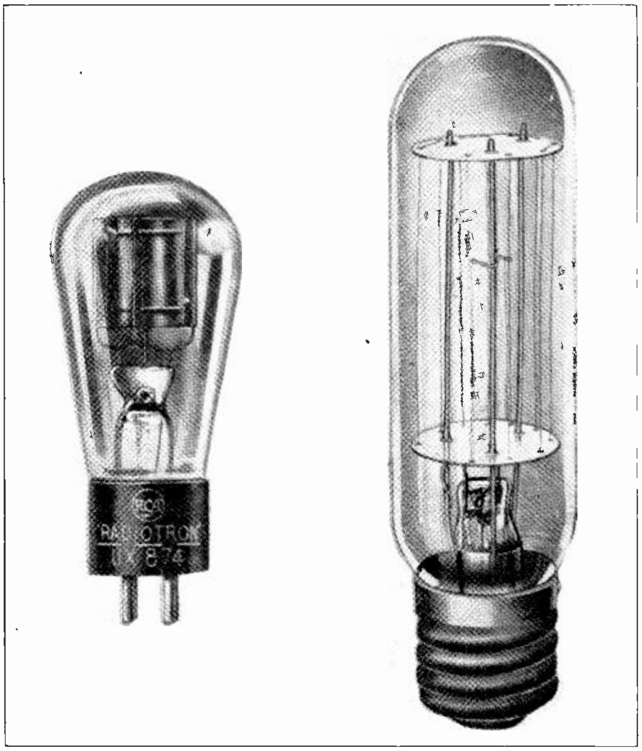


Fig. 68. The smaller tube on the left in this figure is a voltage regulator tube, and the larger one on the right is a current regulator or ballast tube. Tubes of this type are used in power supply units for A. C. receivers (Photo courtesy of R. C. A. Radiotron Co., Inc.)

plained so far, we are ready to take up common types of receiving circuits.

One of the simplest forms of radio receivers is the plain single tube detector set, such as shown in Fig. 49.

You have of course learned that any practical radio receiver must at least consist of a detector circuit, to convert the radio frequency energy into audio frequency impulses capable of operating the headphones and making audible sounds. Most sets have several stages of amplification in addition to the detector, as the detector alone can only receive signals from a limited distance, and can usually only supply power enough to operate headphones.

Examine Fig. 49 again and we find that its important parts are the R. F. coupling transformer, tuning condenser, grid leak and condenser, tube, rheostat, phones, bypass condenser and A and B batteries.

The purpose and function of each of these parts has been generally explained already. It will be well, however, to bring out certain points more in detail at this time.

The R. F. transformer is used to couple the antenna circuit to the grid circuit of the tube by magnetic induction. Inductive coupling of this type is extensively used in receivers as it gives much sharper tuning than direct conductive coupling. By adjusting the spacing between the primary and secondary coils the sharpness of tuning can be varied. Tuning becomes sharper as the coils are moved farther apart or more loosely coupled, and it becomes broader as the coils are more closely coupled.

Close coupling can be used for receiving very weak signals, and loose coupling for receiving stronger signals and keeping out other undesired signals from near by stations, and also to reduce static and other interference.

R. F. transformers or tuners with variable coupling are made in a number of forms, some with a rotating secondary coil and others with a hinged coil, while some have sliding coils. All serve the same general purpose, however.

These coupling transformers also serve to step up the signal voltage applied to the grids of the tubes, as their primary coils are generally wound with fewer turns than the secondaries. Tuning inductances or R. F. transformers for ordinary broadcast wave lengths generally have about 15 to 20 turns of about #28 cotton or silk covered wire on their primaries, and about 45 to 75 turns of #28 on their secondaries.

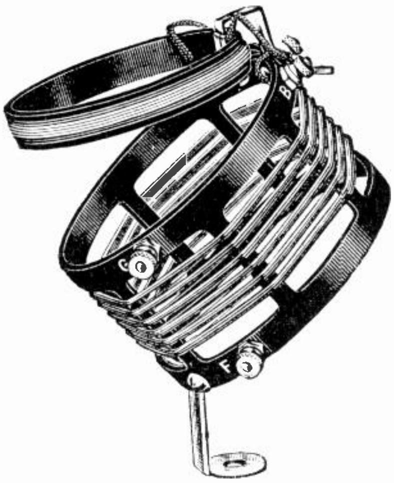
R. F. transformers are generally constructed in a manner to keep the distributed capacity in the coils at a minimum. This capacity is very undesirable in an inductance because of the losses it causes by the absorption of R. F. energy in the capacity effect. In order to reduce distributed capacity in inductances for radio work they are often wound with the turns spaced apart, or crossed at an angle when in more than one layer.

Many inductance coils of this type are covered over with a layer of insulating varnish which holds the turns in place and prevents moisture and dirt from affecting the insulation and inductance of the coil to such an extent as they often do untreated coils.

On the left in Fig. 69 is shown an adjustable type of R. F. transformer with the primary on the small movable form, and the secondary mounted stationary. With this type of transformer or tuner the coupling can be adjusted or set at the best point for the stations desired. The tuner on the right in this figure will be explained later.

The tuning condenser should be carefully chosen to fit the wave length to be received and the inductance of the coils. **A variable condenser of about .00035 mfd. is most commonly used for ordinary broadcast wave lengths.**

The grid leak is generally about 1 to 2 megohms and the grid condenser about .00025 M. F. Any good detector tube with a D. C. operated filament can be used in a battery set of this type. The headphones should be good ones of about 2000 to 3000 ohms resistance or more, and the bypass condenser .002 M. F. The A battery should be from 2 to 6 volts according to the type of tube used and the rheostat from 10 to 25 ohms according to the filament current required by the tube. The B battery should



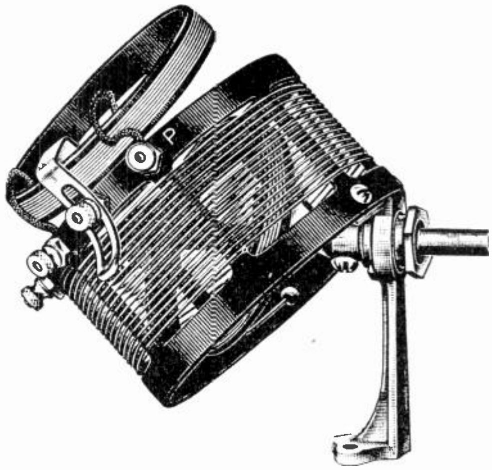


Fig. 69. On the left is shown a tuning coil or antenna coupling transformer with a movable primary for adjusting the coupling. On the right is a three circuit tuner or set of coils used for antenna coupling and regeneration. The small movable coil on the top is the primary, the large stationary coil the secondary, and the inner movable coil the "tickler" or feed back coil.

be from 22½ to 45 volts according to the type of tube used. A number of these values can be found in the tube chart, by noting the data given for the tube selected.

A detector of the type shown in Fig. 49 is extremely simple to tune and operate. One good point to keep in mind is to adjust the rheostat to operate the tube at as low filament voltage as possible with good signal strength in the phones. Burning the filament at excessive temperature does not usually improve the signal and sometimes actually makes it weaker, and it also shortens the life of the tube.

57. REGENERATIVE DETECTOR CIRCUITS

Special circuits using regenerative or reflex principles are sometimes used to get maximum results from one tube . This is often a decided advantage in portable receivers, but generally such circuits have some disadvantages such as objectionable oscillation or producing poorer quality signals.

Fig. 70 shows a diagram of a feed-back or **regenerative** detector circuit, which can be used either in single tube sets or in the detector of a set with amplifier stages.

This circuit makes use of part of the plate current to strengthen the charge on the grid, by induction between a coil L2 in the plate circuit and the grid coil L1. By tracing this circuit you will find that the plate current passes through coil L2.

The radio frequency variations of current which exist in the plate circuit, and which are passed around the phones by the bypass condenser C, set up high frequency flux around coil L2. The strength of this flux varies in proportion to the signal strength on the grid, which causes the pulsations in plate current. This varying flux around coil L2 induces voltage in coil L1 which will aid that induced by the antenna coil L, providing coil L2 is connected with the proper polarity. If this coil is connected wrong its flux will oppose that of coil L1, and the leads of coil L2 should be reversed.

The audio frequency variations in the plate circuit do not affect the grid voltage much by regeneration because the air core R. F. transformer coils L1 and L2 operate most effectively on high frequency. Furthermore, any slight audio frequency which might be induced in the coil L1 cannot pass through the grid condenser as it is too small to pass much energy at low frequency.

As these circuits depend on the R. F. component of the plate current for their regenerative effects the bypass condenser C is very necessary to allow this R. F. energy to flow past the impedance of the phones.

The coil L2 is often called a **tickler coil** because of its boosting effect on the voltage of coil L1 and the grid circuit. The tickler coil is often arranged so it can be adjusted with respect to coil L1, so the amount of feed-back from the plate to grid circuit can be varied by rotating or moving the tickler

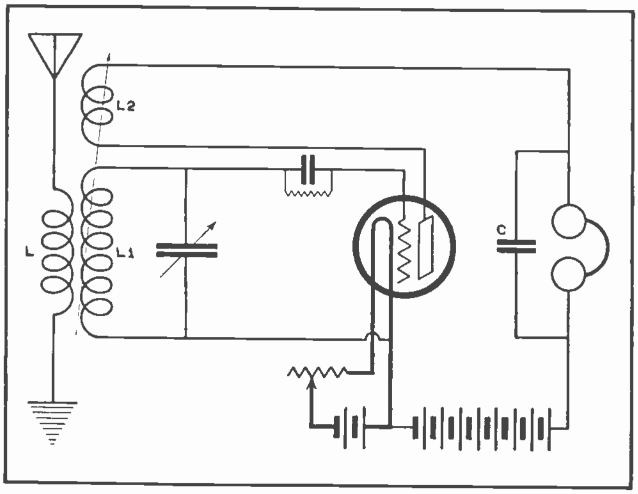


Fig. 70. This diagram shows the circuit of a regenerative detector for obtaining maximum signal strength with one tube. The tuner on the right in Fig. 69 could be used for the coils L, L1 and L2 in this figure.

closer to or farther from the grid coil. In other cases the tickler coil is fixed or stationary and a variable condenser is connected across it to control regeneration.

On the right in Fig. 69 is shown a 3 circuit tuner for use in regenerative detectors. The primary is the small coil on top, the secondary is the large stationary coil, and the movable tickler coil can be seen inside the secondary.

By using the energy fed back from the plate circuit to strengthen the signal voltages on the grid in this manner, such regenerative circuits give considerable more amplification and will receive weaker signals than a nonregenerative set.

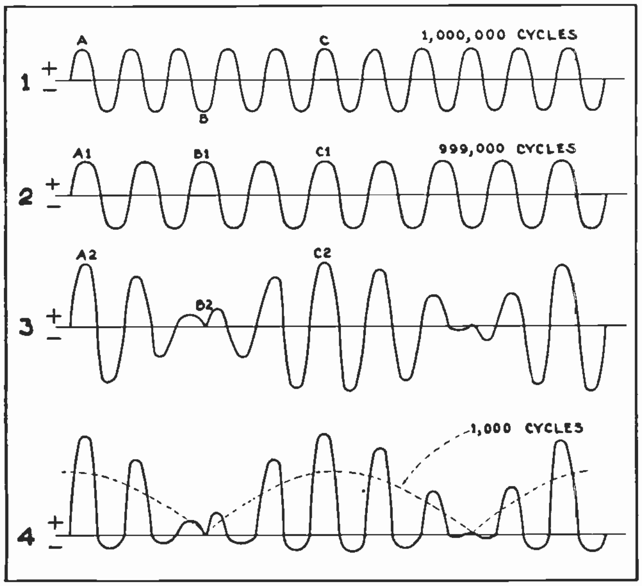


Fig. 71. The above curves illustrate the manner in which energy at two frequencies (1 and 2), can be mixed or heterodyned to produce waves of varying amplitude at 3, which result in a third frequency or beat note as shown by the dotted curve at 4.

58. OSCILLATION AND HETERODYNING OF REGENERATIVE CIRCUITS

Regenerative circuits are also useful for receiving continuous wave code signals, as these sets can be adjusted to oscillate at a frequency of their own and thus set up an audible **beat note** with the received C. W. signal.

Beat notes are produced by waves of different frequencies first aiding and then opposing each other at regular intervals and thus setting up a resulting wave of still another frequency, known as the beat note or frequency. **This beat note is always of a frequency equal to the difference between the two frequencies used to produce it.**

This mixing of two different frequencies to produce a beat note is also called **heterodyning.**

Fig. 71 illustrates the manner in which a wave of 1,000,000 cycles and one of 999,000 cycles blend together to create a beat note of 1,000 cycles.

You will note that the first waves A and A1 of number 1 and 2 sets of curves are in phase, and

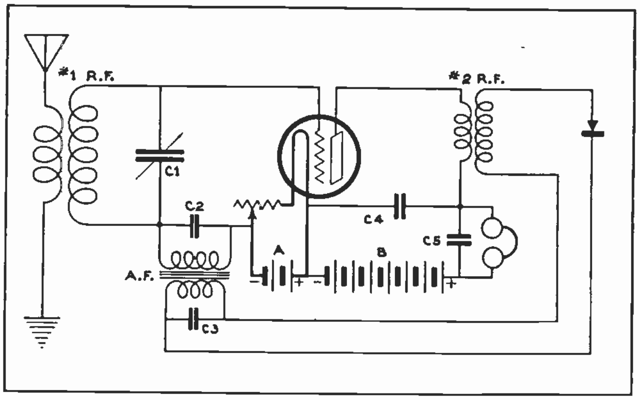


Fig. 72. Circuit diagram of a reflex receiver, in which the one vacuum tube is made to serve both as an R. F. and A. F. amplifier, and a crystal is used as the detector.

unite to make one larger wave A2 in number 3 set of curves. As the waves of the upper two sets progress, however, they get more and more out of phase, until at B and B1 they are in almost exact opposition to each other, or 180 degrees out of phase, and the result shown at B2 is practically zero.

Then as the waves come nearer into phase again the resultant wave builds up greater and greater until at C and C1 where the waves of different frequency are again in phase with each other they build up to maximum value in the circuit again as shown at C2, and so on.

When the resulting wave is rectified by detector action of the tube, the result is shown at number 4, and you will note that the average value then produces a low frequency audible beat note, as shown by the dotted curves.

This same beat note principle is also used in superheterodyne receivers which will be explained later.

One of the disadvantages or objections to the use of regenerative receivers is that they often oscillate when not intended to, and set up oscillations in the antenna circuit which transmit continuous waves that heterodyne and interfere with other near by receivers.

59. REFLEX CIRCUITS

Another method of obtaining maximum results and signal strength from one tube, is by the reflex circuit shown in Fig. 72. This circuit makes the vacuum tube do double duty or serve as both an R. F. and A. F. amplifier, and uses a crystal as a detector. Or if desired, another tube can be used as the detector.

Both R. F. and A. F. currents are handled in reflex circuits by providing two paths, one of low impedance to the R. F. currents and one of low impedance to the A. F. currents. Thus the two frequencies can be separated where desired, and again mixed or handled together where desired.

We know that high inductances such as coils of

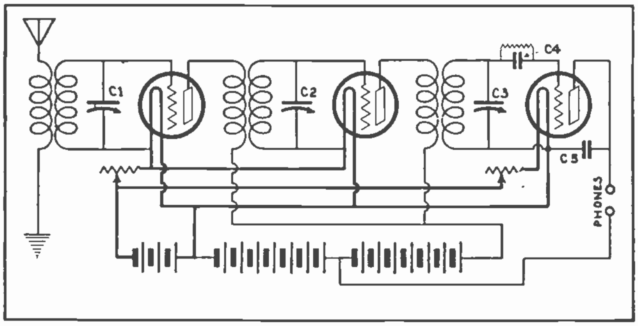


Fig. 73. Circuit diagram of a three tube receiver using two stages of R. F. (radio frequency) amplification and a detector.

iron core transformers or headphones will offer high impedance to R. F. currents, and less impedance to A. F. currents; while condensers offer more impedance to A. F. currents and less impedance to R. F. currents.

With a reflex circuit such as shown in Fig. 72, the R. F. currents in the antenna circuit and primary coil of the first R. F. transformer, induce the R. F. signal energy into the secondary of this transformer, which applies this voltage to the grid of the tube. The grid circuit is completed from this transformer secondary by a direct connection from the top of the coil to the grid, and from the bottom of the coil through the bypass condenser C2 to the filament rheostat and filament. The condenser C2 is connected across the secondary of the A. F. transformer to pass the R. F. currents by its impedance.

The tube acts as an R. F. amplifier to this incoming signal energy, and produces much stronger R. F. impulses in the plate circuit. These amplified R. F. impulses pass from the positive of the B battery through the bypass condenser C5, across the phones, and through the primary of the second R. F. transformer to the plate, returning through the tube and filament to B negative.

These strengthened R. F. impulses through the second R. F. transformer primary, induce still higher voltage in its secondary on account of the step up ratio of the transformer. This energy from the secondary is next passed through the crystal detector to bring out the audio frequency signal variations or pulsations, and this A. F. energy is passed through the primary of the A. F. transformer. This induces A. F. impulses of still higher voltage in the secondary of this step up transformer, and from the secondary they are again applied to the grid of the tube, which now acts as an audio frequency amplifier.

When these A. F. impulses are thus amplified again by the grid of the tube controlling much stronger impulses in the plate circuit, this audio frequency plate curent now passes through the phones which offer less impedance to the low frequencies than does the small bypass condenser C5.

Even though the R. F. and A. F. impulses are mixed in the tube and both being handled at once, we find this is entirely possible and practical with an ordinary amplifier tube. By use of proper bypass condensers and parts in the circuit, to prevent distortion by passing the R. F. currents around the high impedance devices, and by proper tuning adjustment, fairly clear, strong signals can be obtained with these reflex circuits.

However, reflex circuits are used very little in modern sets because the double duty placed on the tube tends to overload it and make it difficult to obtain the best tone quality in voice and music reproduction. The action in reflex circuits is really quite similar to that of regenerative circuits, except that it is audio frequency energy which is fed back through the tube.

The principles of this circuit are explained to help you understand these receivers in case you might be called on to service one, and also because some of the principles used in separating the high and low frequencies are valuable for the radio man to know.

60. RADIO FREQUENCY AMPLIFICATION

Multiple tube sets of more than 3 tubes generally use both radio frequency and audio frequency amplification. The term **radio frequency amplification** applies to all stages ahead of the detector tube, as these stages handle and amplify the incoming signal energy at radio frequency. The term **audio frequency amplification** applies to all stages following the detector, as these stages handle and amplify the rectified audio frequency energy. Fig. 73 shows a diagram of receiver using two stages of R. F. amplification and a detector. The circuit is very easy to trace and its operation is simple.

The R. F. signal energy is stepped up in voltage by the first R. F. transformer and applied to the grid of the first amplifier tube. The increased energy in the plate circuit of this tube is passed on through the second R. F. transformer to the grid of the

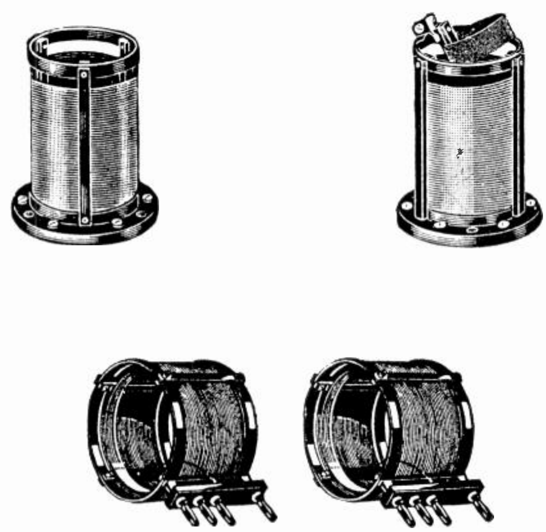


Fig. 74. Several types of R. F. coils or transformers, used for coupling R. F. stages together, or passing the signal energy from the output of one tube to the input of the next.

second tube. Here it is further amplified and applied to the grid of the detector tube, which can be easily identified by its grid leak and condenser. From the detector tube the output energy in the plate circuit is applied to the phones, and is very much stronger than if the R. F. stages had not been used.

For example if the first tube amplifies the signal about 8 times, and the second tube amplifies the output of the first 8 times again, this produces a signal 8 x 8 or 64 times as strong, without counting any amplification which may take place in the detector. Another R. F. stage would increase the signal to 8 x 64 or 512 times its original value. More than three stages of R. F. amplification are rarely used because of distortion and losses due to the leakage and capacity coupling between circuits carrying R. F. currents.

R. F. feedback due to this capacity coupling often results in severe oscillation and howling unless it is prevented by neutralizing the circuit as will be explained later, or by use of screen grid tubes and shielding as is done in later type sets.

Screen grid tubes have such low internal capacity that they do not permit any appreciable feed back through them and are therefore excellent for use in R. F. amplifier stages. If stages using screen grid tubes are properly shielded with grounded aluminum or copper partitions around and between them, objectionable feed back, oscillation, and interstage interference, can be almost entirely eliminated.

The R. F. transformers used to couple the stages of radio frequency amplifiers are generally wound with about 15 to 20 turns on the primaries and 50 to 80 turns on the secondaries, or a step up ratio of about 1 to 3½. These windings are usually wound in plain solenoid form on fibre or bakelite tubing, with the primaries and secondaries spaced a small distance apart on the same tubular form, or on two separate forms one within the other. In some cases the coils are coated with a cement like insulating compound which holds the coils in shape so the forms can be removed. Fig. 74 shows several types of R. F. transformers, and Fig. 75 shows a larger view of another type which has its primary and secondary coils arranged to provide a complete circular path for the flux through both coils.

Transformers of this type are often called air core transformers and are designed to handle R. F. currents only.

In the circuit in Fig. 73 a variable condenser is connected across the secondary of each of the R. F. transformers to tune each stage to the same frequency, as all R. F. stages should be tuned to the wave length or frequency being received, in order to obtain efficient operation and maximum signal strength.

The rotors of all of these condensers can be connected together on one shaft, or by other mechanical means so that they can be operated by one dial, and thus simplify the tuning controls. In order to do this, however, the circuits of all stages must be accurately matched in inductance and capacity. Small trimming condensers not shown in Fig. 73 are often provided and connected across the main tuning condensers to balance up slight inequalities in the circuits, in an original adjustment when the set is tested and installed. These trimmer condensers are shown by dotted lines in Fig. 76.

One advantage of R. F. amplification is that it amplifies the signals without amplifying so much, certain classes of static, audio frequency, interference and microphonic noises, which are amplified by audio frequency stages.

Note that the amplifier tubes in Fig. 73 both have their filaments controlled by one rheostat, and have full B voltage applied to their plates, while the detector has its separate filament rheostat and a lower voltage plate tap on the B battery.

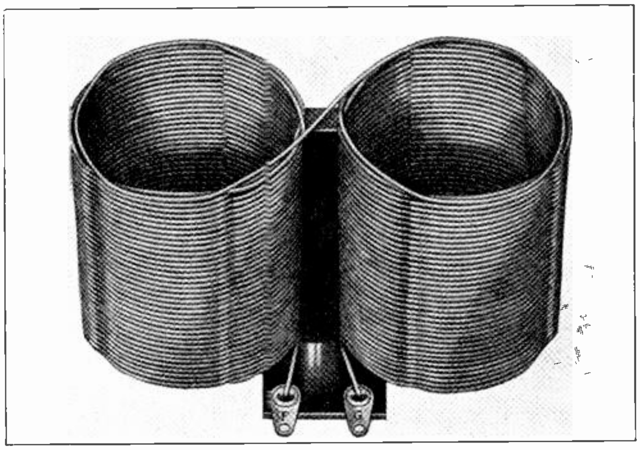


Fig. 75. R. F. transformer with self supporting coils, arranged side by side to allow the flux to take a more efficient circular path through them.

61. AUDIO FREQUENCY AMPLIFICATION

Two stages of audio frequency are very commonly used to further increase the signal energy after it leaves the detector. Fig. 76 shows a diagram of a five tube receiver with two stages of audio frequency amplification in addition to the R. F. stages and detector.

Audio frequency stages use iron core transformers for handling the low frequency pulsating D. C. currents after the detector. The straight lines between the coils in the diagram indicate iron cores in the transformers. These transformers are much more efficient than R. F. transformers, and if properly constructed they will handle the energy from stage to stage with very little distortion. A. F. transformers are wound with several thousand turns on their primaries and secondaries and with ratios of from 1 to 1 up to 1 to 6 or higher. Thus the

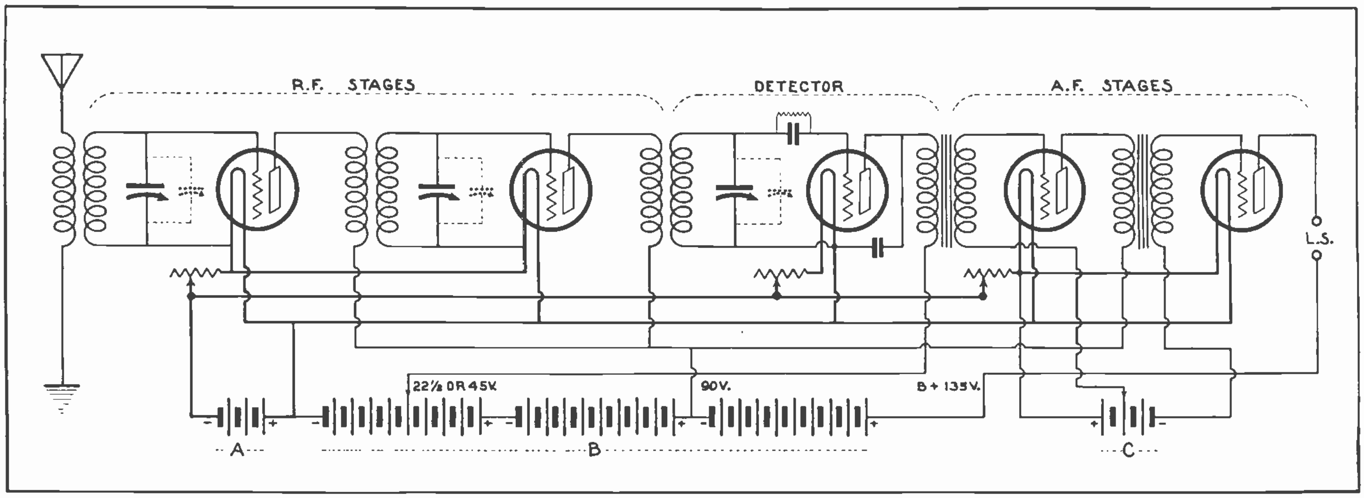


Fig. 76. Circuit diagram of a simple five tube receiver, using two stages of R. F. amplification, a detector, and two stages of A. F. (audio frequency) amplification. Study this circuit carefully as it is quite typical of thousands of receivers in use. Carefully trace the coupling circuits from stage to stage, and also the filament and plate circuits of all tubes.

transformers also aid in increasing the voltage applied to the grids of the tubes. Ratios higher than 1 to 3½ are seldom used, however, as they tend to produce distortion.

