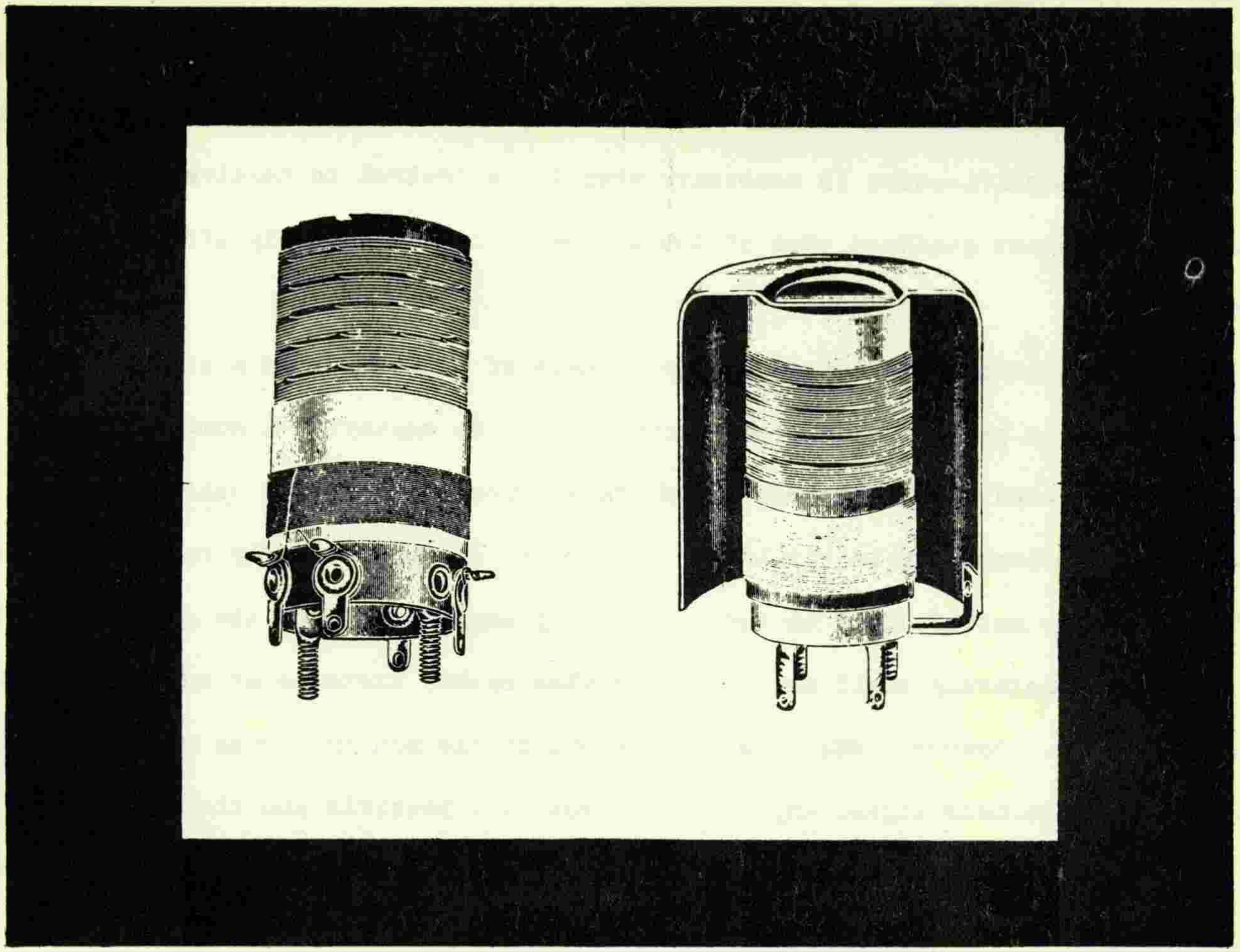

LESSON
24 R

RADIO FREQUENCY AMPLIFICATION

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RADIO FREQUENCY AMPLIFICATION

Radio frequency amplification is the process of amplifying or strengthening an incoming radio signal before it passes through the detector of a receiver, that is, while it is still at the high frequency at which it was sent out by the transmitting station. Such amplification is necessary when it is desired to receive very weak signals from distant stations that of themselves cannot appreciably affect the detector.

In radio frequency amplification use is made of the fact that a signal is "stepped up" as it passes through the vacuum tube. By employing a number of such tubes in cascade and using suitable tuned transformers as coupling units, a large gain in signal voltage can be obtained. The tubes used in the early radio receivers were not entirely satisfactory as radio frequency amplifiers, for the gain available with them was relatively small and they were also rather unstable at such high frequency operation. However, with the development of the modern screen grid and pentode tubes, enormous signal amplification was made possible and the operating stability was also greatly improved, so that tuned radio frequency circuits have become available that are really remarkable in their performance.

IMPORTANCE OF GOOD R. F. AMPLIFICATION

The important features of good radio frequency amplification are the following: In the first place, it makes possible the reception of weak signals from distant stations; that is, it greatly increases the sensitivity of a set. If well designed tuned transformers are used as coupling units between the successive tubes; they serve also as wave filters and permit signals of only the desired frequency to pass through. The extent to which the unwanted frequencies are excluded depends upon the quality of the transformers, the circuit arrangement, the number of such tuned stages that are used and the degree to which the successive stages are aligned to act in step or synchronism with each other. This ability of a receiver to select signals of only a particular frequency and exclude the others is termed the selectivity.

Since static and other disturbing noises are generally of an audio frequency nature, they do not undergo the same amplification that the radio frequency impulses do; and with increased radio frequency amplification, the signals become more prominent in relation to the noises heard, and the quality of the receiver output is better. In other words, the signal to noise ratio is greatly improved.

Although radio frequency amplification appears to offer numerous advantages for obtaining improved performance from radio receivers, it also introduces a serious disturbing condition in the form of self-oscillation due to high frequency feedback in the various stages. These free oscillations manifest themselves as squeals and howls, and it was to overcome these disturbances that the various forms of tuned radio-frequency circuit systems as explained later on were developed.

Radio frequency amplifier systems are classified according to the coupling methods employed into resistance-coupled, impedance coupled and tuned transformer coupled; but of these only the tuned transformer system is now used in radio receivers for broadcast and short wave reception.

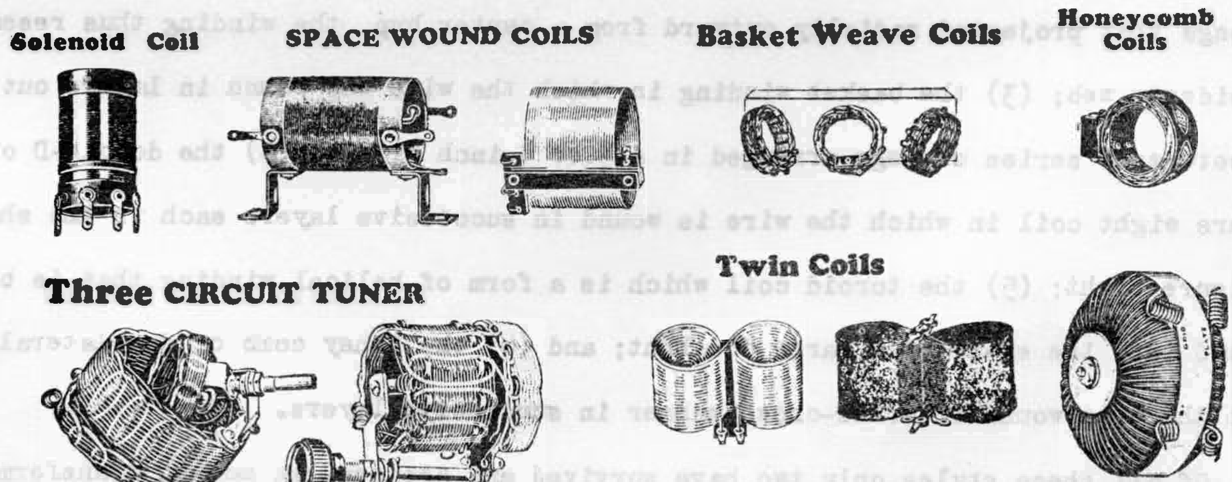


Fig. 1. Here are shown a number of early tuned radio frequency transformers.