Fig. 77 shows an iron core A. F. transformer and Fig. 78 shows how the primary and secondary leads are arranged and marked for proper connection.

Good audio transformers should be designed to amplify as near equally as possible, all audio frequencies from 150 to 5000 cycles, and thus avoid distortion and produce as true reproduction as possible of the words and music. A. F. transformers of course handle frequencies from 20 to 10,000 cycles per second, but most of the notes of voice and music come in the range between 150 and 5000 cycles, so a transformer that handles these frequencies well gives good results.

Good A. F. transformers must have large enough iron cores so that the plate currents they are to handle will not saturate them. When a transformer core is saturated a further increase of current will not produce a proportional flux increase, and thus the output or secondary voltage does not vary in proportion to the primary input, and distortion results.

The primary winding of an A. F. transformer should have an impedance at least equal to that of the plate circuit of the tube to which its primary connects.

As the A. F. stages handle only low frequency currents no tuning condensers are needed. One of the reasons for A. F. transformers being of higher efficiency than R. F. transformers, is that the former use greater numbers of ampere turns in their windings, and low reluctance iron cores. These low reluctance iron cores also confine the flux to the transformer more and prevent so much leakage of stray flux.

There is some leakage of flux around A. F. transformers, however, and to prevent interference from it they should be spaced 4 or 5 inches apart or turned with their cores at right angles to each other. A. F. transformers often have thin metal shields around their cores and windings, and those which do not generally have shielding placed between them in the set to minimize inductive interference.

It is possible to obtain an increase of 400 times in signal strength with the amplification of the tubes and step up ratios of the transformers in two stages of A. F. amplification.

The arrangement of the audio frequency amplifier stages shown in Fig. 76 is known as a **cascade** connection, because of the manner in which the energy passes on through one stage after another.

More than two stages of A. F. amplification are

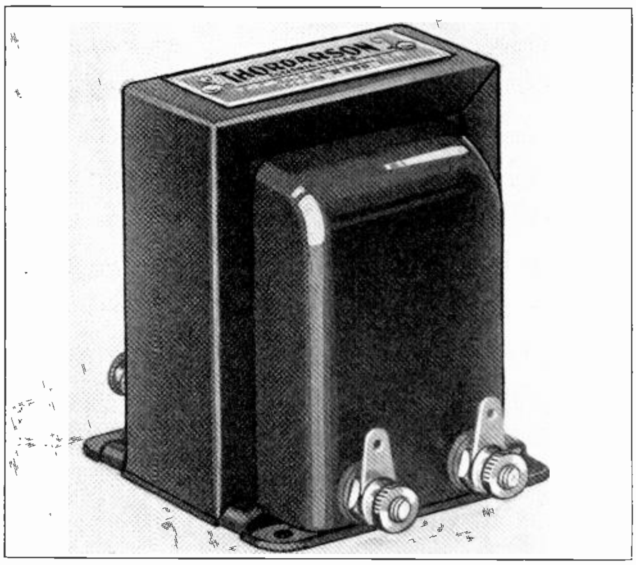


Fig. 77. Photo of a common type of iron-core audio frequency transformer, with a metal case or shield enclosing the core and coils. Transformers of this type are used for coupling between A. F. amplifier stages. (Photo courtesy of Thordarson Electric Mfg. Co.)

seldom used on account of increasing distortion with greater numbers of stages. Another reason for limiting the number of stages of amplification in a receiver, is that when currents of very large value are built up in the wires and leads of the set it is difficult to keep the fluxes around these conductors from interfering and inducing out of phase voltages in other conductors and thus causing distortion and losses.

62. A. F. TRANSFORMER AND AMPLIFIER CONNECTIONS

In Fig. 78 you will note that the outer lead on the secondary coil is marked G for connection to the grid of the tube which this secondary feeds. It is very important to get this proper lead connected to the grid, because the inner lead is closer to the grounded transformer core and thus is more closely coupled to the core and ground by capacity. As the grid of a tube is fundamentally a voltage operated device, we should use the transformer lead which is farthest removed and at highest potential from ground. This lead to the grid should also be kept as short as possible.

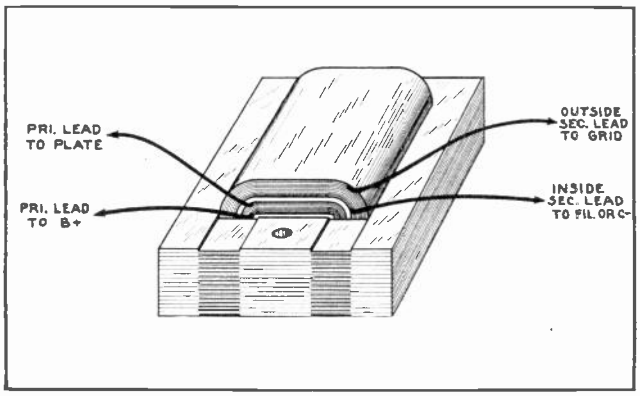


Fig. 78. This sketch shows the common arrangement of the primary and secondary coils and leads of A. F. transformers, and also shows the manner in which these leads should connect to the other devices in the circuit.

The other secondary lead F, should connect to filament terminal or to the negative terminal of the C battery when one is used. Note the C battery connections to the grids of the two tubes in the A. F. stages in Fig. 76. The primary terminals P and B+ are connected to the plate of the tube and to the positive terminal to the B battery respectively.

The primary and secondary leads of most A. F. transformers are marked as described above and as shown in Fig. 78, to make it convenient to connect them properly.

In Fig. 76 you will note again that the detector tube is supplied with lower plate voltage than the amplifier tubes, in order not to overload the detector tube and cause distortion. You will recall that the use of proper voltage on the detector works it at the proper point on its plate current curve to give maximum rectification and best detector action. In

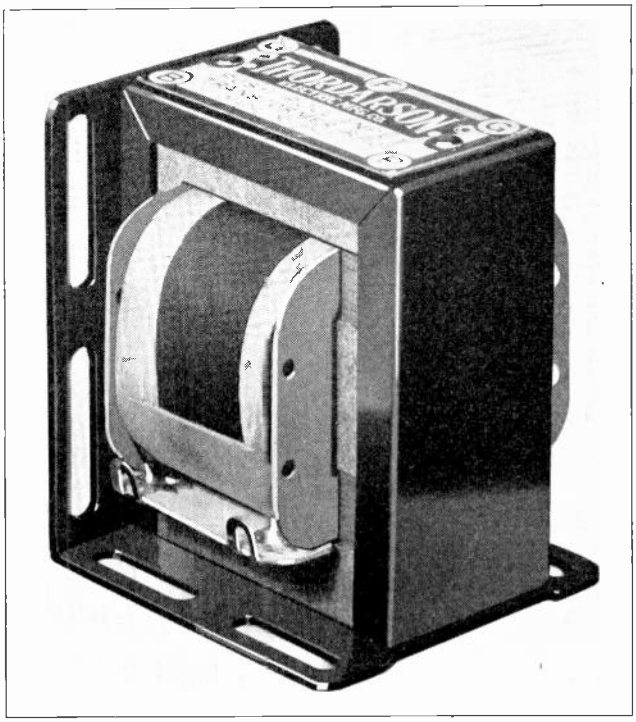


Fig. 79. Audio frequency transformer with sides of metal shield removed to show insulation around coils. This unit is equipped with brackets and slots for convenient mounting either on a horizontal or vertical panel. (Photo courtesy of Thordarson Electric Mfg. Co.)

some later type sets, however, a form of detection called **power detection** is used, and higher voltages are used on the detector tubes by using the proper negative bias on the grid. This bias is obtained from a "C" battery or from the voltage drop in a resistor in the circuit.

In Fig. 76 you will note that the plates of R. F. amplifier tubes use voltage somewhat higher than that on the detector tube, and that the A. F. tubes can use still higher voltage without overloading, because of the C battery negative bias used on their grids. The proper plate voltages and grid bias voltages for various detector and amplifier tubes are given in the tube characteristics chart in Fig. 65.

63. PUSH PULL AMPLIFICATION

The five tube circuit shown in Fig. 76 will ordinarily give plenty of amplification and power output to operate a loud speaker, on signals from powerful stations or stations not too far distant.

When it is desired to operate a loud speaker with considerable volume it may require more power from the receiver than can be handled without distortion by a single ordinary amplifier tube, such as used in the last stages of the circuit in Fig 76

In order to obtain increased volume and improved quality two amplifier tubes can be connected in a sort of parallel arrangement in the last stage, as shown in Fig. 80. This arrangement is called a **Push-Pull** amplifier connection.

By examining Fig. 80 you will find that a push-pull amplifier stage makes use of audio frequency transformers with center taps on their windings. The secondary of the input transformer feeding the push-pull tubes is tapped, and the primary of the output transformer which couples the set to the loud speaker is tapped. The center tap on the secondary of transformer number two connects to the filaments of both tubes, providing a filament return circuit for both grids which are connected to opposite ends of this transformer secondary. A "C" battery can be connected in the grid return lead at X to bias the grids if desired.

With the grids connected in this manner when alternating voltage is induced in the secondary of number two transformer, first one grid is positive and the other negative, and then the other grid becomes positive and the first one negative. Thus each tube handles one half of every cycle, or handles every other alternation.

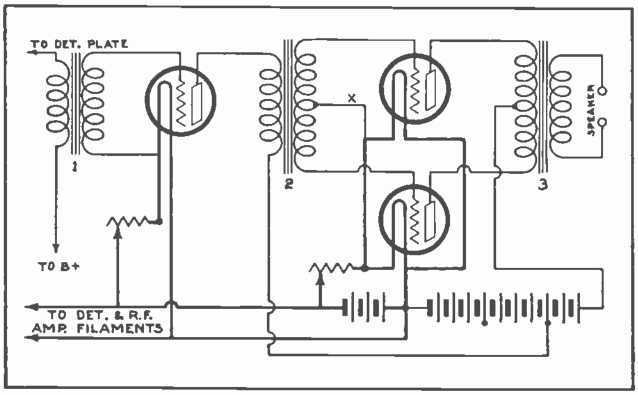


Fig. 80. Diagram showing the connections of a push-pull amplifier, using two tubes in the last stage, to increase the volume and improve the quality of the set.

The positive lead from the "B" battery connects to the center tap of the output transformer primary, and the ends of this split primary connect to the plates of the tubes as shown.

With the grid of first one tube and then the other becoming negative at alternate intervals, the "B" battery feeds current first to one plate and then the other, thus supplying two full plate current impulses to the primary of the output transformer during each cycle. These alternate impulses are in opposite directions through the two halves of the split primary, however, and thus cause a much greater voltage and flux change in this winding than the mere rise and fall of the plate current of a single tube would. Thus the output of both tubes is combined in the primary of the output transformer to deliver greatly increased energy from its secondary to the loud speaker.

Two stages of push-pull amplification, often called **double push-pull**, are sometimes used, and in such circuits a push-pull interstage transformer with center taps on both primary and secondary is used.

Push-pull amplification with the small amplifier tubes is not used so much in modern receivers any

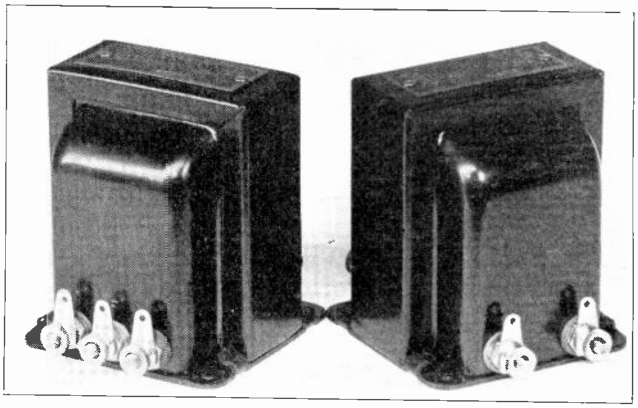


Fig. 81. Photo showing opposite sides of two push-pull A. F. transformers. Note the three terminals on the side with the center-tapped coil. (Photo courtesy of Thordarson Electric Mfg. Co.)

more, because the development of power tubes with much greater output capacity has made it unnecessary. But even power tubes are often connected push-pull in the last one or two stages of heavy duty power amplifiers, used for operating large speakers in public address and theatre installations where great volume is needed to carry the sound throughout a large hall or auditorium.

Fig 81 is a photo of two push-pull transformers with their opposite sides shown in this view. Note the three terminals from the winding with the center tap.

Fig 82 shows a photo of a complete audio frequency amplifier using two number 210 power tubes in push-pull in the last stage, fed by a 227. The 281 sockets are for half-wave rectifier tubes for the power unit. Note the push-pull transformers on the right near the panel or terminal board, and the smaller A. F. transformers to the left.

The sockets and wiring can be clearly seen in this photo, and you will also note the power supply transformer, condenser and choke coil, which will be explained a little later.

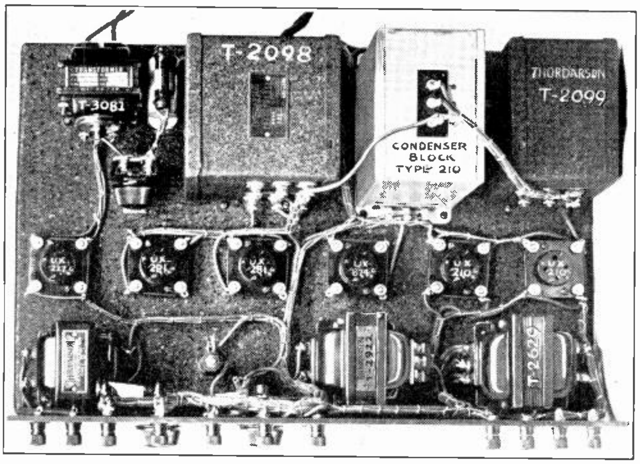


Fig. 82. This photograph shows the wiring and arrangement of parts in a complete power amplifier, without the tubes. Two number "210" power tubes are used in push-pull in the last stage of this amplifier. It also contains its own power supply unit. (Photo courtesy of Thordarson Electric Mfg. Co.)

64. POWER AMPLIFICATION

We have already referred to the use of power tubes where great volume of sound is desired from loud speakers, and some of the figures in the section on vacuum tubes showed tubes of this type. The chart on tube characteristics in Fig. 65 also gives the complete data on various power tubes. Power amplification simply means using power tubes of the proper size in the final stage or the stages of audio frequency amplifiers. The circuits and connections are practically the same as those of the straight audio or cascade, and push-pull amplifiers already shown, except that higher plate voltages and negative grid bias voltages are used on the power tubes. The voltage and current required by their filaments is also a little different, so separate filament resistors are used for power tubes.

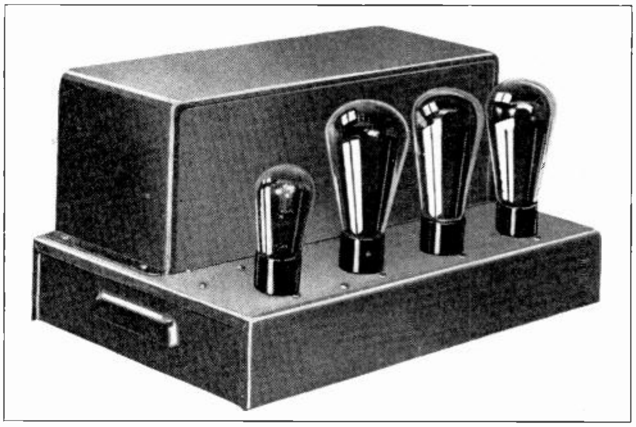


Fig. 83. Photo of a neat and compact power amplifier which can be connected tő the output of an ordinary receiver, an electric pickup on a phonograph, or to a microphone of a public address system, and will supply power enough to operate large loudspeakers. (Photo courtesy of Thordarson Electric Mfg. Co.)

Even where the sound volume requirements of a receiver or amplifier are not so great, one stage of moderate power amplification is often used to provide plenty of undistorted power to faithfully reproduce all notes of voice and music, and thus obtain much better tone quality in the reproduced sound.

The heavy bass notes of music require much more energy to fully reproduce with a loud speaker diaphragm than the higher pitched notes do, and the recent development of power tubes and amplifiers has greatly improved the tone quality of radio sets and speech amplification equipment such as used in talking picture installation and public address systems.

As a comparison of the greater amount of power available from power tubes, the ordinary 201-A or 301-A tube has a maximum undistorted plate power output of about 55 milli-watts, as compared with 5 to 7 watts output for some of the modern power tubes. This you will note is about 91 times as much power output from the large tube, and you can readily understand what an improvement in tone quality, and increase in sound volume this should make possible.

Fig. 83 shows a complete modern power amplifier designed for use where great volume is required. This amplifier can be connected to the output of an ordinary radio receiver, to a microphone or electric phonograph pick-up, or to the pre-amplifier from the sound head of a talking picture machine, and can be used to amplify the audio frequency energy to a point where it will operate very large speakers and fill a large room or hall with sound.

This particular type of amplifier is so constructed that several of them can be connected in parallel to give as great volume as required for most any purpose.

65. VOLUME CONTROL

Where radio sets have considerable reserve capacity it is very desirable to have some form of volume control to prevent excessive sound, or "blasting" of the speaker when receiving nearby stations.

Sometimes the volume is controlled by adjusting the filament rheostat of the detector tube, but this is not such good practice and the detector filament rheostat should only be used to adjust the filament temperature of this tube to a point where the signal is clearest and best. On modern A. C. receivers no detector filament rheostat is provided, but they are in use on most older type battery operated sets.

When a filament rheostat is used for volume control its principle of operation is easily understood. Increasing the resistance in series with the filament decreases the filament current and temperature, thereby reducing the electron emission and amount of plate current flow.

Some receivers use a potentiometer or variable high resistance of 100,000 ohms or more, connected

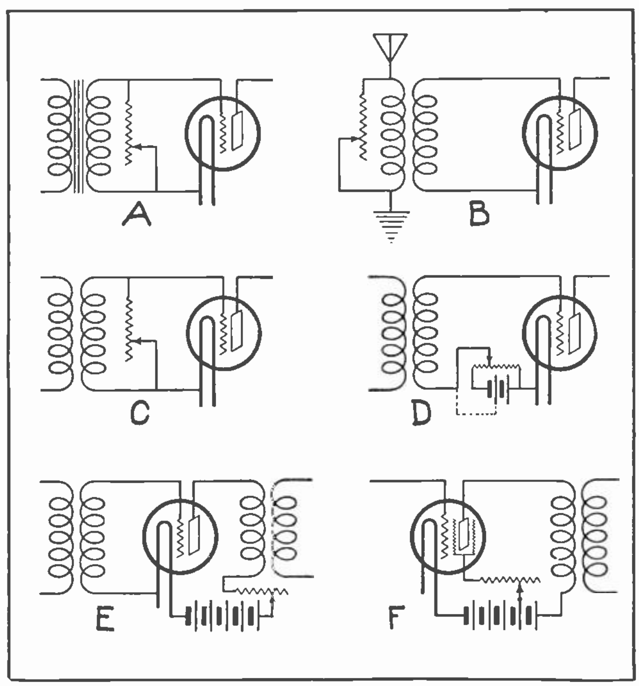


Fig. 84. The above sketches show six different methods of obtaining volume control in the R. F. or A. F. stages of radio receivers and amplifiers.

across the secondary of the first A. F. transformer to control the volume of the set. When the resistance of the potentiometer is reduced it simply shunts part of the energy from the transformer secondary away from the grid of the first A. F. amplifier tube. and thereby reduces the voltage applied to that grid. This in turn reduces the output of that tube and results in less energy and amplification in the remaining stages, and less volume at the speaker. This method of volume control is shown at A in Fig. 84.

Some receivers obtain their volume control in the R.F. stages, by use of potentiometers of several hundred thousand ohms resistance, shunted either across the primary of the first R. F. transformer or across the secondary of one or more of the R. F. interstage transformers, as shown at B and C in Fig. 84.

Any of these methods simply cause a loss of part of the signal energy through the potentiometer resistance, and thus reduce the energy in the circuits and stages from that point on throughout the set.

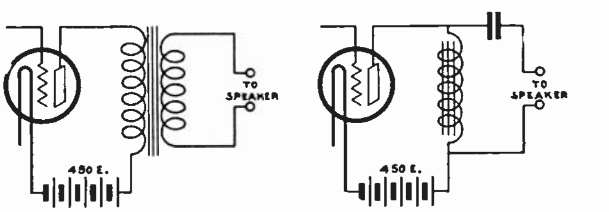


Fig. 85. The sketch on the left shows the transformer method of coupling a loudspeaker to the output or plate circuit of the last tube. On the right is shown the impedance method of speaker coupling.

Volume control can also be obtained by varying the amount of negative bias on any of the tubes, by means of an adjustable resistance across the C battery, or by variable voltage taps on the C battery or negative bias supply. See Fig. 84-D.

Some older type receivers use potentiometers in series with the plate circuits of one or more R. F. tubes, to reduce the plate voltages applied to these tubes, and thereby reduce their output. See Fig. 84-E.

Modern A. C. receivers with screen grid tubes frequently use potentiometers in series with the leads from the B battery or D. C. supply to the screen grids of these tubes. Varying the positive potential of these screen grids varies the space charge and electron flow as previously explained, and thereby controls the plate current and power output of the tubes. This method of volume control is illustrated for one tube in the sketch in Fig. 84-F.

It is easy for one with a knowledge of vacuum tube and amplifier principles to understand how any of these methods explained will effect volume control.

Volume control in the R. F. stages or first audio stage is generally considered to be better than in the last audio stages, because if the volume is reduced in the R. F. stages it prevents overloading of the detector and audio amplifier tubes. There is very little possibility of R. F. tubes ever becoming overloaded when supplied with proper voltages, because the signal energy is too small until after it has been amplified by several stages.

Some radio receivers are equipped with switches for cutting out one or more R. F. or A. F. stages, or with jacks to enable the speaker to be plugged in ahead of the last one or two A. F. stages in order to operate at lower volume.

66. LOUD SPEAKER COUPLING

The armature coils of loud speakers are not usually designed to operate on voltages above 180 volts, and as large power tubes are designed to operate with plate voltages from 135 to 450 volts, some form of transformer coupling must be provided to reduce this output voltage to the speaker.

One of the most common forms of loud speaker coupling is a simple output transformer or audio transformer of 1 to 1 ratio, connected as shown on the left in Fig. 85.

At first thought it might seem that a 1 to 1 ratio transformer would not reduce the voltage applied to the speaker. However, we can readily see that if the speaker armature were connected directly in the plate circuit in place of the coupling transformer primary, it would have the full 450 volt potential applied to its end attached to the positive B supply lead.

With the speaker connected to the secondary of the output transformer it will only receive that voltage which is induced in the secondary winding. The voltage induced in the secondary of a transformer depends upon the amount of voltage drop across its primary and the rate at which the primary voltage and current change.

Only part of the plate voltage drop occurs across the primary of the output transformer, and the rest occurs in the plate circuit resistance inside the tube. Furthermore, as the plate current is pulsating D. C. and never falls clear to zero as long as the tube is operating, we do not have 100% change of maximum plate current during any pulsation or cycle. Therefore, the voltage induced in the secondary and applied to the speaker coil is considerably less than half of the full plate voltage.

Most loud speakers are so designed that they will operate best when used with transformers of a certain impedance, so the impedance of the output transformer should be matched to the design of speaker used. Many loud speakers are built with their coupling transformers attached directly to the speaker base and furnished as a part of the speaker.

Another method of coupling loud speakers to the output of amplifiers is the choke or **impedance** method illustrated on the right in Fig. 85.

Here a large condenser of 4 to 8 M. F. capacity is connected in series with one lead to the speaker, and the speaker leads then connected across a choke coil which is in series with the plate circuit of the last tube.

The amount of voltage and current supplied to the speaker depends upon the voltage drop across the choke coil and the charging current drawn by the condenser. As the condenser charging current depends upon the voltage drop across the choke coil, and this voltage drop in turn depends on the variations of plate current through the choke, the speaker armature and diaphragm will vibrate in proportion to the plate current pulsations and reproduce the sound accordingly.

Another very important reason for using some form of coupling between the plate circuits of the tubes and certain types of speakers, is to get sufficient impedance in the plate circuits. The impedance of the operating coils in many loud speakers is not enough to make efficient use of the plate circuit energy, but the impedance of the primary of an iron core coupling transformer, or the coil of a coupling impedance can be made high enough to match the impedance of the plate circuit.

67. RESISTANCE COUPLED AMPLIFIERS

The amplifiers we have so far explained have been of the transformer coupled type. Another form of coupling used in some amplifiers is known as **resistance coupling.** Resistance coupled amplifiers are often used for short wave receivers and in television equipment, and sometimes in audio frequency stages of ordinary receivers where absolute freedom from all distortion is desired.

One advantage of resistance coupled amplification is that there are no inductance coils nor iron cores in its circuits to set up magnetic induction or eddy currents, which might cause slight distortion and which would offer extremely high impedance to the very high frequencies of short wave signals.

Fig. 86 shows a diagram of a detector and three stage resistance coulped amplifier. The R. F. stages are not shown in this diagram. Resistance coupled amplification is not often used in R. F. stages.

The principle of operation of this method of coupling is as follows. When signal energy is applied to the grid of the detector tube in Fig. 86, it causes pulsations or variations in the plate current in the usual manner.

Instead of a transformer primary in this plate circuit we now have a fixed resistance R1, of about

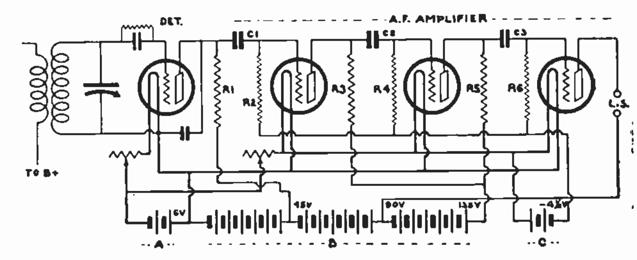


Fig. 86. Circuit diagram of a detector and three-stage resistance coupled amplifier. Carefully study the principles of this circuit with the accompanying explanations.

100,000 ohms. You have already learned that the voltage drop through any resistor is proportional to the resistance in ohms and to the current in amperes. The resistance in this case remains constant but as the plate current varies through resistor R1 the voltage drop across it varies proportionately.

This varying voltage drop across resistor R1 causes corresponding variations in the positive voltage applied to the condenser C1, which is connected between the plate of the detector tube and the grid of the first A. F. amplifier tube. The varying positive potential applied to the plate of this condenser, which connects to resistor R1 and the plate of the detector, causes a varying negative potential to be induced on its opposite plate which connects to the grid of the first A. F. amplifier tube.

You will recall from material in an earlier section of this reference set that when one plate of a condenser has voltage of a certain polarity applied to it, the other plate always takes on an electro-statically induced charge of opposite polarity.

The varying negative potential thus induced on the right hand plate of this condenser C1 is applied to the grid of the first A. F. amplifier tube. This causes pulsations of increased strength in the plate circuit of that tube and through resistor R3, which in turn changes the voltage applied to condenser C2 and the grid of the next amplifier tube, etc.

The condensers are necessary between the plates and grids of successive tubes to prevent the positive "B" potential from being applied to the grids.

The resistors R2, R4, and R6 are merely grid leak resistors to drain away excessive negative charges which would otherwise be stored up on the grids by the blocking affects of the condensers which are in the normal grid return leads. In transformer coupled sets this negative charge can leak off through the secondaries of the transformers and back to the filaments.

The coupling resistors R1, R3, and R5 are all of the same size and usually of about 100,000 ohms regardless of the number of stages. The leak resistors vary in size, however, getting lower as the stages progress and the signal strength and grid voltages increase. For three stages of resistance coupled amplification these leaks are generally of 1 megohm for R2 or the first stage, ½ megohm for R4 or the second stage, and ¼ megohm for R6 or the third stage.

The size or capacity of the coupling condenser is not very critical, ranging from .01 to 1.0 mfd., a very commonly used size being the .1 mfd. condenser.

Fig. 87 shows several types of condensers such as are commonly used for coupling purposes and also for by-pass and other uses in radio sets. Some of these condensers are made with flat sheets of tin foil and mica pressed together and moulded in bakelite or hard insulating compound, after the alternate

Fig. 87. Above are shown several types of fixed condensers used for coupling radio circuits and for bypassing certain frequencies around some of the inductive or high resistance devices in the circuits. (Photo courtesy of Aerovox Wireless Corp.)

foil strips are equipped with projecting terminals or connector lugs which project out through the insulation. Others of these condensers are made with waxed or oiled paper insulation between the foil, and are either of flat pressed or rolled construction, and then the entire element enclosed in a moisture proof metal case which is filled with oil or wax.

Fig. 88 shows several types of resistors which are used for coupling resistors in the plate circuits of resistance coupled amplifiers, for grid leaks, and other purposes in radio receivers and amplifiers. Note that most of these resistors are made in a sort of cartridge unit or tubular form for convenient mounting in spring clips in the set. This enables them to be easily and quickly changed or replaced with resistors of different values when necessary. At the lower left in Fig. 88 is shown a base and the spring clips for mounting a single resistor unit, and at the lower right in this same figure two resistor units are shown in the clips of a double unit mounting.

In some cases condensers are equipped with these spring clips attached to them so the resistors and condensers can be mounted and connected as a unit, thus saving space and wire.

On account of the voltage drop in the plate circuit resistors it is necessary to use somewhat higher B battery voltages to get the proper voltage applied to the plates. Resistance coupled amplifiers generally require about 135 to 150 volts plate supply instead of 67 to 90 as in ordinary transformer coupled amplifiers. One of the disadvantages of resistance coupled amplifiers is their inefficiency due to the losses occurring in the plate circuit resistor.

Where several stages of resistance coupling are used for audio frequency amplification, as in Fig. 86, the voltage applied to the plate of the last tube is generally somewhat lower than that used on the other stages, as the last stage has no resistor in its plate circuit to cause any voltage drop, and the coils of the loudspeaker have only a small amount of resistance as compared with the regular plate circuit resistors.

Some radio sets use just one or two stages of resistance coupled amplification with one or more stages of transformer coupled amplification. In some cases where little or no R. F. amplification is used the first stage of A. F. amplification is transformer coupled, because the plate current of the detector tube is likely to be so small on weak signals that it would not cause sufficient voltage drop in a coupling resistor if such were used in the first stage.

68. IMPEDANCE COUPLING

Some amplifiers use impedance coupling which is very similar to resistance coupling except that an impedance or choke coil is used instead of a resistor in the plate circuit of each tube.

If the resistors R1, R3, and R5, in Fig. 86 were replaced by iron core choke coils, we would then have a circuit for a detector and three stage impedance coupled amplifier. The diagram of impedance coupling for loudspeakers which was shown on the right in Fig. 85, shows an iron core choke coil or impedance of the type used in impedance coupled amplifiers. These coils are also often called **plate reactors.**

The coupling condensers and grid leaks in impedance coupled amplifiers are the same as with resistance coupled amplifiers. The operating principles of the two types of amplifiers are fundamentally the same. With an impedance or plate reactor of the proper value in the plate circuit of an amplifier tube, the plate current will flow through it quite freely but the varying flux due to plate cur-

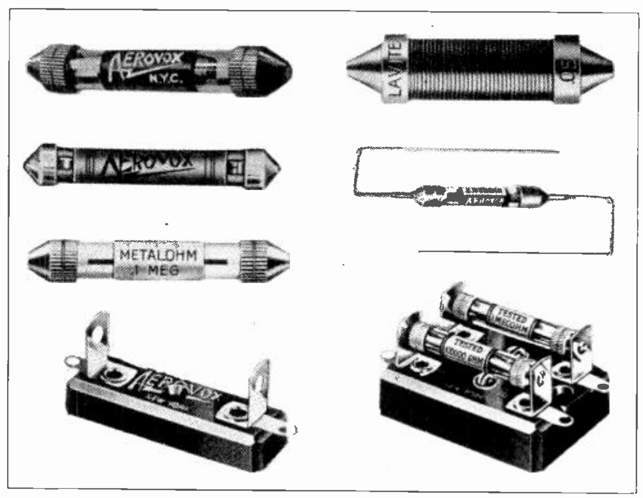


Fig. 88. Photos of several styles of fixed resistor units and mountings, for use in resistance coupled amplifiers, and for grid leaks, and other purposes in radio receivers. (Photo courtesy of Aerovox Wireless Corp.)

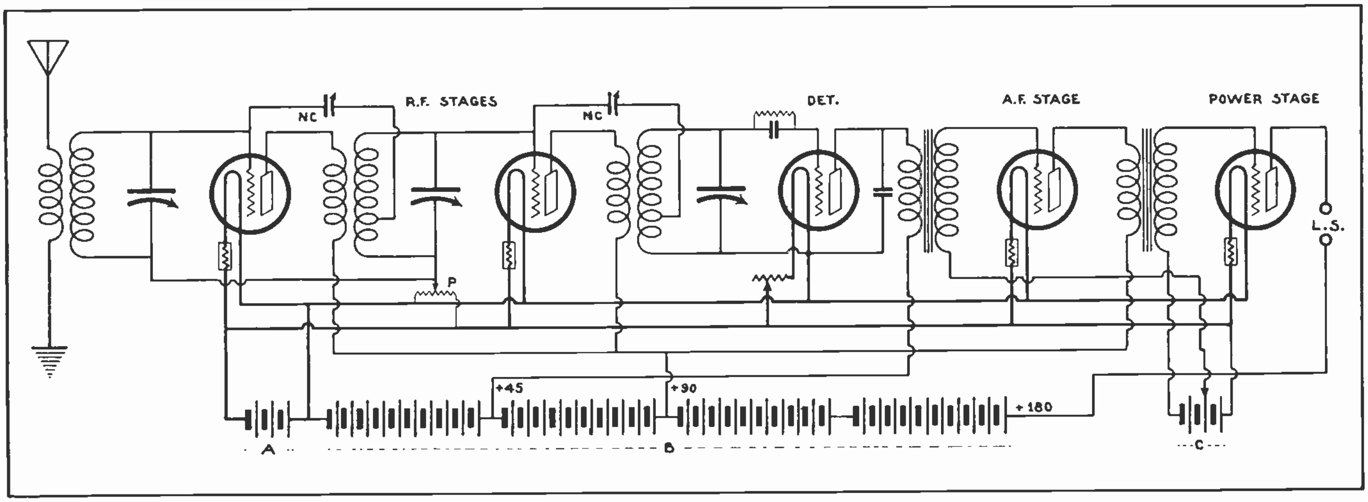


Fig. 89. Circuit diagram of a five tube neutrodyne receiver. Note the two neutralizing condensers N. C. connected across the R. F. amplifier tubes for balancing out the effect of the tube capacity. Also note the tapped secondaries of the special R. F. transformers or "neutroformers", to which one lead from each neutralizing condenser connects.

rent pulsations will induce counter E. M. F. in the coil. The voltage drop due to this impedance or counter E. M. F. varies the voltage applied to the coupling condenser and to the grid of the following tube, etc.

In order to develop sufficient voltage drop with the low frequency currents or pulsations in audio frequency stages, the plate reactors or impedance coils must be of the iron core type. In radio frequency stages, however, air core impedance coils can be used and will develop sufficient counter E. M. F. and voltage drop due to the high frequency energy passed through them.

The inductance of the choke coils used in the plate circuits of impedance coupled amplifiers varies from 100 to 300 henries, and their impedance from 20,000 to 60,000 ohms, according to the types of tubes used and their location in the amplifier. The impedance of these coils is generally quite high with respect to that of the plate circuit of the tube, often from 3 to 5 times as high in ohms as the A. C. resistance or impedance of the plate circuit in which the coil is connected.

69. NEUTRODYNE CIRCUITS AND NEUTRALIZING

In earlier paragraphs we mentioned the necessity of neutralizing or balancing out the capacity between tube electrodes and leads to prevent oscillation and feed back in R. F. stages. There are several different methods of accomplishing this but they all work on about the same general principle of supplying a small capacity or condenser outside the tube to balance that within the tube itself, and also that of its terminals and wiring.

One of the methods which has been very commonly used in earlier makes of battery operated sets, is shown in the R. F. stages of the circuit in Fig. 89. This circuit is commonly known as the Neutrodyne circuit and was very popular a few years back.

Screen grid tubes have now made neutralizing of this type unnecessary in modern receivers, but there are thousands of neutrodyne sets still in use, and it will be well for any radio service man to have an understanding of their principles and adjustment.

In Fig. 89 you will note the two small neutralizing condensers connected from the grid to the output transformer secondary of each R. F. stage. These condensers and the specially tapped secondaries of the R. F. transformers to which they attach are about the only differences between this neutrodyne circuit and an ordinary five tube set with two R. F. stages, detector, and two stages of audio frequency amplification.

The principle of this neutrodyne circuit or of neutralizing undesirable tube capacity in any R. F. amplifier is as follows: First we know that the feedback and oscillation troubles which often occur in R. F. stages without screen grid tubes, are caused by energy feeding back through capacity from the plate to the grid. This changes the grid potential, and causes another surge of plate current which again imparts a potential change to the grid by capacity, and thus sets up oscillation or a continuous repetition of this action.

Now if we connect a small external condenser of just the right size, from the plate circuit back to the grid of the same tube, and in such a manner that it will always supply voltage of opposite polarity to that applied to the grid by plate capacity within the tube, the two voltages should balance or neutralize and destroy each other. That is just what happens with the connections shown in Fig. 89 if the condensers NC and NC1 are of the proper size.

One plate of the neutralizing condenser N C connects to the grid of the tube, and the other plate connects to a point on the secondary of the output transformer where it obtains a small voltage of opposite polarity to that supplied to the plate through the primary. Therefore, the charge imparted to the grid through condenser N C is just opposite to that supplied by capacity from the plate, and the two neutralize and cancel each other thus preventing any change of grid potential from either source and thereby eliminating objectionable oscillation.

Of course the capacity of NC and NC1 must be just right to balance that between the respective tube elements, and as the capacity of different tubes usually varies a little, these neutralizing condensers are adjustable so they can be set at the proper values to match the tubes they are used with. Their capacity is only very small and generally ranges from one to thirty m.m.f. (micro-microfarads).

These little condensers are of various construction, some being merely two pieces of stiff wire pushed into a fibre or glass insulating tube until their ends nearly meet, and with a metal sleeve placed over the outside of the insulating sleeve. In this type the capacity effect between the wires and the outer metal sleeve creates two small condensers in series. Such neutralizing condensers can be adjusted by sliding the sleeve back and forth on the wire ends, but of course never allowing the wire ends to touch each other.

Some neutralizing condensers consist of two small flat strips of metal separated by insulation, and have a screw adjustment for moving one of these plates closer to or farther from the other. For adjusting this type a screw driver made of bakelite or some such insulating material should be used, in order to avoid the effect of body capacity which would be conveyed through the metal of an ordinary screw driver to the condenser.

Some neutralizing condensers are of the single plate rotary or variable type, made in a very small size known as midget condensers.

70. NEUTRALIZING PROCEDURE

To adjust the neutralizing condensers in a receiver, proceed as follows: First tune the receiver to some local or nearby station and adjust the tuning dials and rheostats to the point of greatest undistorted volume.

Then remove the first R.F. amplifier tube and wrap a piece of thin but tough waxed tissue paper around its filament prongs, so the filament will not light when the tube is replaced. (The filament prongs are always the two large ones).

With the tube back in place in its socket but with its filament not heated, again adjust the receiver to the point of greatest volume, and the signal now heard will be coming through this tube by capacity coupling.

Next adjust the neutralizing condenser of this tube until the signal disappears or is brought to the lowest volume possible by this adjustment.

Then remove the paper from the tube prongs and put this tube back in service and proceed in the same manner on each of the remaining R.F. tubes.

In some cases it is not possible to make the signals completely disappear when neutralizing a tube, because of inductive and capacity coupling between wiring and parts of the set.

It is more desirable when possible to use a modulated oscillator to excite a receiver during neutralizing adjustments, instead of tuning it to some station. A modulated oscillator is simply a portable oscillator set which is constructed to give off a continuous wave which is modulated at an audible frequency. When such an oscillator is placed near the antenna of the receiver to be neutralized, the receiver will deliver a note of constant value which is much better than ordinary music when making adjustments on the set.

Instead of wrapping the tube filament prongs with paper, a tube of the same type with one filament prong cut off close to the base is often used to replace the other tubes one at a time while neutralizing each stage.

The potentiometer P in Fig. 89 is connected across the filament supply leads and used to obtain the proper negative bias for the R.F. tubes, by connecting their return leads to the sliding arm of this resistance. A "C" battery is used to get the negative bias for the first audio tube and the power tube in the last stage.

The detector tube in this circuit has a filament rheostat but the filament circuits of all the amplifier tubes are equipped with fixed resistor units called ballast resistors or **Amperites,** which are of the proper resistance for each tube.

71. SUPERHETERODYNE RECEIVERS

We have previously mentioned that it is generally not practical to use more than two or three stages of either radio frequency or audio frequency amplification in an ordinary radio receiver, on account of the losses and oscillation in R.F. stages and the distortion in A.F. stages.

A very popular type of receiver which makes possible several more stages of amplification is known as the **Superheterodyne.**

Superheterodyne receivers use an oscillator tube and circuit to set up a continuous wave of their own, which heterodyne or mixes with the incoming signal to produce a beat note of the proper **intermediate frequency** for efficient amplification through as many as five or more intermediate stages.

Then the amplified energy is passed through a detector tube and two or more stages of audio frequency amplification.

The purpose of using the intermediate frequency energy in a superheterodyne receiver is to be able to handle a lower frequency than the ordinary R.F. carrier waves, and one which therefore does not have so much of the high frequency capacity effects and losses; and yet a frequency higher than audio frequency and which does not need to be handled through transformers with large iron cores that cause distortion.

It is possible to design intermediate frequency transformers which will amplify very efficiently only certain frequencies within a very narrow band. These transformers are tuned so sharply by use of just the right number of turns and by connecting small fixed condensers across them, that they will not pass any other frequencies through.

Intermediate transformers can be designed for frequencies from about 20,000 to 120,000 cycles, but the intermediate transformers for any certain receiver are often designed to handle or pass only waves within a band of 10 kilocycles (10,000 cycles), somewhere within the above mentioned range.

Superheterodyne receivers can therefore be made with extreme selectivity or sharpness of tuning, which is another of their advantages.

The intermediate frequencies used in most modern superheterodyne receivers are around 175 to 180 kilocycles, or a wave length of about 1666 to 1715. The Atwater Kent receivers use a 130 K. C. intermediate frequency and some older sets use 100 K. C.

Some intermediate transformers are of the air core type, while some have small iron cores. Some superheterodyne sets have some of each type in their intermediate stages.

Fig. 90 shows a simple seven tube superheterodyne circuit. The tubes in the circuit are numbered, number one being the oscillator which sets up the wave to mix with the signal wave. Number two is the mixer, "frequency changer", or **first detector** as it is more commonly called, and is where the two frequencies are mixed into the intermediate frequency. Three and four are I.F. or intermediate frequency amplifiers. Five is the second detector or actual detector performing the rectification and change from I.F. to A.F. Tubes six and seven are ordinary A.F. amplifiers.

The intermediate frequency transformers are shown with just one line between their coils.

The circuit of the first detector is provided with a variable condenser to enable it to be tuned to the desired station or signal wave length. The oscillator circuit also has a tuning condenser so it can be adjusted to produce any desired frequency.

As the intermediate transformers are designed to handle only one certain frequency and their tuning is never changed, we must be able to adjust the oscillator to produce a different frequency for each different signal frequency or wave length received, in order to maintain the same intermediate frequency at all tunes.

In operating a superheterodyne receiver the first detector circuit is tuned to the wave length of the desired station, and the oscillator is then tuned to produce a frequency that will mix with the incoming signal to produce a beat note of the proper intermediate frequency. The energy from the oscillator circuit is transferred to the first detector circuit by induction between coil 2 in the oscillator plate circuit and coil 3 in the detector grid circuit. As previously mentioned the beat note or intermediate frequency will always be equal to the difference between that of the incoming signal and that produced by the oscillator.

For example if the frequency of the incoming signal is 1,000,000 cycles, and the oscillator produces a frequency of 950,000 cycles the beat note or intermediate frequency will be 50,000 cycles.

When the signal energy and that from the oscillator are mixed together in the first detector circuit the beat note produced has the audio frequency signal variation from the antenna coil impressed on it, and this is carried through the intermediate stages, greatly amplified, and then separated at the second detector and further amplified by the A.F. stages.

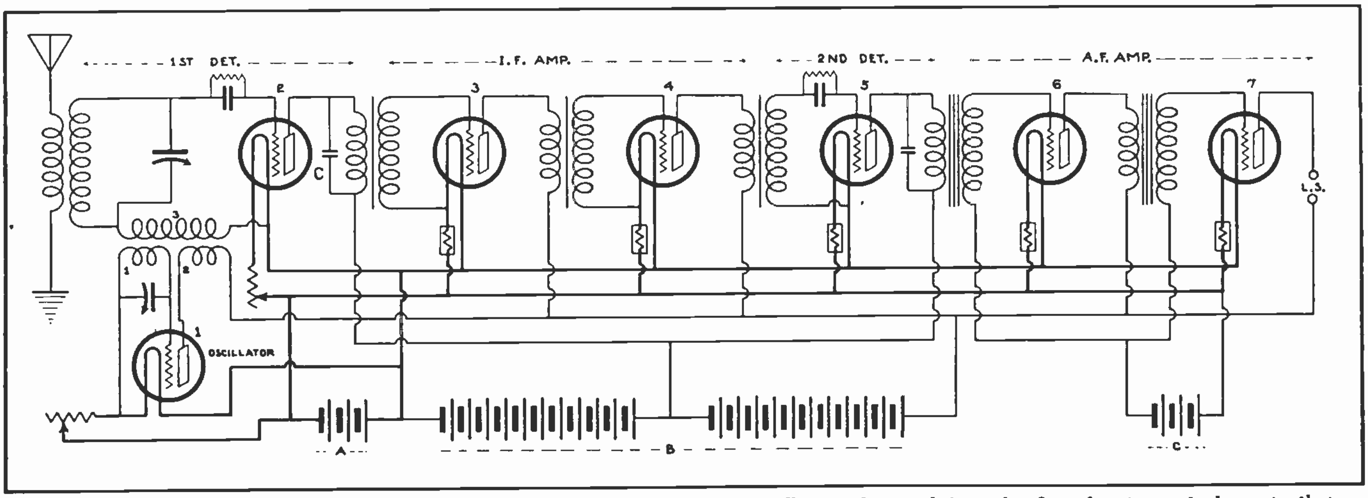


Fig. 90. Circuit diagram of a seven tube superheterodyne receiver. Note the oscillator tube coupled to the first detector and also note that both a first and second detector are used. The stages marked "I. F.amp." are intermediate frequency amplifier stages. Study the principles of this type of receiver very carefully as there are many thousands of receivers of both old and new types which use this principle.

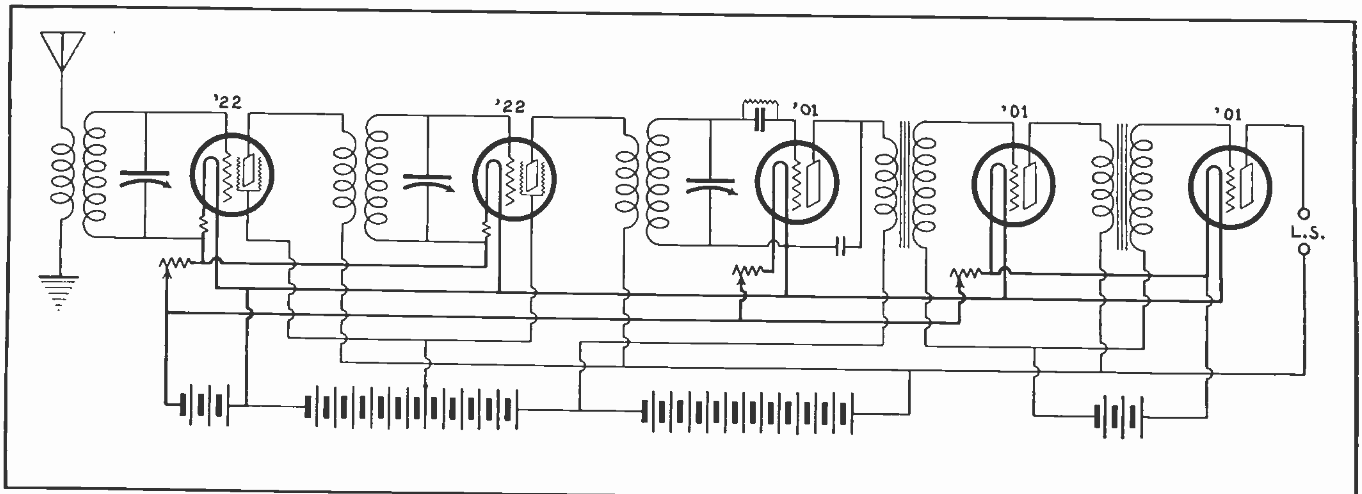


Fig. 91. Diagram of a five tube battery operated receiver using screen grid tubes in the two R. F. amplifier stages. Note the connection of the screen grids to a positive terminal on the B battery, and note that otherwise this circuit is the same as any ordinary D. C. receiver with two R. F. stages, detector, and two A. F. stages.

Some times one or two stages of radio frequency amplification are used ahead of the first detector and oscillator in superheterodyne receivers.

Different types of oscillators with various arrangements of their coupling coils or condensers and tuning condensers, are used with superheterodynes. In some cases no separate oscillator is used, but a feed back regenerative circuit is used on the first detector, so that this tube serves both as an oscillator and mixer. This arrangement is called an **Autodyne** circuit. Another circuit called the **Ultradyne** uses a modulator tube to amplify the incoming signal and then mix it with the energy from the oscillator by direct conductive coupling at the primary of the first intermediate transformer.

In Fig. 90 a fixed condenser C is connected across the primary of the first intermediate frequency transformer to bypass the radio frequency component of the energy in the plate circuit of the first detector. In some "supers" the primaries of the other I.F. transformers also have small fixed condensers connected across them to act as filters and bypass all undesired frequencies.

Superheterodyne receivers are extremely sensitive and capable of receiving very weak signals from distant stations. Many "supers" are operated with loop aerials only, and no outdoor aerials or ground connections.

The extreme sensitivity and selectivity of these receivers makes them a very popular type.

In constructing a superheterodyne set the tubes are not always placed or lined up in the order shown in Fig. 90, but are arranged for the best efficiency of operation and for convenience in connecting or wiring the receiver.

72. SCREEN GRID RECEIVERS

Screen grid receivers are simply ordinary receivers using screen grid tubes in some of the stages.

Screen grid tubes are generally used in the R.F. stages of the receiver as shown in Fig. 91. You will note that this circuit is the same as that of any ordinary five tube set with two stages of R.F. amplification, detector, and two stages of A.F. amplification; except for the leads running from the screen grids of the first two tubes to a positive tap on the "B" battery.

We have already learned in our study of vacuum tubes that screen grid tubes have very small internal capacity and therefore prevent objectionable oscillation and feed back in R.F. stages, without the aid of neutralizing. These tubes also have very high amplification factors, and it is possible to obtain as much amplification with two stages of screen grid R.F. amplification as with four or five stages using ordinary three element tubes.

For this reason screen grid tubes are used very extensively in R.F. stages of modern receivers, and also occasionally as detectors and A.F. amplifiers.

73. A.C. RECEIVERS

All of the circuit diagrams shown so far have used batteries for the current or power supply, in order to make the complete circuits easier to trace and understand.

All early types of radio receivers used batteries almost exclusively for their power, as their tubes were all designed for D.C. operation. Direct current of constant voltage is required for the plate circuits of vacuum tubes for reproducing voice and music without foreign hums or sounds. Because it enables the filament to emit electrons in a smooth even stream, D. C. is also advantageous for heating the filaments of tubes in which the filament serves as the cathode.