RADIO FREQUENCY TRANSFORMERS

The radio frequency transformers used in modern receivers are of very compact and efficient design, the result of many years of research and development work. They are practically all of the tuned type so that they serve not only as coupling elements but also as frequency filtering units.

As such they consist of a primary and a secondary winding, the primary being connected into the plate circuit of the tube the output of which is to be amplified. The pulsating signal current builds up across this primary a corresponding variable potential, and by electro-magnetic induction it is transferred to the secondary winding. The secondary generally contains a greater number of turns so that a voltage step-up also occurs. Further, this number of turns in the secondary is arranged so that when the winding is shunted with a suitable variable condenser, the resulting tuned circuit will respond to a certain range of frequencies, depending upon how and where the transformer is to be used.

Many types and forms of radio frequency transformers have been developed and different styles of windings tried out to obtain improved operating characteristics. Among these were the following: (1) Solenoid or cylindrical coils of various diameters; (2) the spiderweb coil in which the wire was wound in spiral fashion between a series of pegs that projected radially outward from a center hub, the winding thus resembling a spider's web; (3) the basket winding in which the wire was wound in layers out and in between a series of pegs arranged in a 3 or 4-inch circle; (4) the double-Dor figure eight coil in which the wire is wound in successive layers each in the shape of a figure eight; (5) the toroid coil which is a form of helical winding that is bent around into the shape of a large doughnut; and (6) the honey comb or duo-lateral coil with the wire wound in criss-cross manner in successive layers.

Of all these styles only two have survived and are used in modern transformer construction; the rest are now only of historical interest, although at the time they were developed they were considered great achievements. These two types of windings used today are the solenoid and the duolateral or criss-cross. The solenoid coils, however, are much smaller now than the early coils were, the average diameter being only about one inch.

A number of modern radio frequency transformers are illustrated in Fig. 2. The first is a typical high efficiency solenoid coil 1-1/8 inches in diameter and 2-3/4 inches long. The primary is shown wound over one end of the secondary and insulated from it by a layer of varnished cambric or fish paper. The center illustration shows a similar type of coil mounted in a shielding can, and at the right in the figure is a transformer with a duolateral or criss-cross type of winding, the entire unit also being mounted in a shielding can.

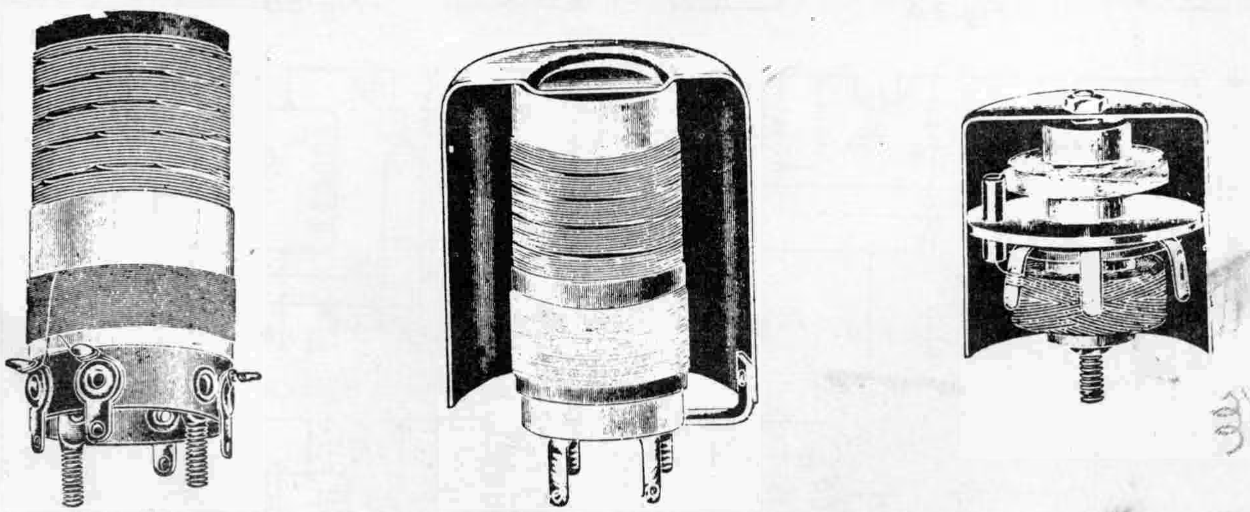


Fig. 2. Three illustrations of modern tuned radio frequency transformers

SIMPLE TUNED RADIO FREQUENCY STAGES

Two forms of simple tuned radio frequency amplifier stages are illustrated in Fig. 3. In each case a radio frequency (abbreviated R. F.) amplifier tube is used and a detector. The output circuit of the detector is not completed, but it can be fed through an additional audio amplifier or can be closed through a speaker or set of head phones.

The tubes illustrated are of the indirectly-heated cathode type, and can be considered as either battery operated or electrically operated, as desired. For example, they may be of the 27 or 56 type and require a 2-1/2-volt filament supply for the heater current, or they may be of the 76 or 37 type and require a 6.3-volt filament supply. Those who wish to build and experiment with the various circuit systems illustrated on these pages, will find it desirable to use two No. 37 tubes, for these tubes can for the time being be operated from a 6-volt storage battery and later on from an electric power unit.

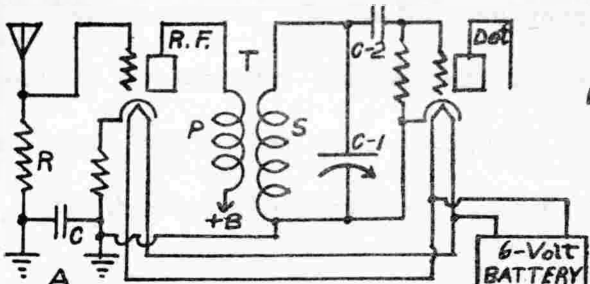


Fig. 3 A

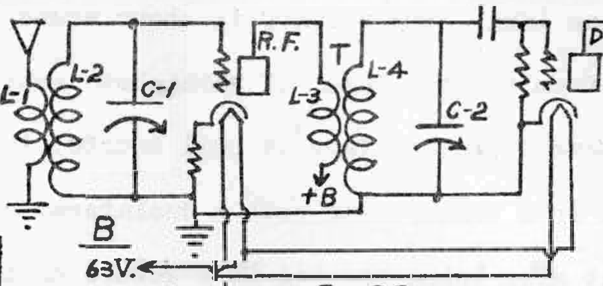


Fig. 3 B

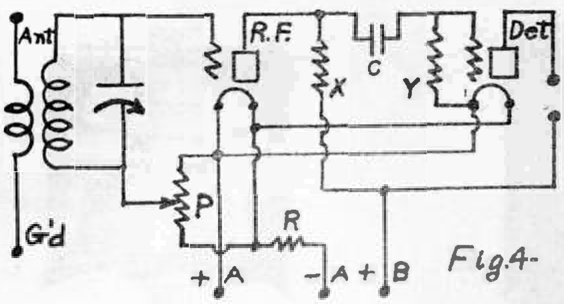


Fig. 4

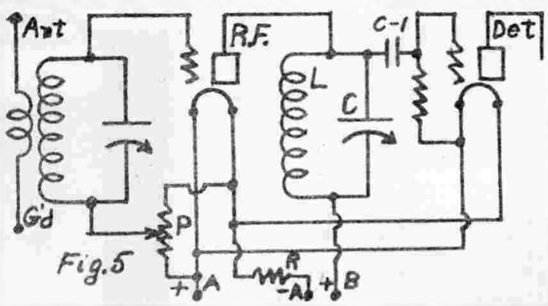


Fig. 5

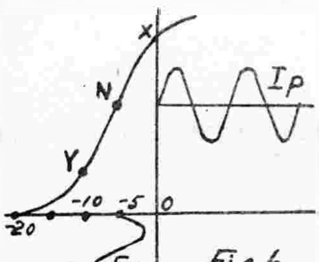


Fig. 6

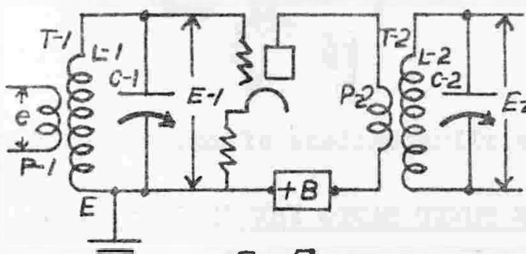


Fig. 7

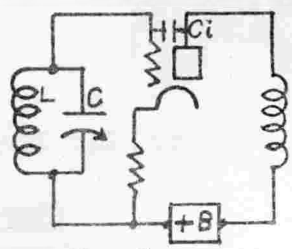


Fig. 8

At "A" in Fig. 3 the antenna coupler consists merely of a resistor "R." of 5000 or 10,000 ohms, and the signal voltage built up across this resistor is impressed on the grid of the radio frequency tube. The grid return circuit is closed through resistor "R". Within the tube the signal is amplified and then appears in the plate circuit as a pulsating current which flows through the primary of the "R. F." transformer "T". It induces a similar voltage in the secondary winding "S", which is shunted by the tuning condenser "C-1". The secondary "S" in conjunction with condenser "C-1" forms an oscillation circuit, the frequency of which is determined by the inductance of "S" and the capacity of "C-1". The amplified signal voltage finally reaches the detector through the grid condenser "C-2".

The signal is thus amplified as it passes through the "R. F." tube and then experiences a slight additional step-up as it is transferred from the primary to the secondary of the "R. F." transformer "T". The "R. F." transformer serves not only as a coupling unit between the "R. F." and detector tubes, but it helps to step up the signal voltage and also acts as a frequency filter due to the tuning feature of the secondary circuit.

Circuit "B" in Fig. 3 employs a tuned "R. F." transformer as antenna coupler. The advantage of this arrangement, although it is more costly, is that due to the transformer action a step-up in signal voltage is produced ahead of the first tube, and the tuned secondary is another frequency filter so that better selectivity is possible. Either two single condensers can be used for "C-1" and "C-2" or a 2-gang condenser can be employed, in which case there will be a single tuning control.

RESISTANCE COUPLED R. F. AMPLIFICATION

In this system a high resistance element and a fixed condenser are used to couple the radio frequency amplifying tube to the detector. The circuit arrangement for battery operation is illustrated in Fig. 4. Resistor "X" has a value of from 50,000 to 60,000 ohms, and condenser "C" a capacity of .006 mfd. This condenser transmits the signal from the plate circuit of the "R. F." tube to the grid circuit of the detector, and also blocks or protects the grid of the detector from the high "D. C." voltage in the plate circuit. Resistor "Y" serves as the customary grid leak. The operation of the entire system is similar to that of a resistance coupled audio amplifier.

Although resistance coupling is inexpensive and yields good quality amplification, it has several disadvantages. One is that the maximum amplification available is only that gained from the tube. Also, resistance coupling is well adapted only for long wave reception and is not readily applicable below 600 meters (500 kilocycles), for at these higher frequencies the internal plate-to-filament capacity of the "R. F." tube offers such an easy return path to the signal oscillations that the resistance coupling is rendered practically ineffective. With special low capacity tubes and at the longer wavelengths, resistance coupling is quite satisfactory, but the system is not satisfactory and is not employed for presentday broadcast reception.

TUNED IMPEDANCE COUPLED R. F. AMPLIFIER

A tuned impedance-coupled radio frequency amplifier is shown in Fig. 5. Here the coupling unit consists of a coil "L" tuned by a variable condenser "C", the coil and condenser being chosen of such a size that the tuning range covered by the combination includes the band of frequencies over which the receiver is expected to tune. The signal voltage built up across this tuned circuit is then transmitted through condenser "C-1" to the grid of the detector. The particular advantage gained is the increased selectivity obtained through tuning the plate circuit. This system as will be proven later on, works out fairly well and has been used in a number of commercial tuned"R. F." receivers.

SELECTIVITY IN RADIO FREQUENCY AMPLIFIERS

Under present conditions with numerous high-power broadcasting stations operating relatively close to each other, a single input tuner can no longer be depended upon, as in the early days, to select the desired signal frequency and to exclude completely the undesired frequencies. In other words, a single input tuner cannot provide the necessary selectivity.

It was to help solve this selectivity problem that the tuned radio-frequency amplifier systems were developed, for not only does a tuned radio-frequency amplifier step up the signal voltage, but the tuned coupling unit (consisting of a coil and condenser, either one or both of which are variable) serves additionally as a wave filter and permits only that frequency to pass through to which the unit is tuned. Thus by increasing the number of such tuned circuits the filtering efficiency is increased and the tuning selectivity improved accordingly.

Tuned radio-frequency amplifier systems of two, three and even four stages were developed. The term, "stage" refers to an amplifier tube with the necessary coupling units. For example, at "B" in Fig. 3 coils "L-1" and "L-2" comprise the antenna coupler, while the "R. F." tube together with the coupling transformer consisting of "L-3", "L-4" and "C-2", comprise the amplifier stage. Two stages of tuned radio-frequency amplification with good tubes and well-designed transformers were found to be ample as far as selectivity and amplification gain are concerned. With more stages the performance becomes rather critical, and unless the successive stages are properly balanced and aligned, their operation is very unstable and reception becomes a mess of squeals and howls.

Numerous types of amplifier systems were developed and to many of them special names were assigned that were coined by the individual manufacturers, but basically these circuits are all more or less alike. Some of these systems have lived right on through the years and are used with very few alterations in present day tuned radio-frequency receivers.

SELF-OSCILLATIONS IN RADIO-FREQUENCY RECEIVERS

Self-oscillations in the high-frequency stages of radio frequency and reflex circuits, formed one of the most difficult problems to contend with in the construction nd operation of this type of set. These free oscillations are the result of feed-back or regenerative actions, and are the cause of the unpleasant squeals and howls.

It is simple enough to eliminate these oscillations altogether, but when this is done, the amplifying action of the tubes is also killed. Oscillations are thus a necessary evil, and the best that can be done is to bring them under convenient control. In fact, in the numerous circuits that have appeared, the main objective has been not so much along the lines of improved methods of tuning or amplification, as in the direction of controlling these tube oscillations. What makes it most difficult is that a radio-frequency amplifier operates at maximum efficiency right near the point of oscillation, or as is often said, just before the tube spills over. The form of stabilizer used, therefore, must make it possible to bring the tubes to this point and to prevent them from going beyond. If the amplifier is worked too far below this point, its effectiveness is impaired and no appreciable amplification is secured.

Many of the cheaper receiving sets were arranged so that this point of oscillation could not be reached, and the resulting decreased efficiency was then made up by the use of additional amplifying tubes. In this way a group of tubes were used to do the same work that one or two could do if they were under perfect control. Such a set is not at all suitable for distance work, because the sensitiveness and efficiency of the tubes have been so impaired that the weaker signals are not accepted. A very sensitive receiver capable of bringing in far distant stations is inherently somewhat unstable. If stability is sought, other qualities must be sacrificed.