Batteries supply smooth constant value D. C. as long as their voltage or state of charge is up to normal, and were thus considered very convenient for radio use.

Wet storage batteries of the 6-volt automobile type are used for filament supply, except on small sets with tubes having filaments for dry cell operation, Dry B batteries consisting of a number of small cells connected in series are used for plate supply.

Some of the disadvantages of batteries, however, are their cost and weight, the fact that they discharge or run down and need to be replaced or recharged frequently, and in some cases cause corrosion and mess from acid fumes, etc.

Nevertheless, there are many thousands of receivers that are still battery operated, in use in farm and rural homes not supplied with electricity. Automobile radios and those used for airplanes are also battery operated.

Most modern sets made for use in towns and homes supplied with electricity are made for operation with current direct from the light socket or convenience outlet. As most of this current supplied in homes for lighting is A.C., most of these receivers are designed for A.C. operation and are commonly called A.C. receivers. Some "all electric" sets are made for operation on D.C. however, where homes are supplied with 110 or 220-volt D.C. for lighting.

The general operation of A. C. sets is the same as that of battery sets, and the circuits and parts are almost the same, except that A.C. filament type or heater element tubes are used in A.C. sets, and a "power pack" or power supply unit is used in place of the batteries.

All receiver tubes require D.C. for their plate circuits, even though the filaments of modern A.C. tubes can be operated on alternating current.

The power pack or unit of an A.C. receiver therefore must operate on the 110-volt A.C. supplied by the ordinary socket or outlet in the home, and it must supply the proper voltages and currents for the various circuits in the receiver.

The section of the power unit which supplies the low voltage A.C. filament current consists merely of a step down transformer. The section which supplies the high voltage D.C. current for the plates of the tubes, consists of a step up transformer, rectifier, and filter. The power unit will be described more in detail a little later.

74. SIMPLE FIVE TUBE A.C. CIRCUIT

Fig. 92 shows a circuit diagram of a five tube A.C. receiver without the power unit. The tubes used in this circuit are all A.C. type 327 tubes which are used both for detector and amplifier duty. These tubes are of the heater element type with five prong bases.

This circuit is a very simple one with which it is easy to compare the circuits of an A.C. receiver with the battery operated types already shown.

In battery sets rheostats are used in the filament circuits of the tubes, to keep the filament voltage properly adjusted as the battery voltage changes slightly during discharge.

Such filament rheostats are not necessary in A.C. receivers as the line voltage supplied to the filament supply transformers usually remains about constant, so the transformer secondary delivers steady voltage of the proper value to the filaments at all times. In case the primary voltage does at times fluctuate with the load on the line the transformer voltage can be kept right by a compensating device in its primary circuit. Note that the filaments of all tubes in Fig. 92 are simply connected in parallel to the 2½-volt A.C. filament supply leads.

In circuits using heater element type tubes as shown in Fig. 92, the grid returns are connected to the cathode terminals as shown. This cathode instead of the filament is the electron emitting element in these tubes.

The plate circuits are also completed through the cathodes. Note that all plate leads connect to the positive terminals of the "B" power supply. The plates of the amplifiers connecting to the 90-volt terminal, and the plate of the detector to the 45-volt terminal. The current flow can be traced from the positive terminal of the power unit, through any plate, through the electron stream to the cathode and then back to the negative (B-) terminal of the plate power supply, which is connected to all cathodes.

The variable condensers used for tuning the R.F. stages in Fig. 92, are shown connected together by a dotted line, which indicates that their rotors are all located on one shaft or operated from one dial.

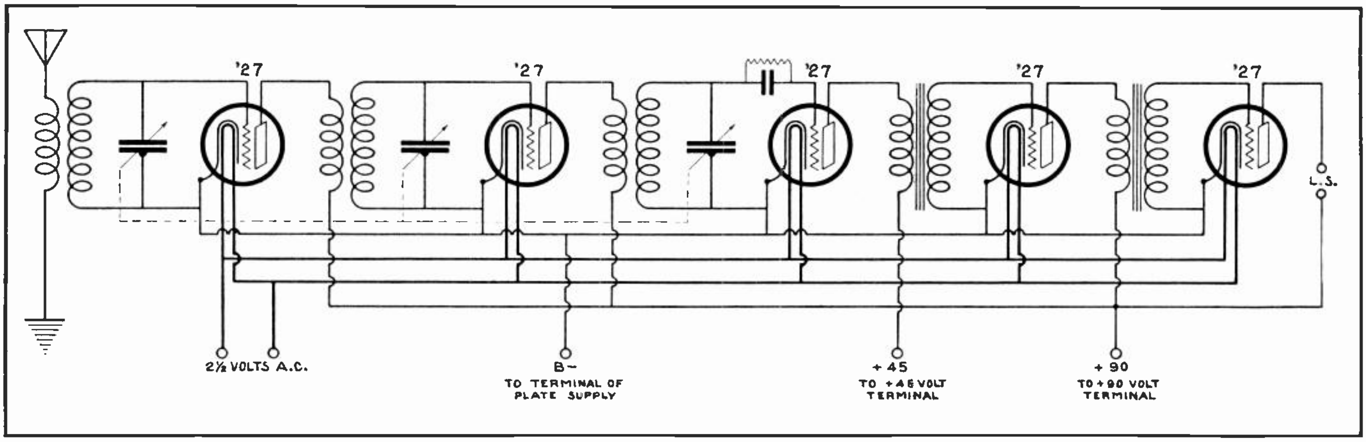


Fig. 92. Circuit diagram of a five tube A. C. receiver using A. C. heater-element tubes. The "27" tubes used in this circuit will serve either as amplifiers or detectors. Note the connections of the cathodes of the heater-element tubes to the B— terminal.

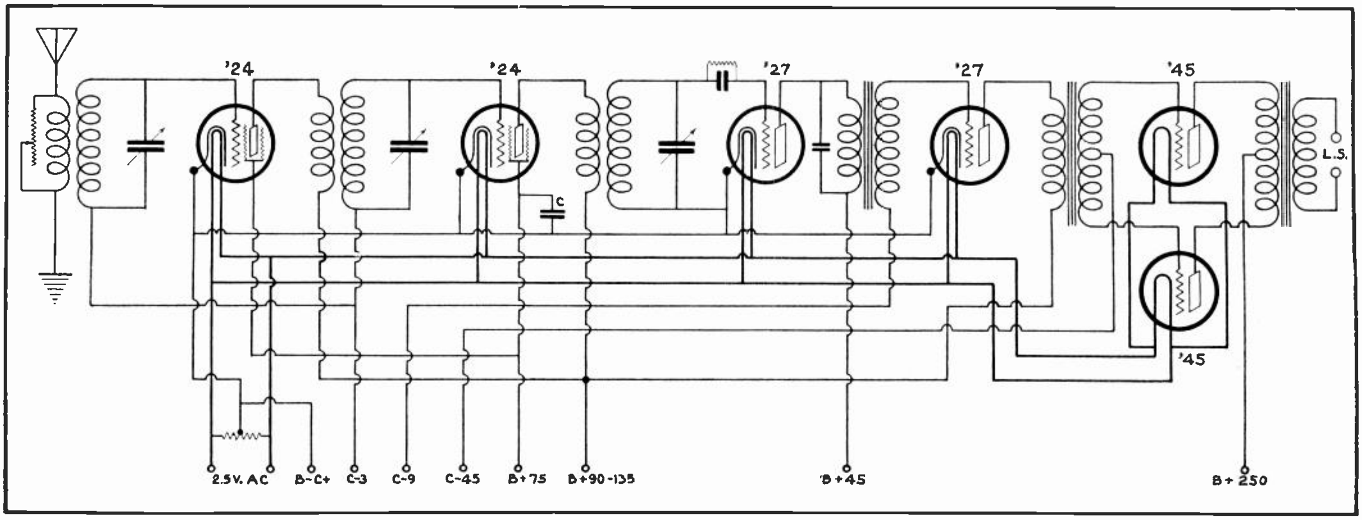


Fig. 93. Circuit diagram of a very popular six tube A. C. receiver, with screen grid R. F. amplifier tubes, and two power tubes used in push-pull in the last A. F. amplifier stage. A. C. heater element tubes are used for the R. F. amplifiers, detector, and first A. F. amplifier. The power tubes in the push-pull stage are "filament type" tubes with the filaments serving as the cathodes, but the filaments of these "45" tubes operate on the same voltage as the heater elements of the other tubes do. Note the high C voltage used for negative grid bias on the power tubes, and note also the various terminals where the leads of this receiver connect to the power supply unit.

This is called single dial tuning control and is the way most modern receivers are equipped.

75. A.C. CIRCUIT WITH SCREEN GRID R.F. AMPLIFIERS AND PUSH-PULL POWER STAGE

Fig. 93 shows a very practical circuit for a 6 tube A.C. receiver using screen grid tubes in the R.F. stages and two power tubes in push-pull in the last A.F. stage.

With the high amplification factors of the screen grid tubes, and the large undistorted power capacity of the "345" power tubes in push-pull, a receiver of this type will give good selectivity, sensitivity, and plenty of volume of good quality sound to meet most any requirements for a home set.

The R.F. amplifier tubes, detector, and first audio amplifier are all A.C. heater element type tubes, and the power tubes in the last audio stage are A.C. "filament type". All of these tubes, however, use the same filament or heater element voltage which simplifies the wiring and power supply considerably.

The screen grids of the "24" tubes in the R.F. stages, connect to a 75-volt positive terminal of the plate power supply unit. A small bypass condenser C is usually connected between this screen grid lead and the negative B lead which connects to all cathodes of the heater element tubes.

Three volts negative bias is used on the control grids of the "24" tubes, 9 volts bias on the grids of the "27" tubes, and 45 volts bias on the grids of the "45" power tubes.

A variable high resistance is shown connected across the primary of the first R.F. transformer or aerial coupler, to be used as a volume control. As this resistor shunts more or less of the received signal energy around the primary of this transformer and thereby controls the amount of energy applied to the grid of the first R.F. tube, this of course controls the volume throughout the rest of the set and at the speaker. This circuit shown in Fig. 93 is very similar to those used in some of the most popular types of modern A.C. receivers.

The power supply unit is not shown, and in tracing the various circuits just start at a positive supply terminal and trace through to negative, etc.

76. A.C. CIRCUIT WITH FILAMENT TYPE AMPLIFIER TUBES

Fig. 94 shows a circuit diagram of a complete 5 tube A.C. receiver. Two of the "26" type tubes are used as R.F. amplifiers, and one "26" tube and one "71" power tube for A.F. amplifiers. These four tubes are all of the A.C. filament type. The detector is a "27" heater element type A.C. tube. The 380 tube shown in the power unit at the lower part of the diagram is a full wave rectifier tube. The negative bias voltage for the amplifier tubes of this circuit is obtained from the voltage drop in a resistor placed in series with the negative return of the plate current supply. The grid returns of the R.F. amplifier tubes and the first A.F. amplifier are all connected together to the C- 9-volt tap on the bias resistor. The grid return of the power tube in the last audio stage is connected to the C- 40-volt point on this resistor. The voltage drop in this bias resistor sets up a difference in potential between the grids of the tubes and the center taps of the resistors R and R1, from which the negative return is taken to the B- and C+ connection of the power supply, and through which the plate current returns.

The plate current of the A.C. filament type tubes flows from the positive terminal of the plate supply through the transformer primaries to the plates, through the electron streams in the tubes, down whichever side of the filaments the A.C. filament current happens to be flowing at that instant, and then through one half of the resistor to the center tap, and from there back to B—.

You will note that the plate of the detector tube is supplied with 45 volts, those of the two R.F. amplifiers and the first audio amplifier with 90 volts, and that of the "71" power tube with 180 volts.

These different voltages are obtained from various points along a resistor shown near the right side of the diagram in Fig. 94, and this resistor and the plate circuit terminals are fed with rectified D.C. which comes through the filter chokes from the rectifier tube.

The high voltage secondary S H of the power transformer supplies A.C. to the rectifier tube, which converts it to pulsating D.C. Practically all of the ripple or pulsation of this D.C. voltage is then smoothed out by the filter system consisting of the filter chokes and the condensers C1, C2, and C3. The lower 5 volt winding on the transformer secondary supplies A.C. to the filaments of the rectifier tube, and the upper 5 volt winding supplies the filament of the power tube. The 2½-volt secondary supplies A.C. to the heater element of the detector tube, and the 1½-volt winding supplies A.C. filament current to the R.F. amplifier tubes and first audio amplifier tube.

77. POWER UNITS FOR A.C. RECEIVERS

The power supply unit or power pack in an A. C. receiver is usually mounted with the rest of the parts of the receiver on one main frame or chassis. The power unit is often mistaken for part of the amplifying equipment.

Fig. 95 shows a photo of a modern A. C. receiver without its cabinet. The R. F. transformers and tuning condensers are in the long metal box or shield in the right foreground and the tubes and A. F. transformers can be seen at the rear. The power unit is located at the left of the receiver units. The power transformer and filter chokes are in the square metal box, and the rectifier tube and filter condensers are at the rear of this box.

By examining Fig. 82 once more you will note a power unit of different arrangement. Here the power transformer is the left one of the three large units at the rear of the set, the filter condenser consisting of several separate units is next in the light colored box, and the filter chokes are on the right.

Fig. 96 shows a circuit diagram of a complete power supply unit a little different from the one shown in Fig. 94.

The primary of the power transformer is connected to the 110-volt supply by means of the plug and cord shown on the left. The lower secondary coil supplies low voltage (7 volt) A. C. to heat the filaments of the two half-wave rectifier tubes. This winding also has a center tap to be used as the positive lead for the plate supply.

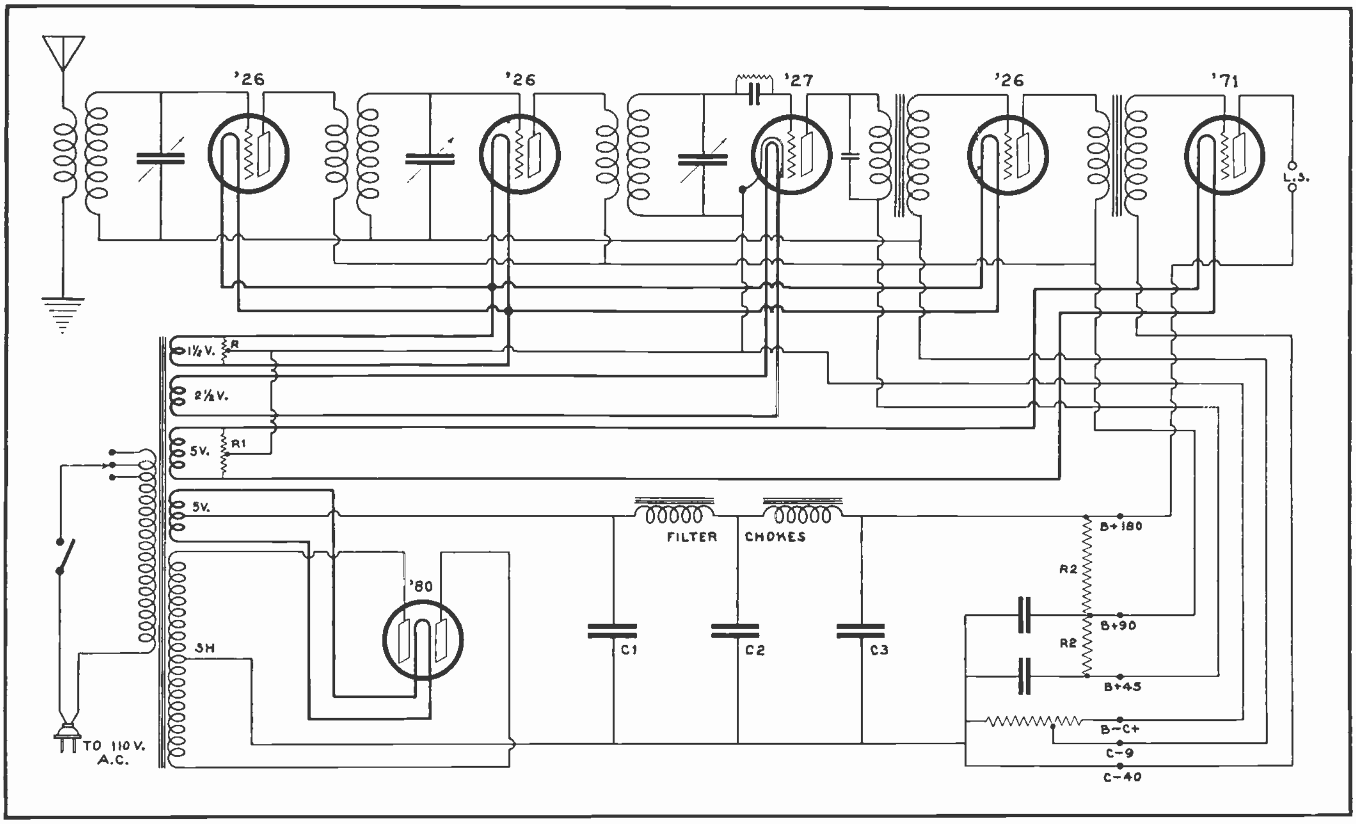


Fig. 94. Complete circuit diagram of a simple five tube A. C. receiver and its "power pack" or power supply unit. This receiver uses only one heater element tube for the detector, and the amplifiers are all A. C. "filament type" tubes. Note the manner in which the grid return leads of the amplifier tubes are made through the C— terminal, through the biasing resistor to C+, and then to center taps on the resistors connected across the filament supply leads. Trace the circuits of the power unit carefully to get a good understanding of this device while reading the explanations in the accompanying paragraphs.

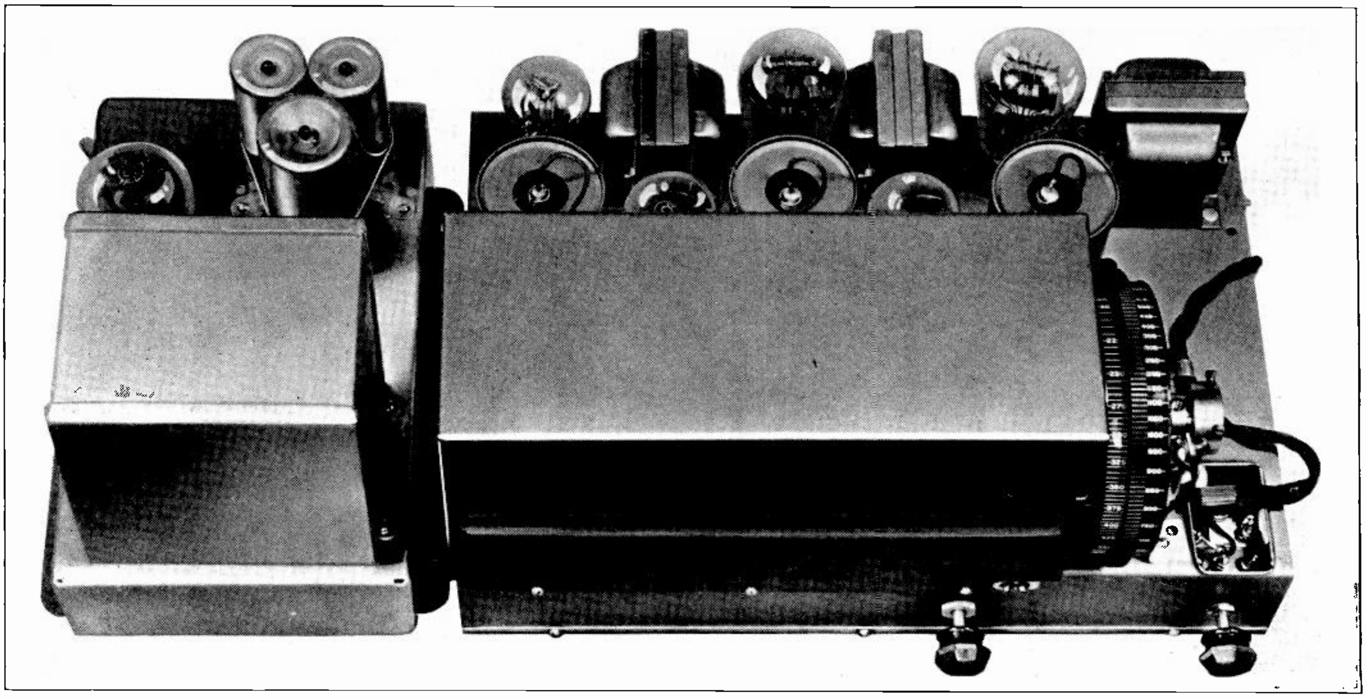


Fig. 95. This excellent photograph shows the construction of an eight tube A. C. receiver and its power unit. Note the thorough shielding of the R. F. transformers and tuning condensers by the large shield, and that of the power transformer and chokes in the smaller shield on the left. The three screen grid tubes are also shielded by individual shield "cans". The R. F. transformers and condensers are also shielded from each other by separate partitions inside the large metal box. (Photo courtesy of Zenith Radio Corp.)

The top secondary coil furnishes 2½ volt A. C. for the filaments and heater elements of the tubes in the receiver. The main center section of the secondary supplies high voltage A. C. to the plates of the rectifier tubes.

The entire power unit consists of four sections, marked A, B, C, and D in Fig. 96. Section A is the power transformer which supplies the various A. C. voltages required. It steps the voltage down from the 110 volts on the primary, to the coils of few turns on its secondary for the filament supply. And it also steps up the voltage on its high voltage secondary which supplies current to the rectifier tubes.

This high voltage secondary winding is designed according to the types of tubes used in the receiver, and the plate voltages required by them. When this winding feeds a full wave rectifier as in Fig. 96, only half of the winding is in use at any one time, each half feeding its respective tube during every other alternation. Therefore, each half of this winding must develop the full voltage required by the rectifier tubes and the highest voltage required by the plates of the power amplifier tubes in the receiver. Note that this secondary has a center tap for the negative B return lead.

Section B of this power unit consists of the two half wave rectifier tubes connected for full wave rectification. Their plates are connected to opposite ends of the high voltage transformer winding, and when alternating voltage is induced in this winding first one rectifier plate becomes positive and then the other does.

When either of these plates is positive it attracts negative electrons from the filament, thus completing the circuit and allowing current to flow from its plate to the filament, but never in the opposite direction.

During the alternation when the upper end of the transformer secondary is positive, current will flow as shown by the solid arrows, out from this positive lead through the upper rectifier tube, on from the filament of the tube through one half of the lower transformer coil, out through the chokes and filter system to B+, then to the tube plates, through the tubes and back to B— which returns to the center of the transformer secondary.

During the next alternation current will flow from the lower end of the winding as shown by the dotted arrows, through the lower rectifier tube, and out along its filament lead through one half of the lower secondary coil, and out on B+ in the same direction as the other alternation.

So we find that the rectifier tubes change the A. C. from the transformer into pulsating D. C. for the plate supply, the center tap on the low voltage winding being the positive lead from the rectifiers, and the center tap on the high voltage winding being the negative return.

The rectified D. C. is pulsating as shown by the curve at A in Fig. 97, and varies too much to be suitable for use on the plates of the receiver tubes.

78. FILTER

The filter unit in Section C, consisting of two chokes in series and 3 condensers in parallel with the plate supply, smooths out this pulsating current about as shown by the curve at B in Fig. 97. This is accom-

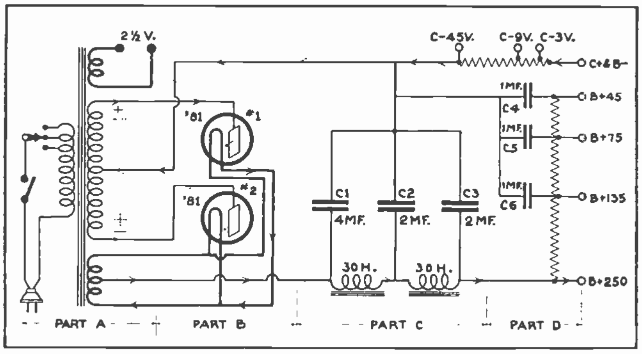


Fig. 96. Wiring diagram of a power supply unit showing the transformer, rectifier, filter, and voltage divider sections. Observe this diagram carefully and make sure you thoroughly understand the function and operation of each part.

plished by the combined action of the choke coils and condensers.

The choke coils which have a very high inductance of about 30 henries, consist of several thousand turns of fine wire wound on iron cores, and are connected in series with the positive lead from the rectifier.

As the voltage of the rectifier current starts to rise during any pulsation, it builds up current in the choke coils and sets up a flux around them which generates in their turns a counter E. M. F. which opposes or limits the building up of this current. During this period of rising voltage the condensers are receiving a charge and are absorbing the peaks of the current and energy waves which are blocked and held back by the chokes.

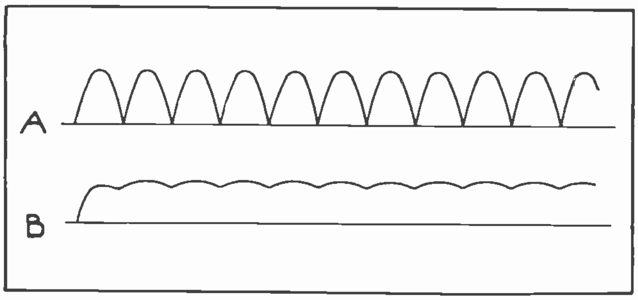


Fig. 97. Curves showing pulsating D. C. as it comes from the rectifier, and also after the ripples have been smoothed out by the filter.

When the voltage of a pulsation from the rectifier starts to decrease toward zero the strong flux already built up around the chokes now collapses and induces in their turns a voltage which tends to keep the current flowing. As soon as this voltage starts to lower the condensers also start to discharge and supply current through the chokes and to the plate circuits of the receiver tubes.

Thus the peaks of the waves or pulsations are blocked by the chokes and stored by the condensers and then fed back into the hollows, smoothing out nearly all of the ripple or pulsations in the D. C. plate supply. Thus the name "filter" given to this part of the power unit.

79. VOLTAGE DIVIDER

Section D in Fig. 96 is the **voltage divider** consisting of a high resistance tapped at several proper points, and having several fixed condensers connected in parallel with its various sections.

The purpose of this resistor is to lower the voltage from the filter to the desired value for the plates of the various tubes. This is accomplished by the plate current flowing through the sections of this high resistance and causing a voltage drop.