CAUSES OF SELF-OSCILLATION IN R. F. AMPLIFIERS

Oscillations in radio-frequency amplifiers are always caused by a regenerative or feed-back action that results from some stray coupling between the grid and plate circuits of a tube, or between the grid circuit of one tube and the plate circuit of an adjacent amplifier tube. Two coupled circuits tuned to the same frequency transfer energy back and forth; and if the feed-back action is great enough, these energy transfers become oscillating currents that manifest themselves as squeals and howls. As soon as sufficient coupling is established between the input and output circuits of a tube, interchange of energy takes place and oscillations begin.

Coupling between the grid and plate circuits of a tube may be internal or external. Internal coupling results from the capacity effect that exists between the elements within a tube. For example, the grid and plate in a tube form two adjacent conductors separated by an insulator, and in effect form a small condenser. In other words, the two elements are electrostatically coupled.

The capacity effect existing between these two elements is known as the internal grid to plate capacity. In the original 201A tube this has a value of 7.5 micromicro-farads (abbreviated mmf), in a type 27 tube 3.3 mmf., and in a type 24A only .007 mmf. Since this internal grid to plate capacity in the 201A tube is so much greater than it is within the 24A tube, the 201A tube is much more susceptible to self-oscillation than the 24A tube is. That also explains why the 201A tube is not as good a radio frequency amplifier as the 24A tube is. In all the newer amplifier tubes this internal grid to plate capacity is held to a very small value, and these tubes are all more stable and can be operated at a much higher gain as radio frequency amplifiers.

Similarly there is an internal capacity effect between the grid and cathode (or filament). This is commonly referred to as the input capacity, for it really is equivalent to a small condenser connected across the input terminals of the tube. A capacity effect is also present across the plate and cathode and this is called the output capacity, for it acts like a small condenser connected across the output terminals of a tube.

External coupling between the grid and plate circuits of a tube can also result in violent oscillations. If the grid and plate wires lie close together, for example, the magnetic fields surrounding these wires may react with each other, that is, the wires may become magnetically coupled, so that an interchange of energy takes place and oscillations set in. Stray coupling may also take place between several tubes that are placed close together, between a tube and a coil, or between two coils, etc., all of which will result in troublesome oscillations. The closer the wires, as in a crowded set, or the closer a tube and a coil, the greater the coupling action and the greater the interchange of energy, and the more prominent the oscillations.

COMBATING AND SUPPRESSING FREE OSCILLATIONS

Since free oscillations are always the result of stray coupling, either electrostatic or magnetic, it is evident that to suppress these oscillations it is only necessary to minimize or eliminate this stray coupling.

Oscillations resulting from electrostatic coupling between the internal elements of an amplifier tube were greatly cut down and almost eliminated by improving the tube design and reducing the inter-electrode capacity. The electrodes were arranged differently within the tubes, new elements were added, internal shields and screens were incorporated, etc., so that the construction of the modern high frequency amplifier tube permits very stable operation, even at extremely high gain. These improvements in tube design and the advantages gained from the addition of new elements are discussed in greater detail in later lessons.

Oscillations resulting from electrostatic or magnetic coupling between the various circuit components have also been greatly reduced, not only through proper arrangement and positioning of the different units and the connecting wires, but more especially through the use of efficient shielding which protects each unit magnetically and electrostatically from the rest. In some cases double shielding has even been employed to insure positively against any form of coupling.

SHIELDING IN RADIO RECEIVERS

Shielding is the practice of enclosing various component parts of a radio receiver in metal "cans", or separating several units with metal partitions. Such shielding protects the coils, tubes, etc. against undue magnetic or electrostatic coupling between one another; and also prevents the enclosed units from picking up noise and signal voltages due to any stray magnetic fields that may be hovering around the receiver. For best results the shielding should be of good conducting metal such as copper or aluminum, but tin-plated or cadmium-plated sheet iron is also used frequently. Highly polished chromium plating imparts a very attractive appearance to the shielding cans on a chassis.

Such protective shielding improves the performance of a radio receiver in several ways. By preventing feedback actions between the various elements, stray coupling effects are eliminated and free oscillations avoided. The tubes can thus be operated at a greater gain, and the performance of the entire receiver is more stable and efficient. Also, operating the successive stages at a greater gain increases the over-all sensitivity of a receiver. By being protected against picking up stray voltages, the receiver operates with better selectivity and free from local noises, and other station interference. Effective shielding accordingly confines each unit and nullifies any disturbing influence it might otherwise have on adjacent parts.

All shielding elements should be well grounded to the chassis or the effectiveness of the shielding is lost. Also, the shields should never be used as part of a grid or cathode return circuit, for they themselvesmay then be sources of stray coupling and defeat the very purpose for which they were intended. Holes in the shields should be avoided wherever possible, and if necessary should not be any larger than needed. Where wire must enter a shield, rubber or fiber bushings should be used to prevent the insulation on the wire from wearing through and causing a short circuit or ground. Shielding should never be placed around a coil in a receiver where shielding was not used originally, for shielding affects the effective inductance of a coil; and unless the coil was designed for use with an enclosing shield, its tuning range will be affected.

SERVICE POINTERS REGARDING SHIELDED RECEIVERS

Good shielding properly installed greatly improves the performance and operating stability of a radio receiver. Poor shielding, on the other hand, can be equally detrimental and greatly impair the operation of a receiver. A prime requisite in all cases is that the shielding elements be well grounded to the receiver chassis, or much disturbancemay result. Sometimes if a poor job is made riveting the shielding elements to the mounting brackets, or if the brackets are not securely attached to the chassis, a disturbing noise may set in, violent oscillations may occur, or worst of all, a fading or intermittent action may result.

Corroded rivetsmay similarly cause such disturbances; or if the shielding elements are held in place with screws and nuts, one of thesemay loosen and allow a floating ground to exist between the shield and chassis. When good contact is being made, the receiver will perform normally; but when the contact is partially or wholly interrupted, trouble will be experienced. In other words, if the electrical contact between the shield and chassis is disturbed, the normal shielding effects are lost, and practically the same disturbances will prevail as though no shielding at all were used.

Therefore, when a radio receiver is brought in for service, and the complaint is noise, oscillation or intermittent reception, one of the first steps in the procedure should be to make a mechanical inspection of the chassis to see that all shielding elements are well grounded, that there is no loose bolt or rivet in any of them, that none are corroded or rusted badly where they make contact with the chassis, and that none of the shields were removed and then not replaced. Such an inspection may often save much time and effort later on in making unnecessary an electrical inspection underneath the chassis.

R. F. CLASS "A" AMPLIFIERS

All high-frequency amplifiers used in radio receivers are of the Class "A" type, that is, they operate on the lower linear portion of the characteristic curve. The position of the normal operating point is determined by the applied grid bias, and the value of grid bias specified by the tube manufacturers generally locates this point half way between the lower bend of the curve and the zero grid axis. As a result, any signal voltages impressed on the grid are reproduced faithfully by corresponding fluctuations in plate current flow.

These conditions are illustrated in Fig. 6, where the straight portion of the characteristic curve extends from "X" to "Y", that is, from 0 to -10 grid volts. The specified grid bias would therefore be -5 volts, so that the normal operating point lies midway between "X" and "Y". Any signal voltage impressed on the grid (Eg in the diagram) then swings the operating point up and down between "X" and "Y" so that corresponding fluctuations occur in plate current flow as shown by the curves labeled "Ip" in the diagram.

If too high an initial grid bias were applied, the normal operating point would lie too close to the lower bend of the curve, and as a result signal voltages applied to the grid would extend into the curved portion and cause dissimilar fluctuations in plate current flow. In other words, the signals would be reproduced in distorted form. Similarly, if too small a grid bias were applied, the grid voltage swings would carry the operating point into the region of positive grid potential, and this would also result in deformed plate current waves or distortion.

It is further evident from an examination of the curve in Fig. 6 that if at normal grid bias the applied signal voltage carries the operating point beyond "X" or "Y", the plate current waves will be deformed and distortion result. This condition is commonly referred to as overloading; that is, the signal voltages supplied to the tube are greater than the grid can properly handle without swinging into the regions of distortion.

HOW SIGNAL VOLTAGE IS STEPPED UP IN AN R. F. STAGE

In Fig. 7 is illustrated a typical tuned radio-frequency amplifier stage, in which "E" represents the signal voltage impressed across the primary of the input coupler. This induces a somewhat higher voltage in the secondary coil L-1 which in turn causes a current I-1 to oscillate in the circuit L-1 C-1. Since this circuit is in resonance with the frequency of the incoming signal voltage, the current is limited only by the resistance of the circuit, for the inductive and capacitive reactance neutralize each other. It builds up a voltage E-1 across the coil, and this voltage is impressed on the grid or input of the amplifier tube as shown in the diagram.

Due to the relay action of the tube, that is, the control effect the grid has on the plate current, this signal voltage on the grid reappears as a pulsating current in the plate circuit and through the primary of the coupler "T-2". Due to the nearness of the grid to the cathode compared to the distance of the plate, the signal voltage produces greater fluctuations in plate current flow than the same signal voltage could cause if impressed on the plate circuit; therefore, the amplifying action of the tube.

Coupler "T-2" now serves the further purpose of converting the pulsating plate current in the primary "P-2" into an alternating voltage in the secondary "L-2"; and the more effectively this is accomplished, that is, the greater the voltage induced in the secondary, the higher will be the gain in the amplifier stage. It is here where efficient coil design plays its important part.

The resulting voltage "E-2" built up across the secondary coil "L-2" is then impressed on the grid of the next amplifier tube. The ratio of "E-2" to "E-1" is commonly defined as the voltage gain per stage, and this depends upon the amplification factor of the tube, the efficiency of the coupling coil employed, the effectiveness of the shielding in reducing losses, and a number of other minor factors. This gain can actually be measured with a vacuum tube voltmeter.

HOW GRID-TO-PLATE CAPACITY CAUSES FEED-BACK AND OSCILLATION

Due to the construction and concentric arrangement of the grid and plate within a tube, a small capacity effect or condenser action exists between the two, called the grid-to-plate capacity. This is illustrated in the skeleton circuit in Fig. 8 where "Ci" represents this internal capacity.

When a potential is impressed on the grid of the tube, not only does the grid control the electron movement and the rate of plate current flow by virtue of its potential, but it also sends across this internal condenser into the plate circuit a charge or impulse that travels around through the plate circuit and returns to the grid circuit in time and in proper phase to reinforce the incoming signal voltage reaching the grid.

The potential on the grid is thus strengthened, greater control is exerted on the plate current flow, and a stronger impulse is sent through the internal grid-to-plate capacity around the plate circuit to further strengthen the grid potential. This feedback action continues; and when enough energy (from the B-power supply) is fed into the grid circuit to cover all losses, self-oscillation sets in, and the current oscillates through the system at a frequency that is determined by the tuning of the circuit "LC". This oscillation persists whether the incoming signal voltage continues or not.

HOW THE SQUEALS AND HOWLS ARE PRODUCED

A small amount of regenerative feedback as just explained is quite beneficial, for it increases the sensitivity of a receiver and raises the amplification gain, thereby improving the general performance of the set. An excess amount, however, seriously interferes with the good performance of a set; it may result in bad distortion and cause very unstable and erratic operation.

If the tuning of the circuit "LC" is adjusted so that its frequency varies from that of the incoming signal voltage, the locally generated oscillations will heterodyne with the incoming signal and form a difference or beat frequency. This beat frequency is then heard usually as a high pitched whistle. As the tuning is varied, the beat frequency also varies, and the pitch of the whistle changes from a high shriek barely audible down to a low rumble. It is these squeals and howls that are heard when an improperly adjusted set is being tuned.

In a two-stage or three-stage radio frequency amplifier it is very important that the successive stages be adjusted so that they operate together in perfect synchronism, that is, they must all be tuned to exactly the same frequency. For example, if in a 2-stage amplifier the first stage is tuned exactly to the frequency of the incoming signal, the signal is amplified and sent on to the second stage. If this second stage is in an oscillating condition and detuned slightly from the frequency of the incoming signal, a difference or beat-frequency results and manifests itself as a whistle or howl. The same condition would result if the first stage were not in tune with the incoming signal.

To operate a 2-stage or 3-stage radio-frequency amplifier satisfactorily, it is necessary that each stage be tuned to exactly the same frequency. Such a condition is generally established in practice by sending a signal from a calibrated oscillator through the receiver and adjusting the trimmers on the tuning condenser until maximum output is obtained, as indicated by some form of output meter. This process of adjusting the successive stages of a radio-frequency amplifier into exact step with each other is called aligning, and is explained in detail in a subsequent lesson.

HOW TO COUNTERACT THE TENDENCY TOWARD OSCILLATION

Since free oscillations in a radio-frequency amplifier are the result of an internal feedback action that causes a parasitic current to circulate through the system, the tendency to oscillate can be combated in several ways. One is to neutralize or counteract the internal feedback action by means of an equal but opposite feedback through an external coupling agent across the grid and plate. This is the operating principle of the Hazeltine Neutrodyne, a circuit system that was very popular in the earlier days of the tuned radio-frequency receiver.

Another method is to introduce resistance losses into the amplifier system so that the feedback current cannot increase to disturbing proportions. Various types of absorption circuits were developed for this purpose as will be brought out in the discussion of commercial circuits later on.

The third way is to cut down the internal grid-to-plate capacity so that the internal feedback action is reduced to a minimum. This is the principle employed in the modern screen grid and pentode tubes. In these tubes the internal capacity effect is reduced through the aid of an additional electrode, the screen grid, mounted between the grid and plate. The feedback action is thus practically eliminated and more stable operation is secured. But multi-stage radio-frequency amplifiers must still be properly aligned, even though screen grid tubes are used. The earliest screen grid radio-frequency amplifier was the No. 24A tube and this was followed by the No. 35 tube, both of which were used in large numbers in commercial sets.

OSCILLATION CONTROL WITH A BIASING POTENTIOMETER

A system of oscillation control that was used in many early tuned radio frequency receivers was to control the grid bias of the "R.F." amplifier tubes by means of a potentiometer (200 to 400 ohms) connected across the filament circuit. With the grid return to the moving contact at "P" as shown in Figs. 4 and 5, the potential of the grid with respect to the filament can be varied.

As the potential of the grid is made less negative, the tendency of the tube to oscillate becomes less, but the amplification is also diminished. If the potential becomes positive, all oscillation can be eliminated though amplification is greatly minimized. With a positive grid potential, the grid to filament path of the amplifier tube acts as a leakage path around the tuning condenser, for the electrons coming from the filament are free to go directly to the positive grid. This of course dampens all oscillations. It is thus an easy matter to control the potential of the grid and dampen all oscillations. But the tendency of the tube to oscillate varies with the wave length received, being greater at the short wave lengths (higher frequencies). With each wave length adjustment the potentiometer can then easily be set for minimum damping so that the tube can be brought right up to the point of oscillation but not allowed to spill over. In such a case, however, a strong signal will readily cause the tube to spill over and this adjustment will have to be gone through again.

The objection to this potentiometer control is that the high resistance introduces too many losses and greatly broadens the tuning and decreases the operating efficiency. This defect is overcome somewhat by using a by-pass condenser to by-pass the radio frequency currents so that they do not have to pass through the potentiometer windings. This condenser should have a capacity of .002 Mfds. Sometimes a high resistance rheostat is connected directly in series with the grid return of the amplifier tube. This increases the resistance of the grid circuit and lowers its efficiency so that oscillations cannot take place.