The output voltage of the filter of a power unit should be just high enough for the plate of the power tube, or the highest plate voltage required by the receiver. In Fig. 96 this is the voltage obtained between the terminals B+ 250 and B—. This voltage is too high for the plates of the amplifier and detector tubes, so these tubes get their plate voltages at the taps along the resistor or "voltage divider", as at B+ 135 and B+ 45. The B+ 75 terminal is for the screen grids of screen grid amplifier tubes.

The fixed condensers connected between the taps on the resistor and the negative lead to the filter, are for the purpose of storing up a charge of energy or current during periods of normal plate current flow, to be delivered to the tube plates when the signal changes on the grids cause the plates to draw more current. If it were not for these condensers, during periods of heavy plate current flow the increased current through the resistor would cause increased voltage drop and thereby reduce the plate voltage temporarily. This would tend to distort the signal and also reduce the amplification of the tube. With the condensers used as shown, when the voltage lowers slightly due to increased current demand and voltage drop, the condenser immediately begins to discharge and thus supplies the extra current required. Thus nearly a

Fig. 97-C. Photo showing several types of fixed condensers used for filter condensers in power supply units. (Photo courtesy of Aerovox Wireless Corp.)

constant voltage is maintained at the plate lead terminal during all normal variations of plate current. Fig. 97 shows several types of filter condensers including three of the electrolytic type in the lower part of the figure.

The proper resistance for each section of a voltage divider of a power unit can be simply and easily calculated by Ohms Law. For example, suppose the receiver supplied by the unit shown in Fig. 96, consists of two 324 screen grid R. F. amplifier tubes, a 327 detector, another 327 for the first audio stage, and two 345 power tubes in push pull for the last A. F. stage.

The two 324 tubes each require about .004 ampere plate current and about .12 ampere each on their screen grids, the 327 tube used as detector requires about .003 ampere plate current, and the 327 tube used as first A. F. amplifier uses about .005 ampere plate current. This totals .040 ampere or 40 milliamperes, to go through the first section of the resistor.

We do not need to include the plate current of the power tubes as their current does not pass through the resistor but goes direct from the B+ 250 terminal to their plates.

As the voltage drop required in this first section is 250 — 135, or 115 volts, and as E ÷ I = R, then 115 ÷ .040 = 2875 ohms resistance needed, to cause the voltage drop and get 135 volts at this terminal for the plates of the two R. F. amplifiers and the first A. F. amplifier.

To reduce the voltage from 135 to 75 volts or a drop of 60 volts, we find the current through the next resistor section is only that of the screen grids for the 324 tubes and the plate current for the detector, or .027 ampere. Then 60 ÷ .027 = 2222 ohms, resistance required in this section.

The last section of resistance carries only the plate current of the detector, and must cause a voltage drop from 75 to 45, or 30 volts, so 30 ÷ .003 = 10,000 ohms resistance required. Convenient resistor units such as shown in Fig. 98, and with different values in ohms, can be purchased for use in power packs.

80. GRID BIAS RESISTOR

The tapped resistance in series with the negative B lead of the filter in Fig. 96, is for the purpose of obtaining the negative grid bias voltages for the various tubes.

All of the current from the plate and screen grid circuits of the receiver tubes must return through this resistor on its way back to the rectifier. This causes a proportional voltage drop of different amounts at the various taps along the resistor.

The negative lead C+ and B— on this resistor which is connected to the B— terminal on the receiver, is negative to the positive taps B+ 45, B+ 75, B+ 135, and B+ 250, but this same terminal is positive to the taps C-3, C-9, and C-45 on the bias resistor. So the negative grid bias voltages can be obtained from the taps on this resistor, and the C+ or grid return lead from the filament is connected to the B— terminal of the power supply unit.

The amount of resistance to be used to get the proper voltage drop in the various sections of this grid bias resistor can be determined by the same rule or method as that used for the voltage divider, except that in this case we include the plate current of the two power tubes with the plate and screen grid current of the other tubes, as it all flows back through the bias resistor. The plate current of a 345 power tube is about 30 milliamperes, so for two of these tubes we would add .060 ampere to the .040 for the other tubes, making a total of .1 ampere or 100 milliamperes.

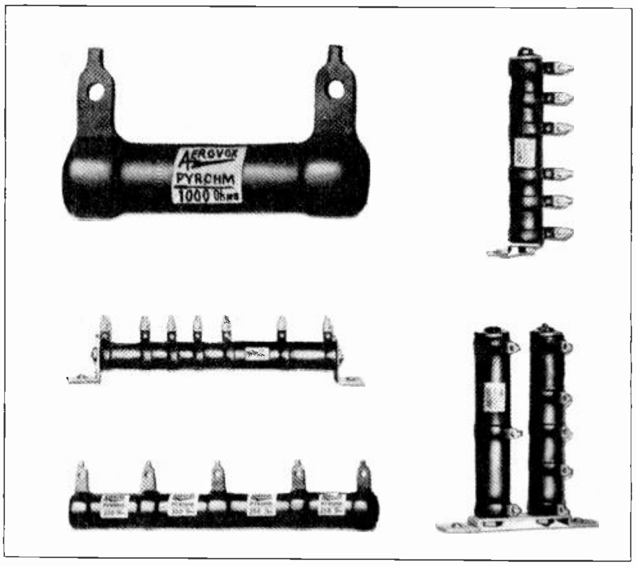


Fig. 98. This photo shows a number of convenient tapped resistor units used for voltage dividers, C bias resistors, etc., in power supply units. (Photo courtesy of Aerovox Wireless Corp.)

81. BATTERY ELIMINATORS

Battery eliminators to take the place of the A and B batteries of a D. C receiver, are very similar to the power unit just described, except that complete eliminators have two separate rectifier units, one to supply the low voltage D. C. for tube filaments, and one to supply the higher voltage D. C. for plate supply.

The rectifier in the A battery eliminator must be designed to handle much heavier currents at lower voltage, than the rectifiers used for the plate supply or B eliminator.

Regular 2 ampere Tungar bulbs are sometimes used as rectifiers in A eliminators and electrolytic and copper oxide rectifiers are also used in some of these devices.

The A eliminator requires a filter system just as in the B eliminator, except that the current capacity of the condensers and choke coils must be much greater to handle the filament current load.

The B eliminator unit is practically the same as the power unit shown in Fig. 96, except that the transformer does not have the low voltage secondary for tube filament supply.

Most B eliminators are designed to supply lower voltage than the power units of A. C. receivers, because most D. C. receivers which were built for battery operation use tubes which do not require such high plate voltages as are used on the power tubes of many A. C. receivers.

A and B eliminators are built in separate units and in combinations of both, and are generally contained in a neat sheet metal case which looks something like a power pack or battery charger. Thousands of D. C. sets which formerly used batteries are now operated from eliminators which have replaced their costly, messy, and troublesome batteries.

82. GASEOUS RECTIFIERS

Vacuum tube rectifiers of the hot filament type have been explained in earlier sections. Rectifiers in radio power units often use a gas filled rectifier bulb called a Ratheon tube, which has no filament. These rectifier tubes make use of a well known electrical principle, that current will flow from a small or sharp electrode through space to a larger electrode quite easily, but will not flow from the large electrode through space to the small one nearly as easily.

Full wave Ratheon tubes have two large electrodes made in tubular or cup shaped form, inside of which are located two small electrodes in the form of small rods or wires. These are sealed inside a gas filled bulb with leads brought to the outside as illustrated in Fig. 99-A, and the leads are connected to the power transformer and filter as shown by figure 99-B which uses the conventional symbol for this type of tube. The small electrodes are connected to opposite ends of the transformer secondary, and the large electrodes are connected together and to the positive lead of the filter.

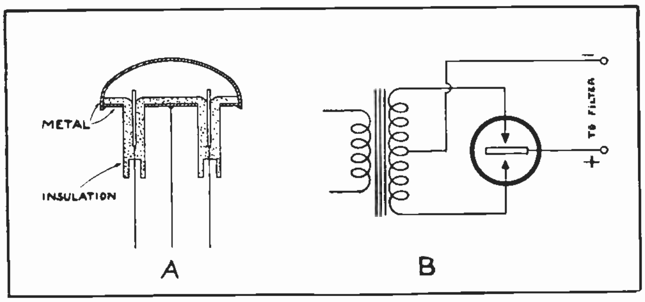


Fig. 99. At A is shown a sketch of the anode and cathodes of a full wave gaseous rectifier tube, and on the right is shown a connection diagram for a tube of this type when used in a power pack.

When alternating voltage is induced in the transformer secondary, first one of these small electrodes and then the other becomes positive. During the periods when they are positive current passes from them, through the ionized gas to the large electrodes, and out on the positive lead to the filter, through the receiver, and back on the negative lead to the center tap of the transformer secondary.

When the polarity reverses so that either of the large electrodes tends to become positive to its small electrode, the current is almost entirely cut off, only a few millionths of an ampere flowing. When either of the small electrodes is positive many thousandths of an ampere flow.

Even though one of the small electrodes is positive when the other is negative, practically no current flows between them because of their distance from each other and also because current cannot easily flow through a gas or space to any small electrode.

When voltage is first applied to a Ratheon rectifier tube is requires about 45 seconds for the gas to become fully ionized and for the current to build up to its full value or the capacity of the tube.

83. AUTOMATIC TUNING AND REMOTE CONTROL

As previously mentioned the circuits of radio receivers are generally tuned to the desired stations or wave lengths by means of variable condensers. In most modern sets all three of these condensers are connected together and operated from one dial. This greatly simplifies the tuning and operation of the receiver.

The dials may be of the disk, drum, or band type, and are generally equipped with scales and markings in wave lengths or kilocycles, or both. This makes it easy to locate or tune in any desired station, once it is charted or the operator learns where it can always be found on the dial.

Some sets have automatic tuning devices which enable one to quickly select any desired station by merely pressing a marked button or lever for that station. Some of these devices are merely a mechanical arrangement whereby the buttons or levers push or move the condensers to the proper point. Other automatic tuners cut in or out fixed condensers of the proper values to obtain the desired wave length change. One very effective type used with superheterodyne sets, simply changes the tuning of the first detector and oscillator circuits by switching in the proper combinations of fixed condensers. Fig. 100 shows a popular type of receiver with automatic tuning. Note the tuning buttons in the small opening on the right hand side of the cabinet.

Some receivers are equipped with remote control tuning features, which enable one to control or tune the set from a small push button block on a desk or chair arm, while the receiver is in another part of the room or even in a different room. The button control block is connected to the set by means of a control cable which may have from two to several dozen wires in it, according to the type of remote control used.

Some types of remote control have a small motor in the receiver, which turns the dial or condensers to a certain position for each button pressed. The motor also operates a switching mechanism and set of relays which break its circuit and stop it at the proper point.

Other forms of remote control merely switch fixed condensers of the proper size in and out of the circuit as with automatic tuning. The switch-

Fig. 100. Popular type of radio receiver with automatic tuning, and in a beautiful console cabinet. The automatic tuning buttons can be seen where the small door is opened on the right of the cabinet. (Photo courtesy of Zenith Radio Corp.)

ing may be done by a set of small relays located in the receiver and controlled by the push buttons and cable, or in some cases the condensers may be mounted in the same block or box with the buttons, and be controlled directly by the button switches.

One type of remote control has an oscillator tube and its tuning condensers located in the control box.

Most automatic and remote control devices for radio receivers are quite easily understood and kept in repair by anyone with a good knowledge of radio principles and circuit tracing and testing. Automatic tuning and remote control are often very great conveniences, and a number of high grade receivers are being equipped with these features.

84. TONE CONTROL

Some recent makes of radio receivers are being equipped with what is known as tone control, for regulating the proportionate strength of the high or low notes of voice or music delivered by the speaker.

Speech amplification equipment for public address systems, and sound picture installations are also generally equipped with tone control.

Tone control can be accomplished by connecting across one of the audio frequency transformers, a condenser of the right capacity to absorb some of the energy of the high frequency notes, thus reducing their strength, without reducing very much the low frequency notes.

A variable resistor of about one megohm is usually connected in series with the condenser to regulate the amount of control or absorption of high notes as desired. The condenser used for this purpose is usually about .004 to .008 mfd. capacity. A choke coil in series with a variable resistor can also be used across the audio circuit, to absorb or shunt out some of the energy of low frequency or bass notes without greatly affecting the higher frequencies.

You have learned that it requires much more energy to reproduce the low frequency notes than is required for those of higher pitch, so in some cases simple resistance volume control is used to cut down the energy or volume and thus reduce the low notes more than the high ones.

With certain voices or musical notes and with certain acoustical conditions in rooms or auditoriums, it is often a great advantage to have tone control to make the reproduction of the voice or music more natural and pleasing.

85. PHONES AND LOUDSPEAKERS

So far we have learned how radio energy is produced, transmitted, received, detected, and amplified. Now in order to reproduce at the receiver the audible sounds which were impressed on the carrier wave at the transmitter, we must use a pair of phones or a loudspeaker. These devices operate on the same general principle as a telephone reciever, and by means of magnetic action on a diaphragm convert the electrical impulses from the amplifier output back into air waves or audible sound.

The construction and operation of telephone receivers have been explained in earlier sections, so we need not go into great detail on those principles here.

Ear phones for use with radio receivers are generally made in pairs and fastened together with a head band as shown in Fig. 101. The two units are connected in series and equipped with a cord with metal tips or plugs for convenient connection to the set.

Ear phones for radio use are made in thin flat units like a central telephone operator's head set, and are made as light in weight as possible for comfort to radio operators or testers who may wear

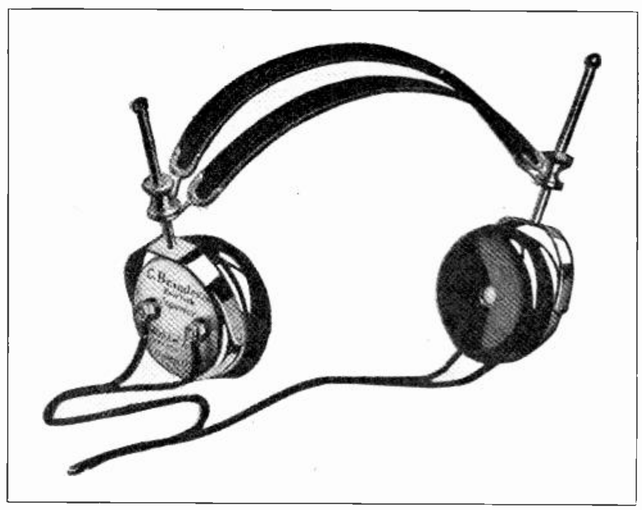


Fig. 101. This photo shows a pair of earphones or headphones as they are often called. Phones of this type are very useful for receiving weak signals that are not strong enough to operate a speaker, and also for testing radio devices and circuits.

them for long periods. The upper view in Fig. 102 shows a head set with the rubber cover and the diaphragm removed from one of the phones to show the magnets and coils inside. The lower view shows a slightly different phone unit for use with small loudspeaker horns.

The coils of the electro-magnets in these phones are usually wound with several thousand turns of very fine enameled copper wire, and good headphone sets have a resistance of 2,000 to 5,000 ohms. The amount of current supplied by radio receivers is very small, so the phone magnets should have a great number of turns to give them as many ampere turns magnetic strength as possible with the small currents which operate them. This is particularly true of phones to be used with crystal receivers and single tube or small low cost receivers, where the phones must be extremely sensitive. It is also desirable to use phones with large numbers of turns on their coils when the phones are to be used with vacuum tube receivers, because if the impedance of the phones is about the same as that of the tube plate circuit, best results will be obtained from the tube.

Fig. 102. The top photo shows a pair of phones with the cover and diaphragm removed from one to show the magnets, and below is shown an open view of a single large phone unit for use on a speaker horn.

Most earphones have a ring shaped or horseshoe shaped permanent magnet in the case, and the coils of the electro-magnets are usually placed over the ends or poles of these permanent magnets, as shown in Fig. 103.

In this sketch a sectional view of the ring shaped permanent magnet is shown at P, with the pole pieces N and S attached. The coils C are placed over these pole pieces as shown.

When no current is flowing through the coils the permanent magnet poles hold the thin iron dia-

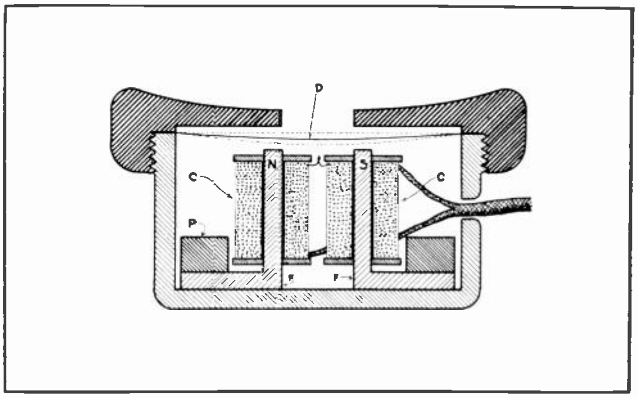


Fig. 103. Sectional sketch showing the construction and operation of an earphone unit. Note the arrangement of the permanent magnet and the electro-magnet coils.

phragm slightly attracted as at D. When current is passed through the electro-magnet coils it sets up flux and polarity which either aids or opposes that of the permanent magnets, according to the direction of current flow. If this current is either A. C. or pulsating D. C. it will cause the diaphragm to vibrate and produce sound waves.

When a pair of phones is connected in the plate circuit of a vacuum tube, a small amount of current (the normal plate current) flows through them all the time the tube filament is lighted. When signal variations are impressed on the grid of the tube the plate current pulsates or decreases and increases, and the pulsating D. C. causes the phone diaphragms to vibrate, as shown by the dotted lines in Fig. 103, and thus reproduce the sound.

When a loudspeaker or phones are connected to the secondary of an output transformer, instead of directly in the plate circuit, the current flowing through them will be alternating, but will also vary in value with the signal variations, so the phone or speaker diaphragm will still vibrate and reproduce the sound.

When handling headphones care should be taken not to allow the diaphragms to become permanently bent or loose. Sometimes a piece of dirt or magnetic material will become lodged between one of the magnet poles and the diaphragm and will interfere with the operation of the phone. The cap can be unscrewed and the diaphragm carefully removed and the dirt cleaned out.

Great care should be used in cleaning or working around the coils as their wires and connections are so fine that they are easily broken. Headphones can be quickly and easily tested for open circuits by connecting them directly across a 1½ volt dry cell. If the circuit is complete a click should be heard in the phones when the connection to the cell is made and broken. Headphones are very useful with small low power receivers, for receiving very weak signals from distant stations, and also for testing receivers. Headphones were used exclusively for radio reception before the development of loud speakers.

86. LOUDSPEAKERS

Where radio receivers are operated in homes and for entertainment purposes it is usually desired to have the sound spread throughout the room so it can be heard by several people anywhere in the room, without the inconvenience of having to sit near the receiver and wear uncomfortable headphones.

To accomplish this we must use a loudspeaker or special reproducing unit which usually has a larger diaphragm than headphones have. It is not practical to try to use ordinary headphones for this purpose, because even if they were supplied with sufficient power from the output of the receiver, their diaphragms are not large enough to produce the desired volume of sound without distortion and chattering.

Early types of loudspeakers many of which are still in use with older receivers, merely used a large sized phone unit very similar to the ones just described, except with larger diaphragms. Such units are attached to the base or throat of a large horn. Fig. 104 shows a speaker of this type and also a large phone or reproducing unit without the horn.

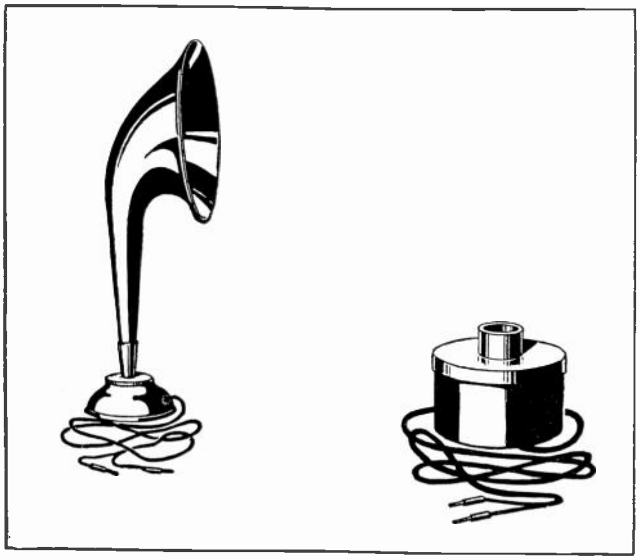


Fig. 104. A simple horn-type loudspeaker is shown on the left, and a reproducer unit similar to a large phone is shown on the right.

The horn serves to give the diaphragm a better "grip" or control of the larger volume of air necessary to move for the louder sound. Speaker horns are usually made of wood, fibre, paper mache or such non-resonant materials, to avoid vibration of the horn, and "tinny" effects such as would be obtained if metal were used. Fig. 105 shows two horn-type loudspeakers. The one on the right has its own amplifier for boosting the output of an ordinary small receiver up to sufficient strength to operate this large unit and horn.

Another type of loudspeaker reproducing unit known as the balanced armature type, is shown in

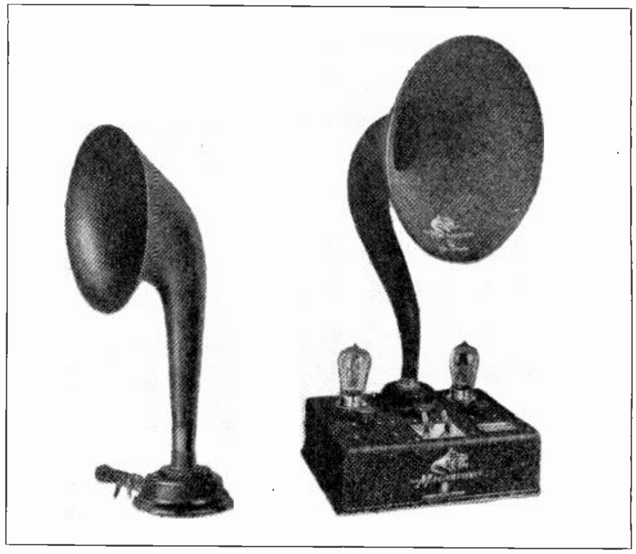


Fig. 105. Two styles of horn speakers, one of which has an extra amplifier attached.

the larger sketch in Fig. 106. In this type of unit a large horseshoe permanent magnet is used to provide a field in which a small balanced iron armature moves. This armature is pivoted at its center and has a thin rod or stiff wire connecting its end to the diaphragm.

The movable armature has a small light weight coil wound on it, or in some cases around it in solenoid form, but not touching it. In either case this coil is connected to the receiver output and when current flows through it in the direction indicated by the arrows, it creates N and S magnetic poles in the armature as shown, causing its right end to swing down and its left end up, because of the attraction and repulsion of the poles of the horseshoe magnet. If pulsating D. C. or alternating current is passed through this armature coil it will rapidly

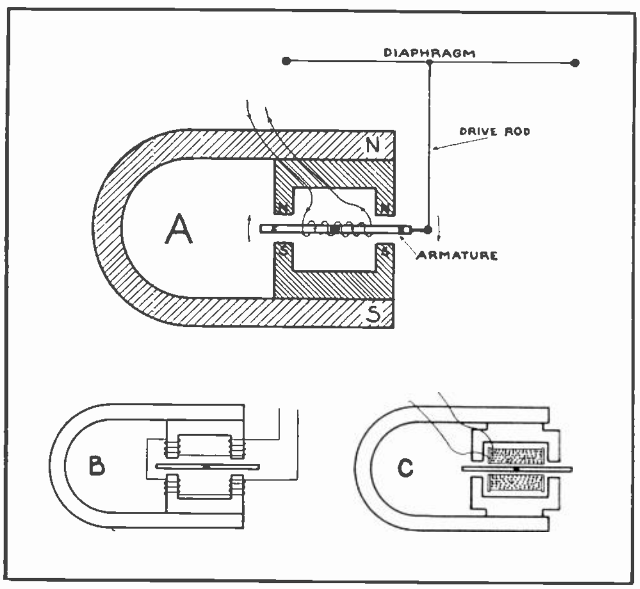


Fig. 106. These sketches show the construction of loudspeaker driving units or reproducers of the balanced armature type.

reverse the polarity of the armature and cause the armature and diaphragm to vibrate.

In another unit of very similar design the coils are wound on the pole tips of the permanent magnet as shown in the small sketch at B in Fig. 106. Pulsating current through these coils causes certain poles to be strengthened and others to be weakened, and the shifting flux causes the armature core to be vibrated as before.

One of the latest speaker units operating on this principle is constructed as shown at C in Fig. 106 and uses a stationary solenoid coil to induce the magnetic polarity in the iron armature. This relieves the armature of all unnecessary weight and eliminates the necessity of having a moving coil, with its possibility of breaking the flexible connections, etc.

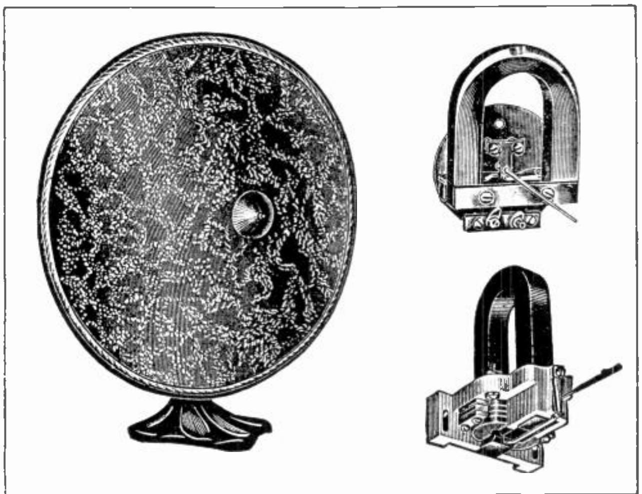


Fig. 107. A cone type speaker is shown on the left in this figure, and on the right are shown two types of driving units or reproducers of the balanced armature type.

The diaphragms used with speaker units of this type do not need to be metal as there is no direct magnetic pull on them, so they are generally made of non-magnetic materials.

In one very common type of speaker called the **cone type,** the driving rod of the speaker unit is connected to the center of a large cone instead of to a small flat diaphragm. These cones are made of paper, fibre, treated cloth, etc.