THE NEUTRODYNE RECEIVER

The neutrodyne is a type of tuned radio frequency receiver in which the internal plate to grid capacity of the tube is compensated or neutralized by means of an external condenser connected across these two elements. The general circuit arrangement of an early 5-tube neutrodyne is illustrated in Fig. 10. It consists of two stages of neutralized tuned radio frequency amplification, a detector and two stages of audio frequency amplification. The two radio transformers consist of two closely coupled coils, a primary and a secondary, the former consisting of 9 turns and the latter of 68 turns shunted by a .00035-Mfd. condenser. The secondary is tapped at the fifteenth turn from the filament end, and from this tap is connected a small variable condenser directly to the grid of the preceding tube. Frequently the radio transformers were known as neutroformers and the small neutralizing condensers as neutrodons.

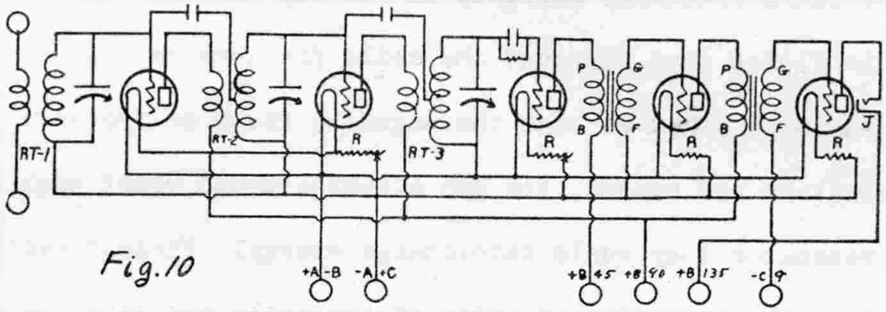


Fig.10

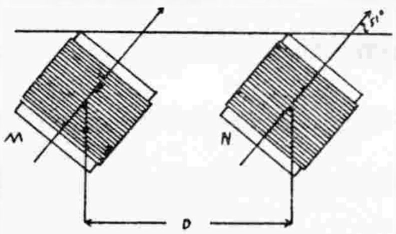


Fig.11

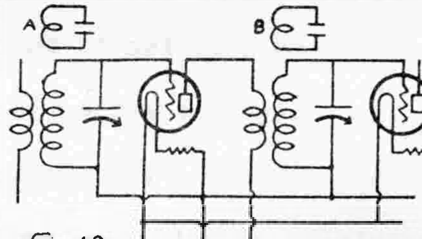


Fig.12

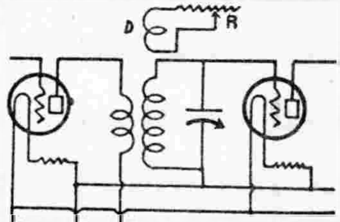


Fig.13

Fig. 10 and 11. The Neutrodyne Circuit and methods of coil mounting illustrated.

Fig. 12 and 13. Several types of absorption circuits for controlling oscillations in radio frequency amplifiers.

The action of the radio frequency amplifier is as follows: The antenna tuner is first tuned to the frequency of the incoming waves, and then the two coupling transformers are tuned into resonance. When this condition is attained, internal feed-back or regeneration takes place and violent oscillations come into action. The plate current in flowing through the primary of "RT-2" induces a current in the secondary, part of which flows through the neutralizing condenser to the grid of the tube. Now if the neutralizing condenser is adjusted to the correct value, the charge through it will be exactly equal to but opposite in phase to the charge being sent through the internal capacity of the tube, and the two charges will neutralize each other. The same condition will occur with respect to the second amplifier tube. When such a circuit is properly neutralized, each stage of amplification can be tuned into perfect resonance and no oscillations will occur.

In order to prevent interstage coupling between the coils or neutroformers of a receiver of this type, these units were mounted at an angle of 51° with the horizontal as is illustrated in Fig. 11. The reason for this can readily be seen if it is recalled that the radio frequency currents in flowing through these coils set up pulsating magnetic fields that surround the coils for considerable distances. If the two coils were near each other so that the magnetic field of the first could influence and induce a current in the second, the two circuits would react upon each other, and when tuned into resonance they would interchange energy. Violent oscillations would again result. Also, the two adjacent sides of the coils act like the plates of a condenser causing capacity coupling in addition to the magnetic coupling just explained. To prevent such interference, the coils must either be placed at such an angle that this coupling effect will not take place, or they must be placed far enough apart that the effect will be negligible.

Two coil arrangements are possible in order to eliminate this interstage coupling. One is to mount all three coils at right angles to each other; the first coil in a vertical position, the second horizontal and parallel with the front panel, and the third horizontal and at right angles to the panel. This coil arrangement is used in a number of commercial sets and is very effective.

The other arrangement is to mount the coils at the angle illustrated in Fig. 11. It can be proven mathematically that in this position the fields of the coils will not react upon each other. The distance "D" between the two coils should not be less than six inches so that the two coil sides "M" and "N" do not face each other, thus avoiding capacity coupling. It may seem that this is paying too much attention to minor details, but radio frequency currents are rather unstable, and unless conditions are made as favorable as possible for their operation, troublesome disturbances are bound to result.

THE PROCESS OF NEUTRALIZING

The method of connecting the neutralizing condensers into the circuit is illustrated in Fig. 10. The neutralizing process is really a simple one if it is done in the following systematic way. A strong local station is tuned in to its loudest point, and after the first radio frequency tube is removed from its socket, all dials are again turned until the signal is at its loudest point. A piece of paper is then placed over one of the filament prongs and the tube is returned to its socket. It will be found that the signal can still be heard, though somewhat faintly. The neutralizing condenser is then adjusted until the signal entirely disappears or is at its weakest point. In this condition the internal tube capacity is neutralized. The paper is then removed and the tube again returned to the socket as originally. The very same process is repeated with the second radio frequency tube.

After these adjustments have been properly made, the neutralization is permanent and need not be touched again. However, if at some future time the tubes are removed, they should always be returned in the same order in the radio frequency stages. If a tube burns out and must be replaced by a new one, that stage should again be neutralized, for the internal capacity of no two tubes is exactly alike. A properly neutralized neutrodyne will operate noiselessly and free from squeals and whistles. Only good neutralizing condensers should be used; that is, condensers that will not vary in capacity or adjustment in the course of time.

CONTROLLING OSCILLATIONS BY ABSORPTION METHODS

There are a number of oscillation control systems that operate on the absorption principle, that is, the excess energy that tends to set up free oscillation is absorbed as inductive losses in special auxiliary circuits. Although these circuits operate at a slightly reduced efficiency, the control systems are rather effective and render very stable operation possible.

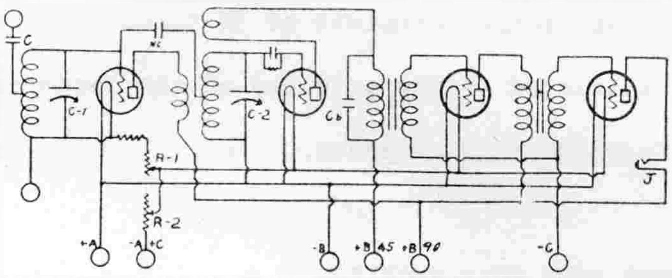
The early Freshman 5-tube tuned radio frequency set, for example, used a form of basket weave coil mounted directly on the condenser. The condenser end plates are of metal, and the magnetic flux set up by the current flowing through the coil induces eddy currents that dissipate the excess energy in the form of resistance losses in the metal. The coils must be mounted at just the right distance from the end plates, for if they are too close, too much energy will be absorbed and the signals weakened, and if they are not close enough not sufficient energy will be absorbed and the tubes will oscillate and cause howling and squealing.

Two other absorption systems are illustrated in Fig. 12 and 13. In the first there are small auxiliary coils "A" and "B" inductively coupled to the secondary coils and shunted by a small fixed condenser. Currents induced in these coils dissipate the excess energy and in this way prevent oscillations. In Fig. 13 the principle employed is very similar, except that the auxiliary coil is connected in series with a variable resistance. Each, of course, is a wasteful process, but each is effective in damping oscillations. The number of turns in these auxiliary coils and the distance that they are mounted from the secondaries, depend upon the design and construction of the secondaries and can be determined only by experiment. Another simple but effective method is to employ a small coil of 3 or 4 turns mounted near the secondary. The ends of the coil are connected together, and when the coil is at the proper distance from the secondary, just enough current is induced in the shorted coil to dissipate the excess energy that would otherwise appear as self-oscillations.

THE BROWNING-DRAKE RECEIVER

The earliest radio-frequency receivers (battery operated) employed a tuned radio amplifier stage ahead of a regenerative detector, which in turn was followed by two stages of transformer coupled audio amplification. A very popular receiver of this type was the Browning-Drake, which was first sold in kit form and later as a factory built set. A new feature in radio-frequency design that first appeared in this receiver was the bunched winding employed in the primary of the "R.F." transformer. This bunched winding permitted the use of more turns of wire and therefore greater transference of energy to the secondary, and also eliminated much of the distributed capacity effect that otherwise existed between the parallel windings of the primary and secondary.

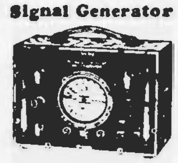
The circuit diagram of the Browning-Drake receiver is illustrated in Fig. 14.

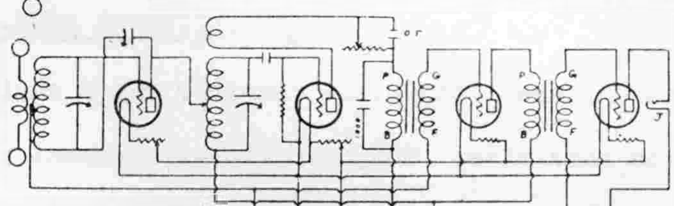


THE BROWNING DRAKE RECEIVER

Fig 14

Signal Generator





THE UNIVERSAL FOUR-TUBE RECEIVER

Fig 15

Fig. 14 & 15. Two early receivers consisting of a regenerative detector preceded by a tuned radio frequency stage.

Four tubes are employed with a common filament supply controlled by a master rheostat R-2. An additional rheostat R-1 for controlling the filament of the "R.F." tube only, serves as a volume control. The neutrodyne system of neutralizing the internal grid to plate capacity of the "R.F." tube is employed. The detector is regenerative, regeneration being controlled by means of a rotating feedback coil or tickler at the grid end of the secondary.

The antenna coil consists of 50 turns of No. 20 "D.S.C." wire wound on a piece of 3" bakelite or hard rubber tubing. The coil is tapped at the center so that in case a very long antenna is used it can be connected to this tap. A .0005 Mfd. (23-plate) condenser is connected across the coil for tuning purposes. The "R.F."

couplin- unit, known commercially as a regenaformer, consists of 77-turns of No. 20 "D.S.C." wire wound on a piece of 3-inch tubing about 5-1/4 inches long. A tap is ken off at the fourteenth turn for the neutralizing condenser, and the entire secondary is shunted by a .00035 Mfd. (17-plate) condenser for tuning. The primary is made by winding 24 turns of No. 30 "D.C.C." wire in jumble fashion in a slot 1/4 inch deep and 1/8 inch wide cut into a round wooden disk that will fit snugly into the 3-inch tubing. The primary should be mounted directly under the first turn of the secondary at the low potential end, that is the end that is connected to the negative side of the filament. The rotor or tickler consists of 30 turns of wire wound on a piece of 2-inch tubing. It is mounted at the grid end of the secondary on a shaft that extends through the panel for adjusting purposes.

THE UNIVERSAL FOUR-TUBE RECEIVER

The Universal four-tube receiver was a similar set that made its appearance at about the same time. This circuit arrangement is illustrated in Fig. 15.

It consists of a balanced stage of tuned radio frequency amplification and a regenerative detector, regeneration being controlled with a 50,000-ohm variable resistor connected in series with a fixed tickler coil. Two stages of transformer-coupled audio frequency amplification are employed. A common filament supply is used with fixed ballast resistors for the two audio tubes. A master rheostat controls the "R.F." and detector tubes, and an additional rheostat is used in the "R. F." stage which is intended primarily as a volume control.

The coils were constructed according to the following specifications. The antenna coupler consists of a primary of 7 turns and a secondary of 68 turns, both being wound on a 3-inch bakelite or hard rubber tube. The secondary is tapped at the center as illustrated in Fig. 15, and is shunted by a .00035 Mfd. (17-plate) condenser for tuning. The regenerative radio frequency transformer also consists of two coils wound with No. 24 wire on 3-inch tubing. One coil consists of 68 turns with a tap at the center to which is connected the plate of the radio frequency tube. It is also shunted by a .00035 Mfd. condenser for tuning purposes. The tickler is separated by about one-eighth inch and consists of 21 turns. The remainder of the circuit is all of standard construction. It should be noticed, however, that the grid leak is connected from the grid directly to the positive side of the filament.

PLATE RESISTANCE CONTROL OF OSCILLATIONS

Another very effective way of controlling self-oscillations in a radio frequency amplifier is by means of a variable high resistor connected in series with the plate circuit of the radio frequency tubes. Such a resistor controls the amount of energy that is supplied to the tubes, and permits an "R.F." amplifier to come to the point of oscillation where it operates at maximum sensitivity but prevents it from spilling over. Such a plate resistor can also be used as an effective volume control.

The general circuit arrangement of a 5-tube tuned radio frequency receiver employing such plate resistance control is illustrated in Fig. 16.

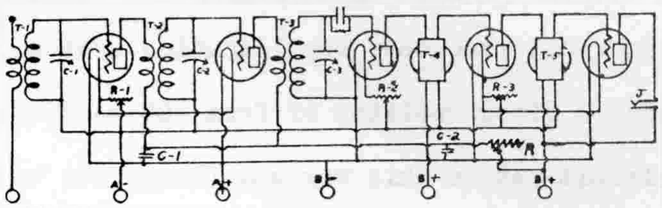


Fig.16

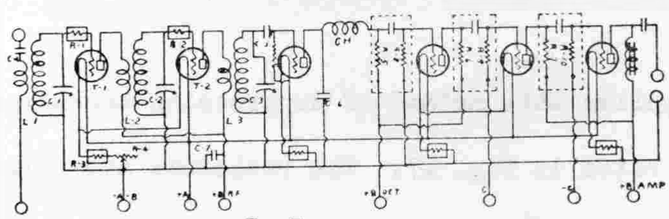


Fig.17

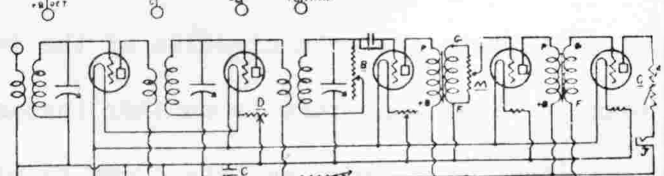


Fig.18

Fig. 16, 17 & 18. Three early tuned radio frequency receivers.

Here it will be seen that the plate circuits of the two radio frequency tubes after passing through the primaries of the tuned transformers lead directly to a variable resistance "R", the sliding contact of which is connected to the positive terminal of the B-battery. This variable resistance, which should have a value of 200,000 ohms, serves to vary the voltage applied to the plates of these tubes. It limits the radio frequency voltage that builds up in the plate circuit and avoids the feed-back through the capacity of the tube which causes oscillation. As the resistance is varied, the direct plate voltage is reduced and this decreases the instantaneous voltage differences between the plate and the grid, thus curbing oscillation.