Cone speakers are capable of moving large volumes of air and of producing great sound volume with very good tone quality. They reproduce the low frequency bass notes of music much better than the small horn speakers do. Fig. 107 shows a cone speaker on the left, and two types of cone speaker reproducing units on the right.

87. DYNAMIC SPEAKERS

One of the best and most popular types of loudspeakers developed in recent years is the **dynamic speaker,** which is used on the great majority of

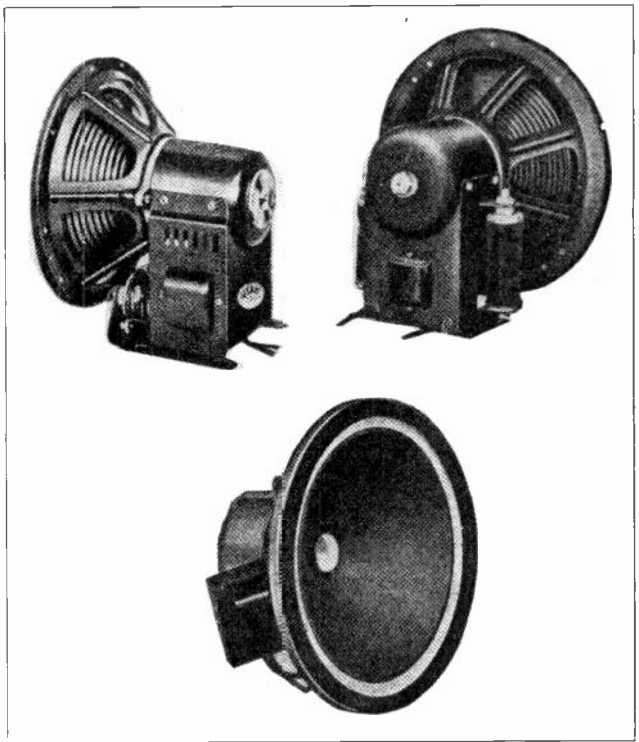


Fig. 108. This photo shows several views of dynamic speakers such as are very commonly used with modern radio receivers.

modern radio receivers Fig. 108 shows three views of dynamic speakers, and Fig. 109 is a sketch illustrating the construction and operation of this type speaker.

The unit consists essentially of a powerful electro-magnet for producing a magnetic field, and a small cone coil or "voice coil" attached to the apex or point of a stiff paper cone.

The electro-magnet or field magnet is wound with a great number of turns of wire around a heavy iron core. When the unit is in operation the coil of this magnet is excited by D. C. either from the power supply unit of the receiver or from a separate rectifier. The rectifier is usually of the dry copper oxide type, or a rectifier tube, and is attached directly to the speaker. This direct current sets up a powerful magnetic field around the end of the iron core, and across the turns of the small movable cone coil.

Then when pulsating or alternating current from the receiver output is passed through this small coil, the reaction between the flux of its turns and that of the field magnet exerts a varying force to vibrate the small coil.

As this coil is attached to the cone it causes the cone to vibrate also. The edge of the cone is cemented to a flexible soft leather or buckskin ring or edging, which in turn is fastened to the frame ring of the unit. See the lower view in Fig. 108.

The cones are often ribbed or corrugated as shown in the two upper views in Fig. 108. The

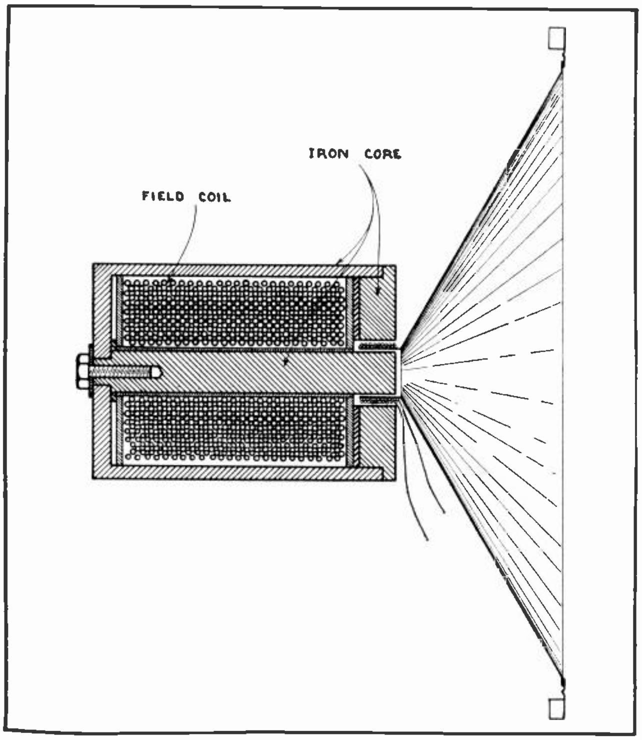


Fig. 109. This sketch shows the construction of a dynamic speaker. Note the large field coil, the small cone coil, the core, cone, etc.

rectifier units can be seen attached to these two speakers.

The large coil of a dynamic speaker not only serves as a field coil, but also acts as a very effective filter choke to smooth out the ripple in the D. C. from the rectifier. When these units are built into a radio receiver, this coil often serves as one of the choke coils in the power pack filter. When used with a separate rectifier of its own, the speaker is equipped with filter condensers connected across its own field coil as a filter choke. Fig. 110 shows a dynamic speaker with its field coil connected in series with the B— return lead of the power unit, and serving as one of the filter chokes.

The voice coil or cone coil is connected to the secondary of the output transformer from the power tube of the receiver. The balance of the receiver is not shown.

Dynamic speakers are made in various sizes for ordinary receivers in homes and for power amplifiers in large halls, theatres, etc. Dynamic reproducer units are also made for use with large horns of the type extensively used in sound picture and public address systems.

It has been found that long throated horns of special design are ideal for handling large volumes of sound in "power jobs".

Fig. 111 shows several horns of this type with both round and square openings. These horns are known as **exponential** and **orthophonic** types, according to their shape and design. Some of the large ones have a "tone travel" or length of 12 feet or more.

Another type speaker which has been used to a limited extent is known as the **electrostatic** or **condenser** type. These speakers consist of two thin sheets of metal with a sheet of insulation between them, or in some cases one thin slotted plate of aluminum on one side of the insulator and a sprayed metallic coating on the opposite side.

When the pulsating voltage output of the receiver is applied to these plates it causes the movable one to vibrate due to electrostatic attraction between them. A D. C. bias of several hundred volts on their metal surfaces often improves the operation of these speakers.

Condenser type speakers reproduce very faithfully all notes of music, with very little of the distortion which some other types of speakers produce.

88. CONSTRUCTION OF RADIO RECEIVERS

It used to be quite common practice for people with a general knowledge of radio to build their own receiving sets, both for the novelty and experience and to save something on the cost. Radio men also made a practice of building sets for their customers.

This practice has been largely discontinued, however, because numerous manufacturers are now turning out all kinds of receivers in attractive cabinets, and cheaper and better than the average individual can build them.

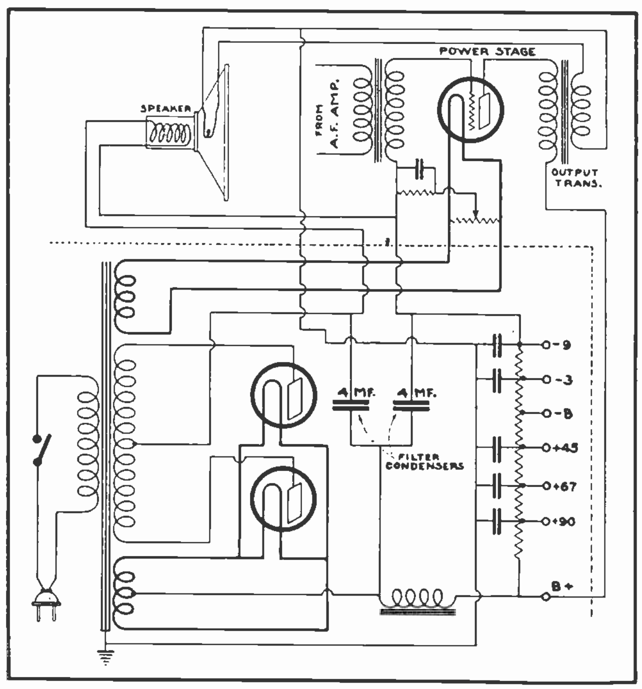


Fig. 110. Diagram of a power supply unit, dynamic speaker, and the last stage of power amplification of a receiver. Note that the field coil of the speaker is connected in series with the negative lead of the D. C. plate supply and serves as one of the filter chokes. Also note the connection of the cone coil, or "voice coil," to the secondary of the output or speaker coupling transformer.

A general knowledge of the proper methods of set construction may be very useful to the trained radio man, however, in case he may desire to build experimental radio equipment or special custom made sets to orders of customers, and it is also useful in making repairs to defective sets.

One of the first rules for building a good receiver or amplifier is to use good parts. Good quality transformers, condensers, and tubes should give efficient and dependable operation if carefully assembled and wired in a good circuit.

Parts should always be neatly and carefully arranged according to their order in the circuit, to keep the connections as short as possible, and yet have proper spacing between parts to prevent interference.

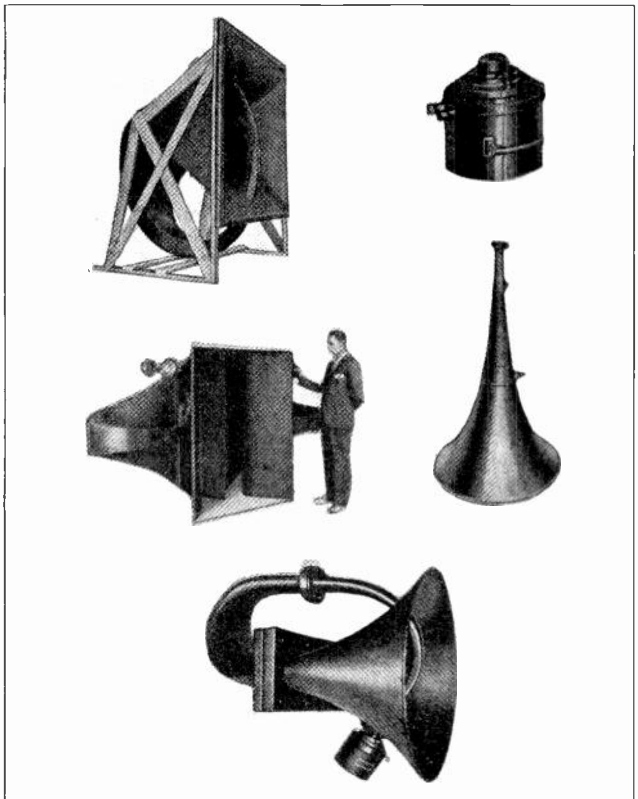


Fig. 111. Several types of large power speaker horns, and a large dynamic reproducer unit such as used with these horns. Horns of the above type are called exponential and orthophonic horns according to their design.

Transformers, sockets, and stationary parts are usually lined up on a base or sub-panel of wood, bakelite, or metal. Wood has the advantage of being easy to mount and fasten the parts on it, while metal aids in shielding the parts and provides convenient common ground connections for various parts of the circuit.

The sub-panel is very often mounted several inches above the bottom edge of the front panel to permit parts to be mounted both above and beneath it for compactness of the set.

A vertical front panel of bakelite or metal is generally used for mounting the variable condensers, tuning controls, rheostats, etc.

R. F. transformers and parts should be spaced several inches apart, or else shielded from each other by enclosing them in partitions or "cans" of sheet copper or aluminum from 1/32" to 1/16" thick. Proper shielding enables the set to be more compactly built and prevents interference between parts and stages. Shields should surround the parts as completely as possible, in order to entirely prevent inductive interference and distortion.

Never use iron or any magnetic materials, or any very thin high resistance metals for shielding. Shields should be kept about an inch from the sides of R. F. coils and two inches from their tops.

Parts in separate circuits or stages should be enclosed in separate shielding compartments. Any parts which are mounted on the shields should be carefully insulated from them unless the part is supposed to be connected or grounded to the shield, in which case a secure dependable connection should be made.

Take particular care to see that any uninsulated wires or terminals do not touch the shields. See that all shields are well fitted and fastened securely so they cannot vibrate, and see that they are all well grounded. The grounded metal chassis and shields of modern sets are generally used as a common ground for all negative return leads.

If audio transformers are not shielded and are to be mounted very close together, it is well to mount them with their cores at right angles to each other to prevent linking of their fields.

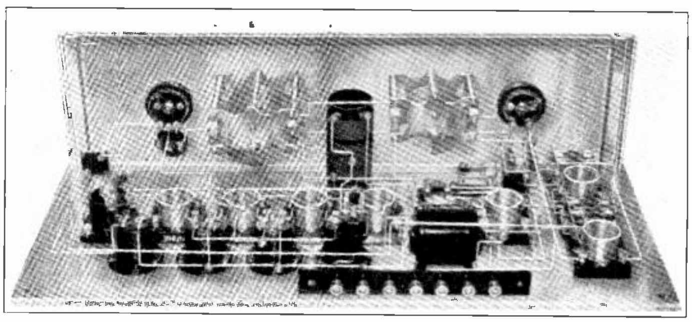


Fig. 112. This view shows the wiring and parts arrangement of a battery operated receiver, which is very easy to construct.

89. WIRING

Radio set wiring was formerly extensively done with stiff, bare, nickel plated copper wires of about No. 14 B & S gauge, known as bus wire. This form of wiring properly done makes a neat and impressive appearing job, but it is no better and in some cases not as good as the wiring with flexible rubber covered wires which is used almost exclusively in modern sets. Fig. 112 shows a neat job of bus wiring and neat arrangement of the parts of a battery operated set.

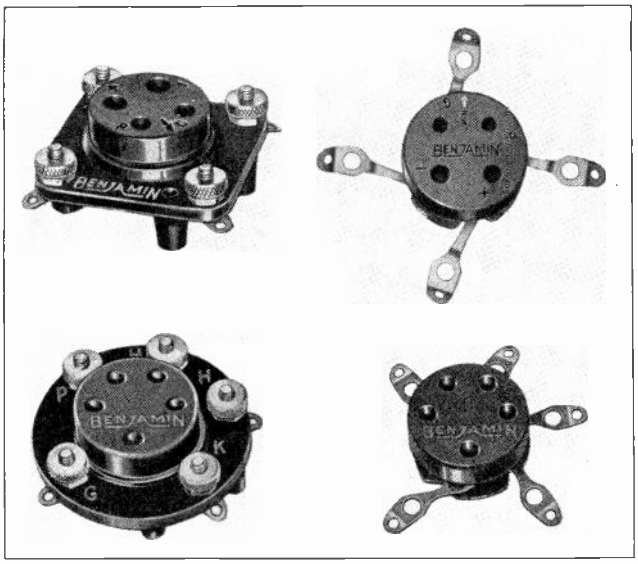


Fig. 113. Several types of tube sockets for both four and five prong tube bases. Note the connection terminals and soldering lugs for securely attaching the wires. (Photo courtesy of Benjamin Electric Mfg. Co.)

The flexible wiring is much quicker and cheaper, is more compact, and fully as efficient if properly done. The wire used for this purpose is usually a flexible wire of number 14, 16, or 18 size, and insulated with rubber but no braid.

All joints and connections whether made between wires, or between wires and terminals on parts and devices, should be carefully and securely made, and then well soldered. This is extremely important because the energy in some of the circuits is so small that any appreciable resistance in the connections will greatly reduce the efficiency of the receiver. It is also important because joints or connections which work loose even slightly, will cause a lot of crashing and sputtering noises in a receiver when the set or wires are vibrated or jarred.

Radio parts are usually equipped with connection terminals or soldering lugs. Fig. 113 shows several modern tube sockets with their soldering lugs and terminal nuts for attaching the wires to them. Fig. 113-A shows several filament rheostats with terminal, nuts or "binding posts".

When soldering joints and connections in radio receivers or amplifiers, always use a good non-corrosive flux, and take pains to do a neat and thorough job. Make sure the splice is well cleaned, heated, and fluxed so that the solder when applied will flow freely and neatly, and make a permanent low resistance connection. "Resin joints" or soldered connections which appear good on the outside, but from which the flux was not thoroughly heated or boiled out, are often the cause of failures in radio receivers.

When wiring a receiver never run grid and plate wires parallel or close to each other, on account of the objectionable feed back coupling and distortion this will cause. Also avoid running parallel to each other any conductors which carry high frequency currents, unless these wires are separated an inch or more apart, or are shielded.

Fig. 114 shows a rear view of a factory made receiver chassis with its power unit and loud speaker mounted on a separate base. Note the shielding of the R. F. transformers located to the right of the tuning dial, the gang condensers on the left, and also the shields around six of the tubes. The audio frequency transformers, some other small parts, and most of the wiring, are located under the sub-panel.

Fig. 115 shows a front view of another factory made A. C. set. The power pack is on the left and the gang condensers with the front of their shield removed, are shown to the right of the tuning dial. Note the arrangement of the shielded tubes and R. F. transformers at the rear. The tube shields can be distinguished by their perforations to let out the heat. The non-perforated "cans" contain the R. F. transformers. The A. F. transformers are under the sub-panel on this set also.

Fig. 116 shows still another arrangement of tubes, R. F. transformers and shielding of a factory built chassis. Note the power transformer, tubular electrolytic filter condensers and rectifier tubes of the power pack on the left. Also note the screen grid tubes, distinguishable by their top connections, the large power tube at the rear, the tuning condensers, tuning dial, etc.

Fig. 117 shows the under side of the sub-panel of

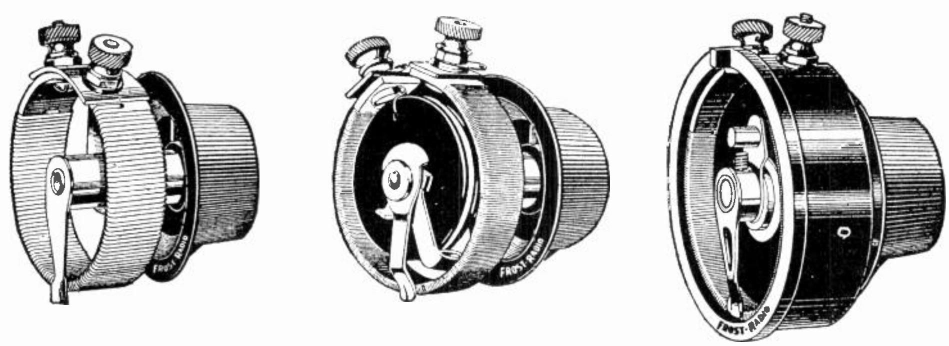


Fig. 113-A. Above are shown several types of variable resistors such as are used for filament rheostats, volume controls, biasing potentiometers, etc.

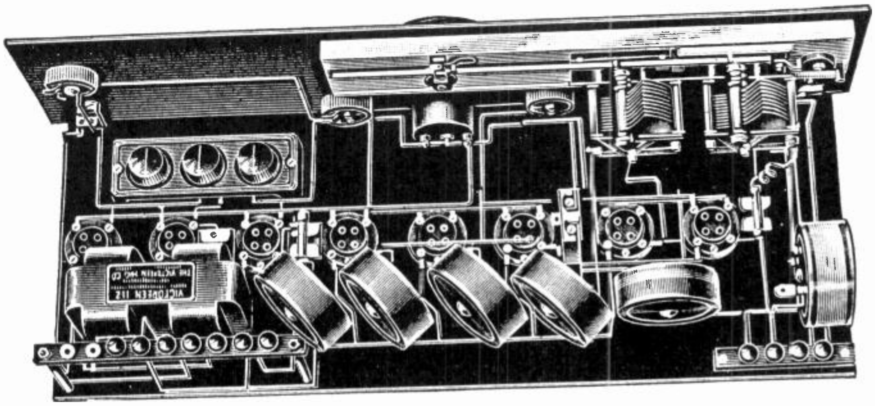


Fig. 113-B. This view shows the wiring and parts arrangement for a superheterodyne radio receiver in which the parts are all mounted on the top surface of the baseboard and on the rear of the front panel. The round coils shown in the foreground are R. F. and I. F. (intermediate frequency) transformers. Shielding from "body capacity" effects between the tuning condensers and the operator's hands, can be made in a set of this type by placing a sheet of aluminum or copper on the back of the vertical panel, between it and the condensers. If this is not done body capacity sometimes causes detuning and howling.

one type of chassis and a great deal of the set wiring.

These various views just shown give a general idea of the type of construction, wiring, and shielding used in modern factory built sets. You can readily see how sets of this type should if properly built, give better results than home made sets will, unless considerable time and trouble is spent on the shielding and wiring of the home built receiver.

Many good receivers, amplifiers, and special experimental radio devices can be built on wood panels in the home or small shop, however, if the parts are properly spaced, or shielded, and if the general rules just given are carefully followed.

90. TESTING AND SERVICING RECEIVERS

One of the best fields of opportunity in which the radio man can profitably apply his knowledge, is in the testing, servicing, and repairing of radio receivers in homes, and speech amplification equipment in theatres, schools, hotels, etc. There are millions of radio set owners who really don't know much about their sets or what to do when they go wrong, and a radio service man who builds a good reputation in his community for being able to quickly locate and correct troubles in these sets, will usually find his services in demand.

Radio manufacturers and dealers, department stores, hardware and electric shops that handle radios, are generally glad to find and hire a really good radio service man.

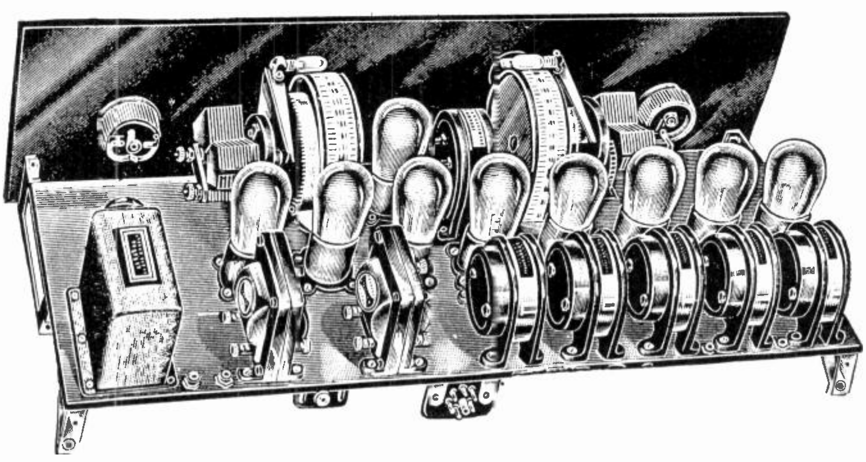
Radio trouble shooting and service work are both easy and interesting for one who has a good general knowledge of radio principles and devices, and a thorough knowledge of electricity and circuit tracing and testing. Your practical shop training in these subjects here at Coyne, and a careful study of the material covered in this reference set, should well fit you for capable work in this line.

When starting to look for any trouble in a radio receiver, always use a definite systematic method of testing for fault location, and keep in mind what we have emphasized before, that any trouble or fault can be located by careful and systematic testing.

91. COMMON TROUBLES

There are a great many possible causes of trouble in radio sets, but the most frequent and common troubles are caused by only a few things such as defective tubes; weak batteries; failure of power supply; broken, loose, corroded and high resistance antenna or ground connections; defective condenser or transformer; or an open circuit, short circuit, or ground in the set wiring.

Fig. 113-C. This view shows the parts arrangement in a superheterodyne set using a raised sub-panel beneath which the wiring is done. This makes the wiring much more convenient, and when a metal sub-panel is used it shields the wiring from the parts and devices of the set. The I. F. transformers, A. F. transformers, tubes, tuning condensers, tuning dials or drums, rheostats, and oscillator coupling coil can all be clearly seen in this view.



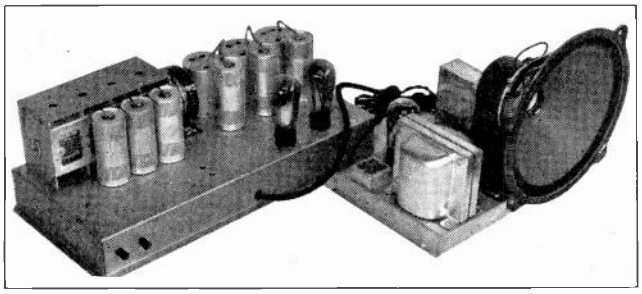


Fig. 114. Photo of a factory made A. C. receiver, with a metal chassis and thoroughly shielded parts. The dynamic speaker and power supply unit are also shown in this view. (Photo courtesy of Silver Marshall Inc.)

Defective tubes are the most common cause of trouble in all kinds of receivers. Weak, discharged batteries or corroded battery terminals are one of the most common troubles in battery operated sets, and poor antenna and ground connections are also frequent causes of poor operation. In many cases the service man finds it only necessary to replace or tighten a plug in the convenience outlet, or to turn on a switch on the power unit or in the light circuit, to put the set back in operation. So these common things should be carefully checked before spending much time looking for more complicated troubles.

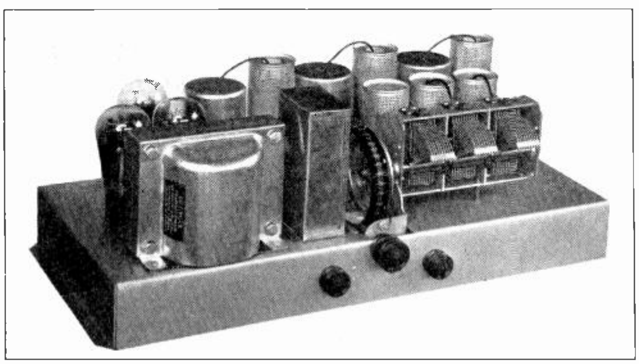


Fig. 115. This photo shows another view of compact, factory made receiver with the power unit located on the left. Note the arrangement and shielding of parts. The wiring, A. F. transformers, and some other small parts are located beneath the sub-panel. (Photo courtesy of Silver Marshall Inc.)

92. TEST EQUIPMENT. SET ANALYZERS

Radio service work does not necessarily require a lot of expensive test equipment, as most troubles can be found with a low voltage test lamp and battery, a portable voltmeter or ohmmeter, and a tube tester. A good set analyzer is a great help and time saver, however, and any service man who is doing much of this work should by all means have one.

Fig. 118 shows a popular type of set analyzer with which practically any service test can be made on a radio receiver. There are a number of these devices on the market, ranging in price from $20.00 to $100.00 or more, for the very complete types.