Two large bypass condensers, C-1 and C-2, lead the radio frequency currents from the primary of the coil back to the negative filament of each tube. Therefore, there is no resistance in the radio frequency circuit and the sharpness of tuning is not affected. These bypass condensers should have a capacity of 0.1 Mfd. The remainder of the circuit is of standard construction.

THE GRID SUPPRESSOR METHOD OF OSCILLATION CONTROL

Another very effective scheme and one that was adopted by very many commercial set manufacturers for controlling oscillations in radio frequency amplification systems, is the grid suppressor method. In this method a fixed resistor of from 200 to 700 ohms or more is placed in series with the grid circuit and in this way stabilizes the radio frequency circuit.

A circuit in which is applied this method of suppressing undesirable radio frequency oscillations is illustrated in Fig. 17. The resistors are here shown as R-1 and R-2 connected into the grid circuits of the two radio frequency tubes T-1 and T-2. It would seem at first that this is another instance of the so called "loser system" in which sufficient resistance is introduced to prevent the oscillations from occurring. But this is not quite the case, for the resistors here serve to prevent the flow of currents in the grid circuits. If the resistances are of the correct value, and are constructed as to have a very low capacity, there is really no loss in the circuit except the loss of the undesirable grid currents which excite the oscillations.

An important feature of this suppressor method of oscillation control is the fact that it permits practically uniform radio frequency amplification over the entire wavelength range, because the radio frequency resistance of these suppressors automatically increases with the frequency. This means that at the higher frequencies (short wavelength) where the tendency toward oscillation is greatest, the resistance increases sufficiently to prevent the flow of current in the grid circuit. Also, at the lower frequencies (higher wavelengths) the resistance decreases so that the point of oscillation can be more nearly approached. It is thus evident that the suppressor method affords good sensitivity at both the lower and higher frequencies. It is at the higher wavelengths (especially over 500 meters) that many control systems so affect the sensitivity that few stations can be tuned in on this section of the dials.

The exact value of grid suppressor to use depends upon the characteristics of any individual circuit. Grid suppressors are available in values ranging from 100 to 1800 ohms, and the best rule to follow is to use the lowest value that will satisfactorily suppress oscillations. It is an easy matter to install these grid suppressors in an old tuned radio frequency receiver that has no provisions in it for oscillation control, for it is necessary only to open the grid circuit at the socket terminal and to insert the suppressor similar to the manner in which a grid leak would be inserted.

An excellent 6-tube circuit employing the grid suppressor method of oscillation control, is illustrated in Fig. 17. As can be seen, the circuit consists of two stages of tuned radio frequency amplifications, a detector and three stages of resistance-coupled audio amplification. The circuit is a good one for selectivity and tone quality and is not costly to build. It can be made entirely free from all oscillating howls and squeals.

In the two tuned radio frequency stages the suppressors R-1 and R-2 are used in the grid circuits to dampen or suppress oscillations. Resistors of 600 ohms will serve very well, although in some sets it will be possible to use considerably lower values to good effect. The coils L-1, L-2 and L-3 consist of three high grade radio frequency transformers tuned by means of three 0.00035-Mfd. variable condensers C-1, C-2 and C-3.

The filaments of the two radio frequency tubes are controlled by means of a single ballast resistor labeled R-3 in the circuit and in series with this ballast is a 6-ohm rheostat R-4. This rheostat acts both as a delicate adjustment for the tubes when tuning in distant stations and also as a very efficient volume control. The detector circuit is of standard form using a 0.00025-Mfd. grid condenser and a 2-megohm grid leak. Into the plate circuit of the detector tube is connected a radio frequency choke coil "CH" to keep the radio frequency currents out of the audio amplifier. These radio frequency currents are then by-passed to the negative side of the filament through the 0.0005-Mfd. fixed condenser C-6. A fixed condenser C-4 of similar capacity is connected in series with the antenna to sharpen the tuning and to reduce interference. A 1-Mfd. condenser C-7 is used across the battery terminals to by-pass the radio frequency currents across the B-battery. The audio amplifier consists of three stages of resistance coupling, each coupling unit consisting of a plate resistor, a blocking condenser and a grid leak.

VOLUME CONTROL METHODS USED IN EARLY T. R. F. RECEIVERS

The function of the volume control in a radio receiver is to adjust the level or intensity of the output to the requirements of the room or place where the receiver is being used. A good volume control consists of a device that is easily adjustable and that can be inserted somewhere in a radio circuit so that by a continuous and smooth variation the volume can be regulated to any desired intensity. It is also important that this volume control device be so connected that the changes in volume will not introduce distortion or affect the tonal quality.

The earliest and simplest method of volume control used was the familiar potentiometer. With the potentiometer the volume was decreased by gradually bringing the grid of the tube to a positive potential. This method had two serious objections. As the grid of the tube becomes positive, the plate current increases greatly and this puts an excessive drain on the B-battery. A positive grid also causes grid currents to flow, and these in turn cause unpleasant distortion. Another scheme used was to control the brilliancy of the audio frequency amplifier tubes. The objection to this method was that as the filament temperature changed, the operating characteristics of the tubes were also altered and distortion again set in.

The better and more commonly used methods of volume control are all illustrated in the circuit diagram shown in Fig. 18.

The scheme shown at "M" is applicable to practically any receiver. Here the amount of energy supplied to the grid of the first audio tube is controlled or regulated by means of a 500,000-ohm variable resistance sometimes known commercially as a modulator. The modulator has three terminals, the outer two being connected to the grid and the filament terminals of the first audio transformer, while the center or sliding contact is connected directly to the grid of the tube. As the slider is moved toward the grid terminal of the transformer, the volume is increased; and moving it in the opposite direction decreases the volume. This method is a very good one, in that it permits a smooth control and does not introduce any appreciable distortion.

Another method is illustrated at "A". Here we have a variable high resistance (200,000 ohms) connected in series with the radio frequency plate battery supply. By increasing the resistance, the plate voltage and also the radio frequency amplification are reduced. This method is a very good one for several reasons. By regulating the amount of energy fed to the detector, it prevents overloading of this tube, which in turn reduces the possibility of distortion. On account of the low grid potentials, the plate currents cannot easily be distorted even though the plate voltages are reduced greatly.

A third method of volume control is shown at "B". In this case, a 50,000-ohm non-inductive variable resistance is connected across the secondary of the second radio frequency transformer and regulates the amount of energy that is supplied to the detector. It is very important that this resistor have a complete "off" position, as otherwise trouble may be experienced in bringing in very weak stations. Contrary to what might be expected, this volume control does not broaden tuning, for the resistance is too high to have any appreciable effect in this way.

At "C" we have a variable 500,000-ohm resistance connected in series with the output circuit of the last tube. Although this is a very effective method, it is not quite as satisfactory as the previous methods. The resistor regulates the entire output, but no provision is made to prevent the overloading of any of the tubes in case exceedingly powerful signals are being received.

Another efficient method of volume control and one that was used by many, is illustrated at "D". The general tendency in receivers was toward the use of fixed rheostats with all tubes. However, a variable rheostat controlling the filament of the first radio frequency tube at the same time forms an efficient volume control. It regulates the amount of energy supplied to all the successive tubes and does so without the least danger of introducing distortion or of influencing the performance of any of the other parts of the receiving circuit.

It is not a difficult matter to add any of the above described methods to a ready-built receiver. If the set is of the tuned radio frequency type, the use of a 200,000-ohm plate resistor is recommended, for this at the same time acts both as a volume and oscillation control. Of course, it is very important that suitable by-pass condensers be used as a shunt around the high resistance for the radio frequency currents, as otherwise the operating efficiency would be greatly impaired.