In general the set analyzer consists of a voltmeter with several scales for reading low and high voltages, an ammeter with several scales for reading amperes, and milliamperes, one or more sockets for inserting and testing tubes from the radio set, a plug and adapter for inserting in the various tube sockets of the receiver and testing the condition of each stage, a small dry battery for supplying test voltages, a set of test prods or points with their flexible leads for making continuity tests in the wiring, and the various terminals and control buttons for obtaining the different readings. Each of these various parts can be seen in Fig. 118.

The various meter readings of millivolts or volts, and milliamperes or amperes for the different parts of the circuit under test, can be obtained with the multiple scale instruments by pressing the proper switches on the panel to connect the proper resistances in series with the voltmeter and the proper shunts across the ammeter. Some set analyzers have a greater number of meters, with single scales for separate test readings.

Set analyzers are very convenient for locating weak or defective tubes by testing them one at a time in the analyzer socket and taking meter readings of the filament current, grid voltage, plate voltage and current, and thus determining the exact condition of the tube. They are also a great time saver in determining what stage of the receiver a fault is located in, by starting at the R. F. end, with the set in operation, removing one tube at a time and placing the plug of the analyzer in the socket from which the tube is removed, and noting the readings or output of each stage in this manner.

Set analyzers are usually supplied with an accompanying trouble chart and test directions supplied by the manufacturers. By following these instructions for any particular analyzer until one gets used to the instrument, it is very easy to make the various service tests with it.

Some manufacturers of set analyzers also supply convenient test data charts such as shown in Fig. 119, for various common makes of radio sets. These are very helpful in making quick and accurate comparisons throughout the set, stage by stage. If these

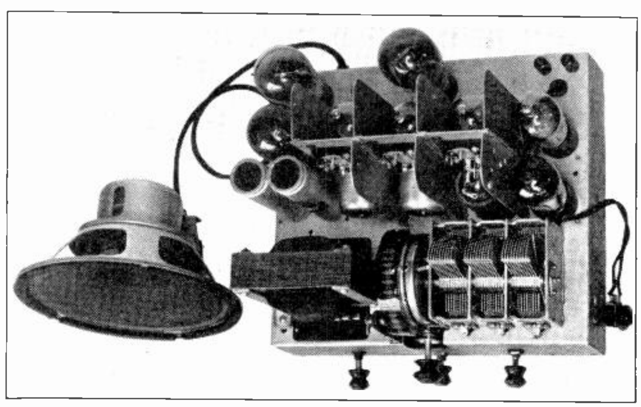


Fig. 116. This photo shows a top view of an A. C. receiver of still different construction and shielding than either of those shown in Figures 114 or 115. (Photo courtesy of Silver Marshall Inc.)

charts are not supplied with the set analyzer they can usually be obtained, along with a circuit diagram for any particular receiver, by writing to the manufacturer of that receiver. Every radio service man should have this material on hand for the sets he is most frequently servicing.

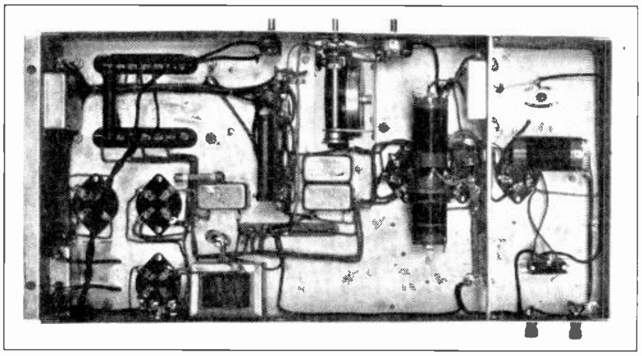


Fig. 117. This view shows the under side of the sub-panel of a modern factory made receiver. Note the wiring and parts which are conveniently arranged beneath this panel. (Photo courtesy of Silver Marshall Inc.)

93. CLASSES OF FAULTS, AND GENERAL SYMPTOMS AND TESTS

Common radio set troubles can be divided into four general classes as follows: 1. Complete failure to produce signals; 2. Signals weaker than normal; 3. Signals distorted from normal tone quality; 4. Noisy reception.

In some cases more than one of these troubles occur at the same time. When a set gives abnormally weak signals, distortion and noise will often accompany them.

Distortion can be divided into several different kinds as follows: Loss of low notes, producing "tinny" high pitched reproduction; coarse or rattling reproduction; loss of high notes, producing muffled reproduction.

Noise can be divided into the following types: Hum, static, motorboating, whistling or squealing, and microphonic noise.

Experience and practice will enable one to recognize certain common radio troubles by the sounds or symptoms they cause. For example there is a certain characteristic howl of a microphonic tube; a certain type of hissing and crackling noise caused by weak A or B batteries; certain classes of distortion due to defective tubes in detector or first A. F. stages, or defective A. F. transformers; low pitched 60 cycle hum due to defects in power supply unit, defective bypass condenser or open grid circuit on first A. F. tube. Other symptoms of this nature will be explained later.

In starting to locate trouble in a radio receiver, if some familiar symptom does not indicate just about where the trouble is, you should first make a quick general examination of the tubes, antenna and ground connections, batteries if used, plug, cord and 110-volt power supply if used, speaker connections, etc.

If this general examination does not show up the trouble, you should then try to localize the trouble and determine whether it is in the antenna circuit, R. F. stages, detector, A. F. stages, power unit, or speaker.

If no signals are obtainable from the set, the trouble will usually be found in some part of the antenna circuit or in the power supply.

If all the tube filaments light and if a noticeable click is heard in the speaker when the rectifier tube is removed from its socket, it is quite likely that the power supply is all right, and that the trouble is probably in the aerial circuit. The click heard when the rectifier tube is removed indicates that the plate circuits of the receiver tubes are supplied with power.

If all but one or two tubes light up, those which do not are probably burned out, although their failure may also be due to an open in some part of the filament wiring.

If any of the tubes in an A. C. receiver light up to their normal brilliancy it indicates that the primary of the power transformer is all right.

The power supply unit is a very vital part of the receiver and is more apt than almost any other part to cause complete failure of the receiver.

In case weak signals are heard and the selectivity and sensitivity of the set are poor, the trouble is usually in the R. F. stages. A simple test to determine whether the trouble is in the R. F. or A. F. stages, is to lightly tap the detector tube with a

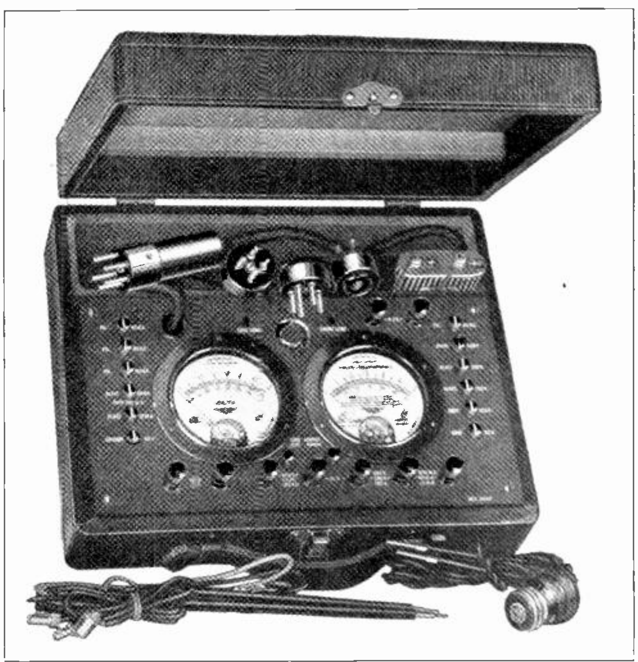


Fig. 118. Convenient test kit or set analyzer for shooting trouble and making accurate fault location tests on radio receivers. Instruments of this type are very useful to the modern radio service man. (Photo courtesy of Jewell Electrical Instrument Co.)

pencil or finger nail. If this produces a ringing note in the speaker, it is a fairly good indication that the A. F. stages are functioning properly, and we can look for the trouble in the R. F. stages.

If the signals are noisy and distorted from their natural tone the cause of the trouble will usually be found in the A. F. stages, although either the aerial system or R. F. stages may at times be to blame for noise and distortion.

After one becomes familiar with the various forms of distortion you can usually determine about where the trouble is.

TUBE NO. IN ORDER ①	TYPE OF TUBE ②	POSITION OF TUBE 1ST RF DET ETC ③	READINGS. PLUG IN SOCKET OF SET									
			TUBE OUT		TUBE IN TESTER							
			A VOLTS ④	B VOLTS ⑤	A VOLTS ⑥	B VOLTS ⑦	C VOLTS (CONTROL GRID) ⑧	CATHODE-HEATER VOLTS ⑨	NORMAL PLATE M.A ⑩	PLATE M.A. GRID TEST ⑪	PLATE CHANGE M.A. ⑫	SCREEN GRID VOLTS ⑬
1	224	1st RF	2.15	152	2.1	140	3	3	2.6	5.6	3	76
2	224	2nd RF	2.15	152	2.1	140	3	3	2.6	5.6	3	76
3	227	Det.	2.15	84	2.1	82	14	14	1	-	-	-
4	227	1st A	2.15	140	2.1	80	3	3	2.1	3	.8	-
5	245	2nd A	2.4	228	2.45	208	38	-	22	26	4	-
6	245	2nd A	2.4	228	2.45	208	38	-	22	26	4	-
7	280	Rect.	4.3	-	4.1	-	-	-	64	-	-	-
8												
9												
10												

Fig. 119. Convenient data charts for making continuity tests with set analyzers, can be obtained from the instrument manufacturers or from the makers of the receiver to be tested. These charts are a great aid to the service man.

If the audio stages are suspected, a simple test to determine if the fault is there, can be made by removing the detector tube from its socket. If the noise still continues the trouble is in the A. F. stages. It does not, however, always indicate that the audio stages are allright if the noise stops upon removal of the detector tube.

If all the tube filaments light, but we nevertheless suspect that a defective tube is the cause of the trouble, if no set analyzer or tube tester is available the tubes can be changed around or replaced one at a time with a good one, until the defective one is located.

94. LOCALIZING THE TROUBLE

If a receiver does not operate or give any signals at all, then a definite systematic inspection and test is necessary to locate the trouble. Before starting detailed tests of the internal parts and wiring of the set, always remember to carefully check the antenna circuit, tubes, power unit or batteries, and the speaker.

In checking the antenna circuit make sure that the antenna and ground connections are clean and tight at the set, and that the ground connection to the water pipe or ground rod is also clean and tight. See that the antenna is not down, or grounded by contact with some other wire or metal structure.

See that all tubes light or burn, but remember that the filaments of modern A. C. tubes do not need to light up brightly, but only glow a dull red. Test the tubes in a set analyzer or tube tester, or by replacing them with good tubes. If all tubes fail to light the trouble is almost certain to be in the A battery, power unit, or filament switch or wiring, although it is possible that all tubes are burned out due to some wiring defect or wrong connection having placed the "B" voltage on their filaments.

In checking the A battery, test it with a hydrometer for state of charge, and carefully check for corroded terminals. In checking a power pack, first see that the light circuit to which it is plugged is alive, by testing with an A. C. voltmeter or 110 volt test lamp. Examine the cord to see that the wires are not broken under the insulation, and see that the plug and all connections are tight. Test the filament voltage supply terminals with a low reading voltmeter and the plate voltage supply terminals with a higher reading voltmeter.

In checking the speaker, see that its cord is not broken or shorted, and see that the connections both at the output of the set and at the speaker unit are secure. See that the diaphragm or cone is not jammed or badly bent. If the speaker is of the dynamic type the field coil can be tested by holding a nail, screwdriver or some magnetic object, near the end of the iron core inside the cone, while the set is turned on. If the coil is alive a strong magnetic pull will be felt. Examine or test the flexible fine wire leads to the cone coil as these often get broken.

An ordinary magnetic speaker having only two leads can be quickly tested by tapping its terminals on a B battery, which should result in a loud click. With dynamic speakers the same test can be made with the cone coil leads, assuming of course that the field coil is supplied with power and is energized. Do not leave the speaker connected to a B battery or its coil may be burned out.

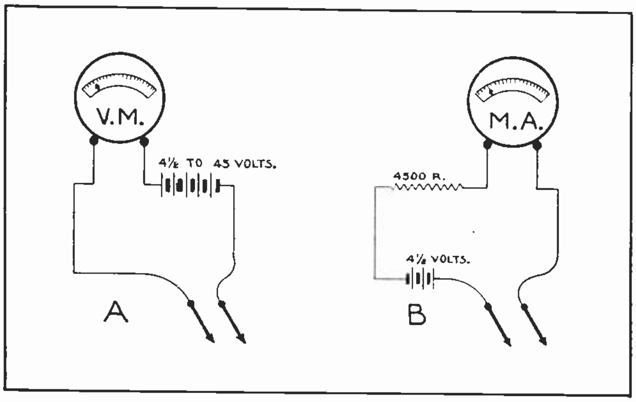


Fig. 120. The sketch at A shows the connections for using a low reading voltmeter for making continuity tests, and the one at B shows the connections for using a milliammeter for this purpose.

95. CONTINUITY TESTS

If the antenna circuit, tubes, batteries or power pack, and speaker all test O. K., and the set still refuses to operate, then we must make a thorough test of the set itself, starting at the antenna and ground terminals or primary of the first R. F. transformer, and proceeding straight through to the output or speaker terminals.

This test should include every device in the set, such as transformers, R. F. and A. F., condensers fixed and variable, resistors, rheostats, potentiometers, sockets, wiring joints, etc., to determine whether there are any open circuits, high resistance connections, short circuits or accidental grounds in any of the devices or wiring.

A test of this nature is known as a **continuity test,** as it tests the continuity of each circuit and determines whether the circuits are continuous and in normal condition or not. A continuity test is the surest and best method of locating some elusive fault that cannot be found by the general tests or inspection so far explained.

Fig. 120-C. Convenient Ohmeter or circuit tester which is also very valuable for continuity testing and radio trouble shooting. (Photo courtesy of Weston Electrical Instrument Co.)

Continuity tests can be made with set analyzers which are provided with test leads and points that can be attached to the terminals of a voltmeter or milliammeter in the analyzer, and with a small "C" battery in series to produce the readings.

If no set analyzer is available, continuity tests can be made with a small portable voltmeter and test leads and prods, with a C or B battery in series as shown in Fig. 120; or with a low reading milliammeter having a scale for 0 to 1 milliamperes, in series with a "C" battery, resistor, and the test points, as shown in Fig. 120-B. A portable ohmmeter with a self contained 1½ volt flashlight cell is also a very convenient instrument for making continuity tests. Fig. 120-C shows an instrument of this type with a double scale for both low and high readings.

In making continuity tests a circuit diagram of the receiver should be referred to unless you are thoroughly familiar with the set, and each circuit should be tested to see that it is complete and that its resistance is normal, or what it should be for that circuit or device when in good condition. Here again is where the continuity test charts supplied by manufacturers are a great help to the service man. These charts show the readings which should be obtained on every test and are a valuable guide and time saver if carefully followed. For this reason the service man should have this data on all sets he is commonly working with.

In testing a circuit make the test thorough and complete from its start to finish, as each wire and device in every circuit has a function to perform and it requires only one invisible open, short, ground, or high resistance connection to prevent proper operation of the entire receiver.

As each device, circuit or stage of a receiver is tested and found to be normal, that part can be eliminated as a possible cause of the trouble.

Before starting a continuity test the receiver should be disconnected from the batteries, or if it is an A. C. receiver its power supply plug should be removed from the 110 volt socket or receptacle, so the receiver will be entirely dead. This is necessary to prevent obtaining false readings and also to prevent possible damage to the test instrument or receiver tubes, when various wires and leads are touched with the test points.

When a milliammeter is used for continuity testing the resistor or the battery voltage should be adjusted so that when the test prods are shorted together the meter will give nearly full scale reading. Then when testing across wiring joints or connections or at the terminals of low resistance coils or devices the reading should still be nearly full scale. When testing very high resistance devices such as potentiometers, grid leaks or coupling resistors of

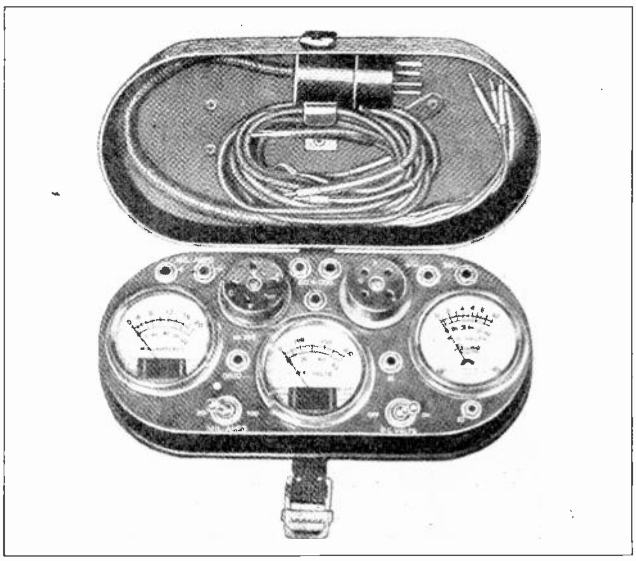


Fig. 121. Another type of small and convenient radio test instrument which is less expensive than some of the larger testers.

thousands of ohms resistance, the reading will drop in proportion to the resistance. The resistance of windings of R. F. or A. F. transformers is not high enough to make much difference in the reading of a 0 to 1 milliammeter. An open circuit will give no reading. A good condenser will show no reading when tested with a milliammeter and battery. If the milliammeter shows any reading on a condenser it indicates that the condenser is shorted. If it is a fixed condenser it must be replaced. If it is a variable condenser the trouble may be corrected. Condensers should always be disconnected from their circuit before testing or a false reading will be obtained from attached closed circuits.

When using a voltmeter for continuity tests the meter should be of the proper rating or design to give a full or nearly full scale reading with the voltage of the battery used, when the test points are shorted together. When the test points are then applied to circuits and devices the reduced meter reading indicates the voltage drop through them. Testing across wiring joints or terminals or across R. F. coils or transformers and other low resistance devices, should show no appreciable voltage drop unless there is some high resistance fault or open circuit in them. An open circuit will give no reading at all on the voltmeter. Windings of audio transformers and chokes are high enough resistance to show a little drop from full scale reading, but if the meter shows a considerably lower reading on them, it indicates a high resistance connection.

When testing very high resistance devices such as potentiometers, grid leaks, and resistors of many thousands of ohms, the voltmeter will show considerable voltage drop by a much lower reading.

When using an ohmmeter for continuity testing, the instrument reads directly the resistance of any circuit or device being tested, and thus gives very reliable and easily understood indications. After performing a number of continuity tests one gets to know just about what readings to expect from the tests on various devices in good condition, even without the manufacturers data, and even though the readings may vary slightly on different makes of equipment.

96. MECHANICAL TROUBLES, AND GENERAL

All moving parts such as variable condensers, rheostats, potentiometers, etc., in defective radio receivers, should be carefully examined for damage due to mechanical wear, or for parts or flexible connections having become loose.

Variable condensers should also be checked to see that none of the plates have become bent so they touch, or that dirt of a conductive nature is not partially shorting the plates. Bent or rubbing condenser plates will usually be indicated by a harsh scratching sound when the condenser is rotated during operation of the receiver.

Very weak signals are often caused by gang condensers being out of balance, and in such cases they should be carefully re-balanced by adjusting the small single plate balancing or trimming condensers while listening to the output reception of a local station, or with the set excited from a modulated oscillator. An output meter on a set analyzer is a great help to balance condensers more accurately.

Spring contacts in tube sockets sometimes become bent or corroded so that they do not make contact, or only make a poor high resistance connection to tube prongs. These contacts can usually be bent back into firm connection with the tube prongs, and cleaned with a narrow strip of sandpaper or emery cloth held over the end of a flat pointed stick. Sometimes, on tubes in the old style sockets where the tube prongs only make contact at their tips, these tips may need to be brightened and have corrosion removed from them by moving the tube back and forth in the socket, or by removing it and lightly polishing the prong tips with fine sandpaper or a fine file.

Audio transformers sometimes develop open circuits due to corrosion from soldering flux eating away the fine coil-lead wires near their terminals. A transformer with an open or burned out winding should be replaced with a new one of the same type and ratio.

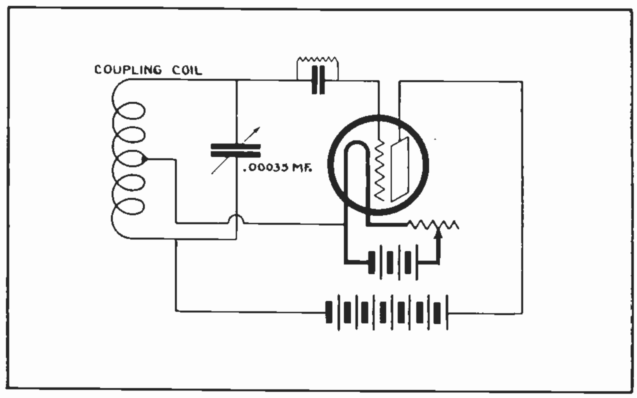


Fig. 122. Circuit diagram of a portable modulated oscillator which can be easily and cheaply made and is very useful for testing, balancing, and neutralizing radio receivers.

97. TUBE AND VOLTAGE TROUBLES

When testing the plate voltage, plate current, grid voltage, and filament voltage of tubes with an analyzer or test instrument, these values should be very close to those given in the manufacturers test data for the tubes. The plate current may, however, vary some for the same tubes when used in different receivers, but if it is very much off there is probably some fault causing it.

Some of the common causes of wrong voltage and current on tubes are as follows: Excessive plate current may be caused by too high plate voltage; too low grid bias voltage; too high filament voltage: leaky condenser or poor circuit insulation; or a defective tube. Insufficient plate current may be caused by too low plate voltage; grid bias voltage too high; low filament voltage; or defective tube.

If a test with a meter shows that the plate voltage is excessive this may be due to an open circuit in the negative end of the voltage divider in the power unit, to excessive negative grid bias: to low filament voltage; or a defective tube. Too low plate voltage may be due to failure of the power supply unit; low negative grid bias; too high filament voltage; or a defective tube.

If the grid biasing voltage is found to be too low, too high or reversed, this may be due to an open circuit at the "C" battery or bias resistor; a shorted bypass condenser across the "C" battery; leaky insulation or blocking condenser between grid and plate supply circuit; open transformer secondary in the grid circuit, or a defective tube socket.

If the filament voltage is wrong it may be due to a weak A battery or loose, corroded connections; a faulty or poorly adjusted A eliminator; an overload or partial short on the filament circuit; or improper line voltage on the house circuit to which the power unit is plugged.

A defective tube may cause wrong readings due to loss of vacuum, which will generally cause a bluish glow in the tube; a dead or deactivated filament; or to a short circuit in the tube, caused by the grid touching the plate or filament.

Some tubes are very microphonic and produce a howl at the speaker every time the receiver is vibrated slightly. This vibration causes a loose filament or grid to vibrate, and the changes in spacing between them and the plate cause corresponding plate current variations and sound. Microphonic tubes should be replaced, or a temporary remedy can be effected by fitting a piece of heavy rubber hose or inner tubing tightly over the top of the tube to dampen its vibrations.

98. COMMON TROUBLES IN R. F. STAGES, DETECTOR, AND AUDIO STAGES

Lack of sensitivity in the R. F. stages of a receiver may be caused by poorly balanced tuning condensers; an open or shorted R. F. transformer coil; open or shorted bypass condenser; defective tube; wrong filament, grid, or plate voltages; or a high resistance antenna or ground connection. Dampness or moisture absorbed by R. F. coils and condensers may also be a cause.

A continuity test will usually locate any faulty device or circuit, and repairs or replacement can be made according to the nature of the trouble.

Broad tuning or lack of selectivity may be due to most any of the causes of poor sensitivity just mentioned; or it may be due to too long an antenna; wrong "C" bias voltage on the tubes; or to some trouble in the circuit or volume control. Sometimes

Fig. 123. This photograph shows a service man on the job with a set analyzer, making trouble tests on a radio receiver.

broad tuning is blamed on the receiver when it is really caused by some powerful local station.

In such cases if the undesired station cannot be tuned out by the receiver when it is in good condition and fairly selective on other stations, a **wave trap** consisting of an auxiliary tuner or variable condenser and inductance, can be shunted across the antenna and ground terminals of the receiver and used to tune out the undesired station.

Oscillation in R. F. stages may be due to poor shielding; careless wiring; defective volume control; set not neutralized; bad tube; or wrong voltages.

Foreign noise in R. F. stages is generally due to loose connections in the wiring, or at the terminals of condensers, sockets, rheostats, etc.; or to loose shield cans; rubbing condenser plates; or defective volume controls or filament rheostats.

Trouble in the detector circuit may be due to a defective tube; wrong voltages; loose connections; wrong grid leak resistance or C bias, etc.

Lack of sensitivity in detectors is often due to a bad tube; wrong plate or filament voltages: or an open circuited grid lead, condenser or "C" battery.

Noise from the detector may be caused by a microphonic tube; dirty or loose tube socket connections; poor or loose grid leak resistor, etc. Too high resistance in the grid leak will cause "motor boating", or a put, put, put, sound like an engine exhaust.

A. C. hum may be caused by poor shielding: lack of proper bypass condensers in grid and plate circuits; or to induction from nearby A. C. circuits.

Troubles in audio stages may be due to poor tubes; defective A. F. transformers; wrong voltages on tubes; defects in wiring; dead "C" battery;

defective bypass condensers, etc. An open transformer primary will cut off the plate voltage to the tube preceding it, or in whose plate circuit the primary is connected. An open transformer secondary will cut off the grid voltage to the tube following it, or in whose grid circuit the secondary is connected.

Open, shorted, or burned out A. F. transformers can be easily located by a continuity test, and should be replaced by ones of the same general type and the same ratio.

Loose connections in A. F. transformers are quite common and cause a lot of noise when the set is jarred or vibrated.

99. SPEAKER TROUBLES

Trouble in magnetic type speakers may be caused by loose connections; jammed or bent diaphragms or cones; loose armatures of the balanced type striking the pole tips; loose driving rod or parts; collection of iron filings or magnetic particles in the narrow gaps between poles and armature or diaphragm.

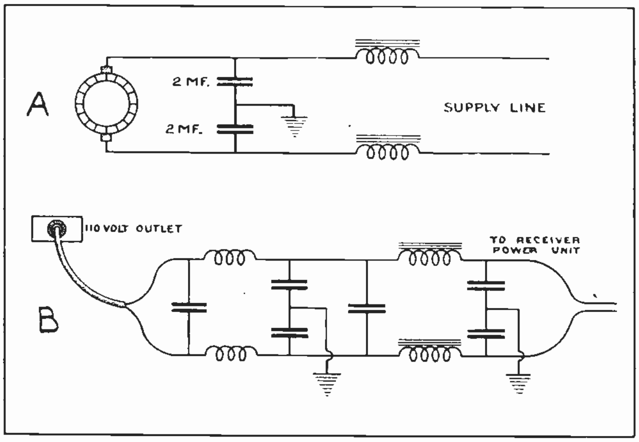


Fig. 124. Two types of filter circuits for interference elimination, or for reducing radio interference caused by electrical disturbances near the receiver.

Damaged cones or diaphragms usually cause a weak tinny sound, and when found should generally be replaced instead of trying to repair them. Loud chattering sounds are caused by the armature striking the pole tips. Rasping, scratching sounds are caused by dirt or magnetic particles rubbing on the armature or diaphragm. Light rattling sounds are generally caused by a loose driving rod or parts.

Poor volume may be due to a weak permanent magnet; open or short in a coil; or to defective insulation on the speaker cord. A broken connection at one of the electromagnet coils may cause a permanent open, or it may cause a lot of noise as the speaker vibrates slightly.

Trouble in dynamic speakers may be caused by an open field magnet coil; by failure of voltage supply to field coil due to defective rectifier tube, defective dry oxide rectifier, or defective filter condenser or transformer of separate speaker power supply unit. Dynamic speaker troubles may also be caused by a shorted or open cone coil; damaged cone; filings or dirt stuck between magnet and cone coil; or cone off center.

Failure of the field magnet coil is usually indicated by weak, raspy reproduction and almost no bass notes. This field magnet can be tested as previously mentioned by holding some clean iron object near its center pole to note the strong magnetic pull, if the coil is operating properly.

An open circuit in the cone or voice coil will stop all reproduction, and a partial short of this coil will cause reduction of bass notes and poor sound reproduction. These cone coils often become shorted by being off center and rubbing on the field magnet poles. Their flexible leads also become broken occasionally by vibration or abuse.

If iron filings are found in the magnetic gap they should be cleaned out by collecting them on a pointed magnetic tool, or with a stiff piece of paper. If necessary the cone can be removed and the filings and dirt wiped out with a cloth or brush.

If the cone becomes broken or damaged very badly it is usually best to replace it.

On dynamic speakers which have their own power units for supplying D. C. to the field coil, the rectifier tube may become defective or entirely dead, or the dry oxide rectifier, if one is used, may have reached the end of its useful life and if so should be replaced. A shorted filter condenser will cause failure of the current supply to the field coil, and an open circuited filter condenser will cause 60 cycle hum in the speaker. An open in the transformer or cord, or failure of the 110 volt supply will of course cause the speaker to fail.

Some dynamic speakers use a means of balancing out 60 cycle hum by feeding a small amount of the pulsating field current into the cone coil through a variable resistor. By adjusting this resistor the hum can be completely balanced out when the speaker is in good condition.

100. POWER SUPPLY TROUBLES

Troubles in power supply units may cause complete failure of the unit, wrong supply voltages, or bad A. C. hum.

Complete failure is generally due to an open in the 110 volt supply line or power transformer windings; to a defective rectifier tube; shorted filter condenser; or to an open circuit in a filter choke or in the wiring. A continuity test will locate any of these faults.

Wrong supply voltages may be caused by a bad rectifier tube; open circuit in the voltage divider resistance; shorted or open condensers or chokes; overload on the power unit due to shorts in the receiver; or to incorrect supply line voltage.

If the line voltage is too high or too low it can usually be corrected by adjustment of the line ballast resistor or taps in the circuit of the power transformer primary.

Rectifier tubes have a limited useful life and should therefore be tested or compared with a new tube when suspected of causing trouble.

Defective resistors, condensers or chokes should be replaced, unless the defect is merely a broken connection at the terminal.

101. MODULATED OSCILLATOR

We have mentioned that a modulated oscillator is a very useful device for exciting receivers with high frequency energy when neutralizing them, or when balancing gang tuning condensers and making comparative tests of any kind. These oscillators produce a high frequency wave that is modulated at an audible frequency, by the "spilling" action of the grid leak and condenser.

Portable oscillators of this type can be purchased, or they can be easily built at very low cost. Fig. 122 shows a connection diagram for a simple modulated oscillator using a 201-A or 301-A tube; grid leak and condenser; a simple center tapped inductance coil for coupling the grid and plate circuits for regeneration and oscillation, and also for inductively coupling the oscillator to the receiver; a tuning condenser for adjusting the pitch of the audible note; and the necessary A and B batteries and filament rheostat. The coupling coil consists of a center tapped coil of about 100 turns of No. 24 or 26 wire, on a tube or form about 1½" in diameter, and the tuning condenser is of .00035 mfd.

An oscillator of this type can be coupled to a receiver by merely setting it with the coupling coil close to the aerial lead of the receiver, or by setting it 15 or 20 feet from the receiver and running a wire from the coupling coil to any R. F. transformer coil, according to which stage you wish to test. The ends of the coupling wire can be just looped loosely around the sides of the coils, and capacity will give sufficient coupling through the insulation.

When using an oscillator of this type to balance the tuning condensers of a set the oscillator can be connected or coupled to the antenna circuit or first R. F. coil and adjusted to about 200 meters or 1500 kilocycles by setting the dial on the receiver at this point, and then adjusting the oscillator until it gives maximum sound at the speaker, or maximum reading on an output meter connected to the receiver in place of the speaker. If the maximum sound or reading is too great when the receiver and oscillator are tuned to resonance, reduce the filament temperature of the oscillator tube by means of its rheostat.

Now with the receiver operating from the oscillator, adjust the receiver gang condenser to maximum volume as indicated by the speaker or output meter. Then adjust each of the small balancing or trimmer condensers to the point where they give best results or increase the output to maximum. The condensers are then balanced for that wave length.

Next set the receiver dial at about 500 meters or 600 kilocycles and adjust the oscillator to resonance with it again. Once more adjust the trimmer or balancing condensers to get maximum output from the receiver. But when adjusting them this time, if it requires a change from their former setting to get best results, carefully note just how much change is required by counting the turns of the adjusting screw or noting their positions, and then set each trimmer back just half way between their best positions for the two different wave lengths. This will balance the gang condenser for best average results over the broadcast band.

The output meter mentioned, is simply an A. C. voltmeter which reads the signal variations or amplitude in the plate current of the receiver output.

102. INTERFERENCE

The radio service man is often called upon to locate and stop radio interference from sources outside the receiver, but which causes such a lot of noise or man-made static in the set that it makes good reception impossible.

Radio interference may be caused by nearby electrical machines or equipment, such as D. C. motors with sparking brushes, X-ray or high frequency machines, arc lights, gasoline engines with electric ignition, sign flashers, nearby power lines or A. C. circuits in the building, defective insulators on high voltage lines, or from other radio receivers which are in a state of oscillation.

Then of course there is also the interference from natural static or atmospheric electricity, and from powerful nearby radio transmitters. Even door bells and signal buzzers, and the switching on and off of lights in a building will often cause considerable interference in sensitive radio receivers.

A great many noises from such outside interferences are often blamed on the receiver, by those who are not able to recognize the sounds. Any high voltage sparks or arcs such as those caused by X-ray machines, ignition equipment, sparking motors or trolleys, arc lamps, or leaky power line insulators, are radiators of high frequency energy and serious offenders in the matter of radio interference. They produce high frequency energy by oscillations set up between the arc or spark and the inductance and capacity of the circuit in which the arc occurs.

X-ray machines generally cause a loud hissing or crashing sound in the speaker for intervals of a few seconds to a few minutes in length. About the best way to prevent radiation of interference from X-rays is to completely shield the machine or the room it is in, with wire screen or sheet metal on the walls and then thoroughly ground this metal shield.

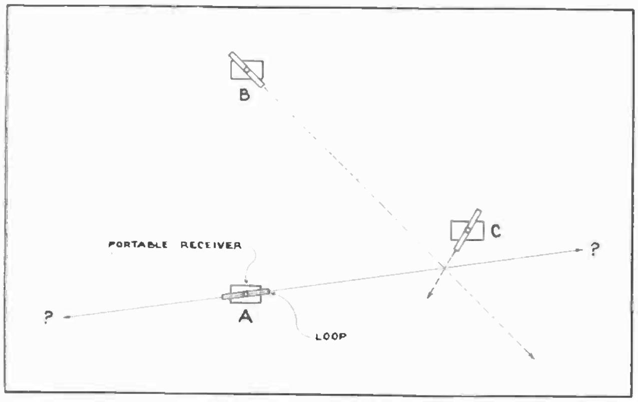


Fig. 125. This sketch illustrates the method of locating a source of radio interfernce with a portable receiver and a loop aerial.

Ignition equipment usually causes a continuous put, put, or clicking sound for single cylinder engines, or a rapid and regular sputtering for multiple cylinder engines, such as automobile or airplane types. Ignition interference can usually be prevented by shielding the spark plug leads and ignition coils with sheet metal, and the high voltage conductors with tubular copper braid, and then grounding these shields. A condenser connected across the make-and-break contacts in the ignition coil primary, and with its case grounded, will also help to eliminate interference from this source.

Either D. C. or A. C. motors of the commutator type are common sources of radio interference, much of it coming from small motors on washing machines, oil burners, refrigerators, fans, etc.

Interference from this source can be quite effectively prevented by connecting two condensers of the proper voltage rating, and from 2 to 6 mfd. capacity, across the line to the motor, and then grounding the connection between them as shown in Fig. 124-A. One or more choke coils in series with the supply line will also help to cure the trouble.

The condensers tend to absorb the high frequencies and pass them to ground, and the choke coils block the high frequencies preventing them from being carried out on the line and radiated as from an antenna. The chokes do not interfere at all with the passage of D. C. power current, nor do they appreciably affect the passage of 60 cycle A. C. They must be made of large enough wire, however, to carry the line current without overheating or causing appreciable resistance voltage drop.

The interference filters should be located as close to the motors or sources of trouble as possible to prevent radiation of the R. F. energy from the lines.

Interference from sign flashers and certain other sources can be largely eliminated by means of a filter such as shown for the motor in Fig. 124-A, by simply connecting this filter in and across the line leads as shown.

Where interference is not filtered out at its

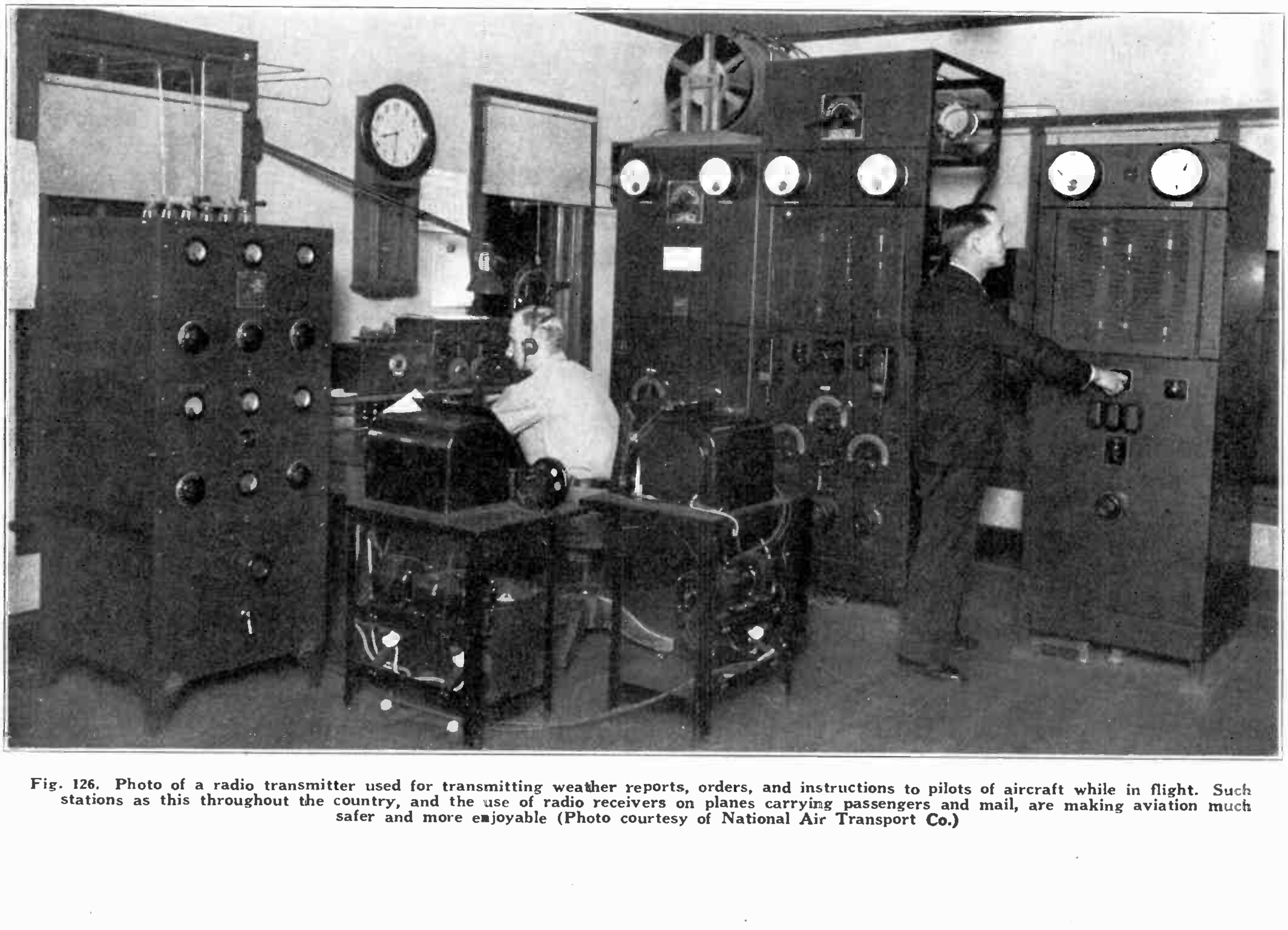


Fig. 126. Photo of a radio transmitter used for transmitting weather reports, orders, and instructions to pilots of aircraft while in flight. Such stations as this throughout the country, and the use of radio receivers on planes carrying passengers and mail, are making aviation much safer and more enjoyable (Photo courtesy of National Air Transport Co.)

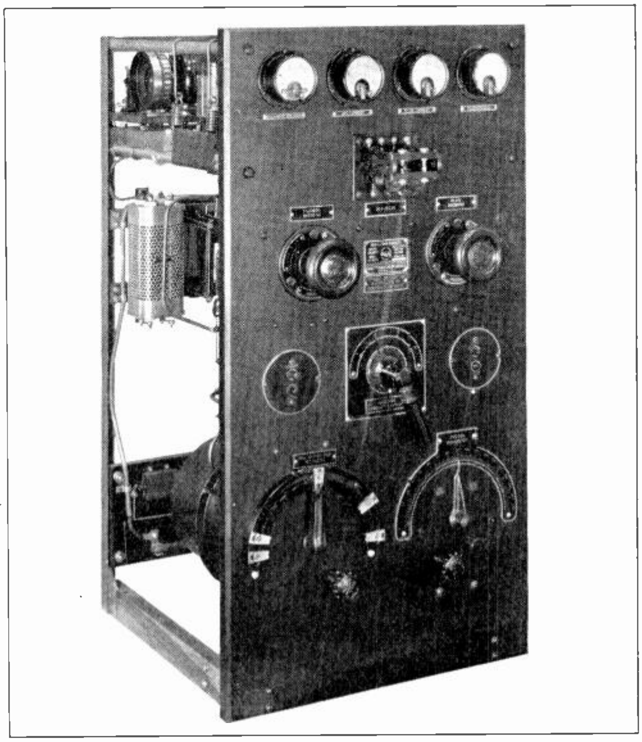


Fig. 127. Front view of a marine type vacuum tube transmitter for use on ships for communication and distress signal uses. Vacuum tube transmitters of this type are rapidly replacing all spark transmitters. (Photo courtesy of Radiomarine Corp. of America.)

source, it will travel over the line or the light or power wires, as a sort of "wired wireless for considerable distance, and either by radiation or conduction will get into any receivers attached to, or near to that line. When a line to which a receiver is attached seems to be full of such interference energy, a filter such as shown in Fig. 124-B can be installed between the outlet and the receiver to greatly reduce the amount of interference reaching the set. This filter consists of both R. F. and A. F. chokes in series with the line, and condensers across the line. In many cases a less elaborate filter or interference eliminator, consisting of two chokes and a pair of grounded condensers, will be sufficient or will greatly improve the condition.

Conductors carrying large amounts of alternating current will often induce considerable A. C. hum in a nearby receiver, by ordinary low frequency magnetic induction. Wires run in grounded conduit rarely cause this trouble.

If the source or sources of radio interference are in the same building with the radio set, they can often be located by a general inspection of the premises.

If the interference seems to be coming from outside the building and no nearby electrical machinery can be located, then the trouble may come from a nearby high voltage power line, distribution line, or arc light circuit. Leaky insulators which occasionally or continuously spark over, transformers with poor insulation, arc lamps in operation, or even incandescent street lamps of the series types with film cutouts, are all common causes of radio interference.

The source of bad interference, even though it is at some distance can be quite easily located by the use of a portable receiver and a loop aerial, with its directional characteristics. By carrying the receiver to a location where the interference can be heard, and then rotating the loop to a point where the sound is loudest, we know that the plane of the loop will point in the direction of the source, or that the source of interference lies in line with the loop in one direction or the other. This is shown by the set and loop at A in Fig. 125, and by the solid line pointing each way from the edges of the loop.

Lay out this line on a sketch or map of the territory and then carry the receiver off a distance of a block or so at right angles to the first line, as shown at B, and again set the loop for loudest reception of the interference. This time we know in which direction from the loop edge the source of interference lies, because it must be the direction toward one of the other lines as shown by the light dotted line in Fig. 125.

Lay out this line on the map and note where it crosses the other, and you will know just about where the trouble comes from.

Then by going close to this spot and testing once or twice more from different angles as shown at C, the loop will point as shown by the short, heavy dotted line, to the very building, transformer, line insulator, street light, or whatever it is that the interference comes from.

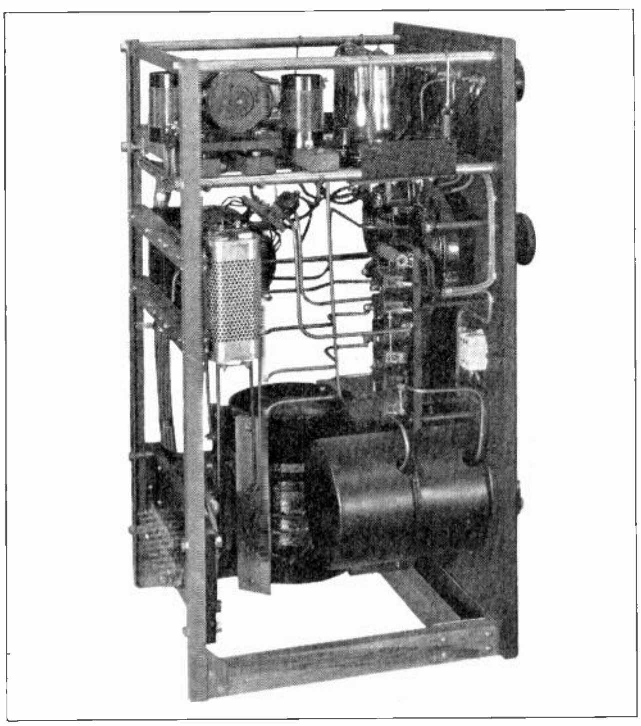


Fig. 128. Side view of marine type vacuum transmitter such as shown in Fig. 127. (Photo courtesy of Radiomarine Corp. of America.)

cal power companies are usually glad to co-ate in eliminating interference if it is proven e coming from their equipment.

he portable set and loop direction finder can be used for locating badly oscillating regenera-e receivers, which radiate serious interference t sets up a continuous howl in other receivers en a half mile or more away. Radio amateurs or perimenters who may be transmitting code with-ut a license, or on a poorly tuned transmitter can lso be located in this manner, and a report to the earest radio inspector will put a stop to their interference.

Observers may think you are looking for a buried treasure or a lost radio program, but your search will usually be worth while.

And we are sure that if you frequently refer to and make good use of the practical material covered in this entire section, and in the entire reference set, it will also be extremely well worth your while.

Get the habit of regularly looking in this reference set for any practical electrical or radio information you want, and never allow any dust to collect on it.

You'll find it like a good tool on the job, very valuable if you use it at every opportunity until you are really familiar with its every possible use, but of not much value if allowed to lay and gather rust (or dust) and until you forget where it is.

With your actual shop training and experience on the equipment, this reference set and your notes to use as reminders, and plenty of real ambition you should surely succeed in **electricity**.

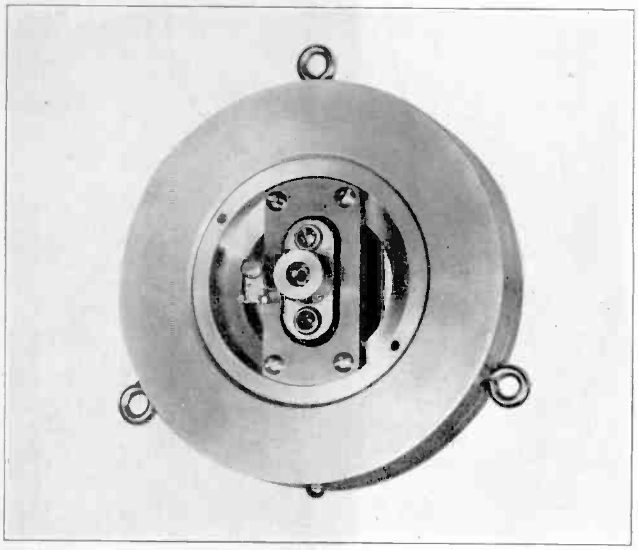


Fig. 130. Photo of a radio microphone without its case. These microphones are used in studios of broadcast stations and are similar in principle to ordinary telephone transmitters but are much more sensitive and accurate.

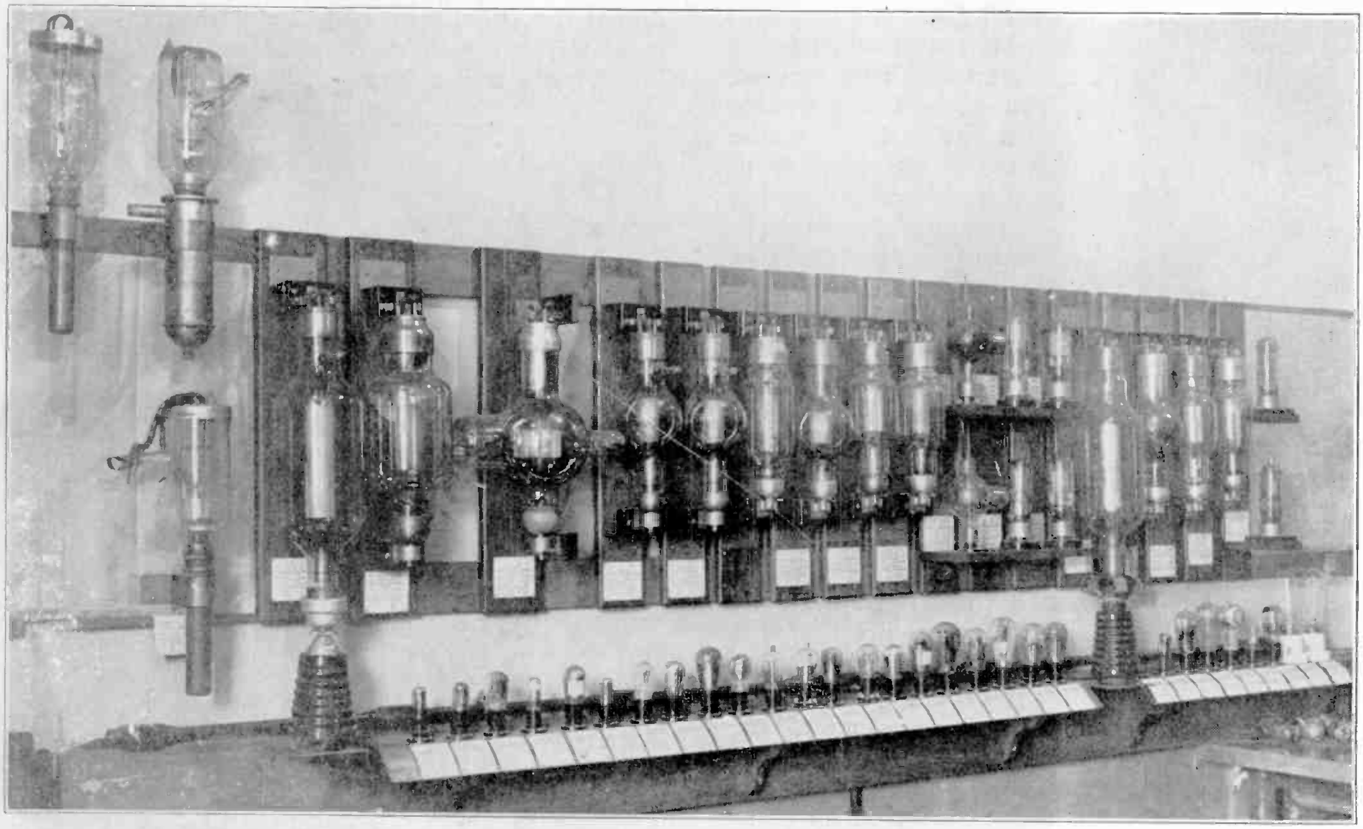


Fig. 129. This excellent photograph shows a display of a large number of vacuum tubes for radio use. These tubes range all the way from the smallest receiving tubes at the left end of the lower row to the large water-cooled transmitter tubes shown at the left of the upper row. These large transmitter tubes can handle 20,000 watts of power. (Photo courtesy of Westinghouse Electric and Mfg. Co.)