NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

NRI

Radio-Trician
(Trade Mark Reg. U. S. Patent Office)

Lesson Text No. 13
(2nd Edition)

RADIO FREQUENCY AMPLIFICATION

Originators of Radio Home Study Courses
··· Established 1914 ···
Washington, D. C.

SOME GOOD STUDY HABITS

A Personal Message from J. E. Smith

The Habit of Forming New Habits. There is such a thing as getting in the way of making and breaking habits at will. Happy is the man who can do this. It requires wonderful control to be able to say to some strong habit, "Now cease, be still for a while," or to call into play some new habit on a short notice. This can be done. It is nothing to be amazed at. All you need to do is to practice the art for a while. Try breaking off an old habit and forming a new one occasionally just to show yourself that you can.

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Radio-Trician's

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

RADIO FREQUENCY AMPLIFICATION

As you have learned at an earlier stage in this course in practical radio, there are several main parts to a radio receiver. These main parts are (1) **the radio frequency amplifier,** (2) **the detector,** (3) **the audio frequency amplifier,** and (4) **the reproducer.** In this lesson we are concerned with the radio frequency amplifier only. The general arrangement of these various parts in a radio receiver is shown in figure 1. The radio frequency amplifier strengthens the signals before they reach the detector, the latter changes them so that they are put into a condition to be heard.

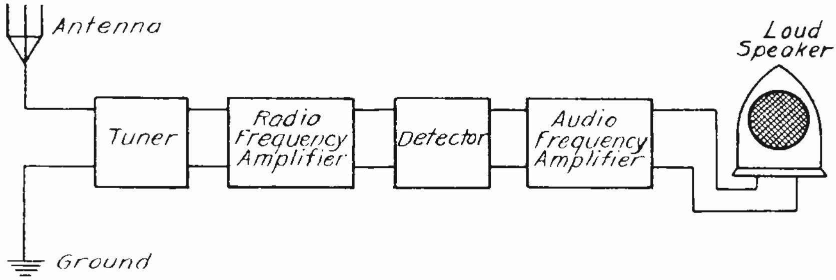


Fig. 1—General arrangement of parts in a Radio Receiver.

The radio frequency oscillations, as the term implies, have a frequency extremely high. They could by no means operate a loud-speaker, or, even if they could, the human ear could not respond to them. So it is the duty of the detector to modify them; we say the detector rectifies them; and in the output circuit of the detector we have such a kind of current flowing that can operate a loud-speaker.

Now, unfortunately the detector acts poorest when we need it most. The response of a detector to a signal is strong on a strong signal and weak on a weak signal. That is to say, the response of a detector varies as the square of the signal voltage applied to its input. For the sake of example, suppose we impress on the input of the detector a signal whose strength is 2. Then suppose we double the signal to 4. The response of the detector (that is, its alternating plate current) will then not be doubled but quadrupled, that is, increased four times. Suppose we double the signal again, or make it 8 times as strong as it originally was. The response will then be increased 64 times.

Or, if we look at the thing the other way, if the signal is cut in half, the response is cut in quarter; if the signal is cut to 1/8 its original strength then the response is cut to 1/64th of its original value. So you see, that in order to get as much as possible out of the detector, it is necessary to amplify the signals before they reach the detector; this places a much larger signal voltage at the input of the detector than would be there if we had no radio frequency amplifier.

The great advantage of using a radio frequency amplifier before the detector can be easily understood when we consider the output of the detector. The sensitivity of a radio receiver depends mainly upon the voltage which comes to the detector input, for there is a certain limit to the amount of audio frequency amplification which we can place after the detector. Suppose we add one stage of radio frequency amplification preceding the detector, and this stage amplifies the radio frequency signal voltage four times. Then on account of the square law of the detector, the over-all sensitivity of the receiver is increased **16 times!** Or, if we add two stages, having an amplification of 4 each, then the total sensitivity of the receiver is increased (16x16) or **256 times!** With such remarkable gains in sensitivity obtained when we add radio frequency amplification to a receiver, there is hardly any need of further explaining why it is used in all the up-to-date receivers.

Of course, as we hinted before, it might be possible to increase the amplification by using more stages of audio frequency amplification, but also as we have said before, it is not generally advisable to use more than two or three stages of transformer coupled A. F. amplification or three stages of impedance coupled amplification. The reason for this is that when such a great amount of A. F. amplification is used it is difficult to keep the system in a stable condition. Howling or audio frequency oscillations are generally set up, and is very difficult to control. It is much easier to add an extra stage of R. F. amplification, and when we do this we have the added advantage of increasing the selectivity of the receiver. Every stage of R. F. amplification added means another tuning circuit added to the receiver, and the more tuned circuits the more selective the receiver becomes. So, viewed from every angle the addition of R. F. stages to a receiver is a very good thing to do. There is one other feature which we must not omit, however, before we go further, and that is, with one exception, the addition of R. F. amplification to a receiver does not introduce additional distortion in the signals, as would the addition of more A. F. stages. The exception which we mentioned is where regeneration is used. Regeneration may spoil the quality of reproduction; we shall learn more about regeneration later on in this lesson.

Now we must begin discussing the radio frequency amplifier in detail. There are many different circuits for the radio frequency amplifier, but as you have learned before, all these circuits are based on the same fundamental circuit of the electron

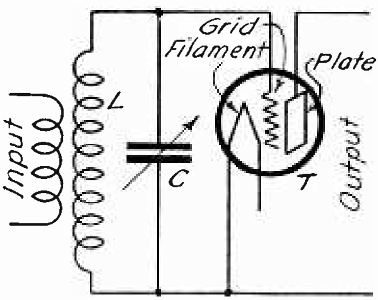


Fig. 2.

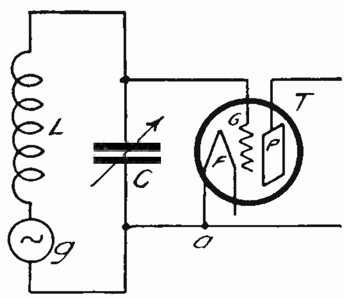


Fig. 2-A.

tube. There is a tuned input to the tube, and the output of the tube may be tuned or untuned, according to how and where in the circuit it is employed. Look at figure 1. This shows the location of the radio frequency amplifier in the receiver, and in figure 2 we have one stage of this amplifier shown in detail. For the purpose of simplicity we have omitted the various batteries, but you must remember that there is always a "B" battery supply connected to the plate of the tube, and there is always an "A" battery required to light up the filament of the tube. There are various ways of connecting these batteries, however, which we will discuss later on.

In figure 2 the signal voltage is impressed upon the R. F. stage at the left. It passes into the tuned circuit which includes the coil L and the condenser C; this tuning circuit allows us to **tune** the system to the frequency of the signal voltage, or to separate the particular signal we want to listen to from other signals which have different frequencies or different wavelengths.

Now, before we go any further, **I** want you to get into your head one thing—and be sure that you never forget it. This thing is a source of constant trouble to most students, and it is for that reason that we want you to be sure to get the idea right. It is—the secondary circuit, that is the tuned circuit, is **NOT A PARALLEL** circuit, it **IS A SERIES** circuit. You are, no doubt, surprised to hear this, for it is easy to see that the circuit looks as if the condenser C and the coil are connected in parallel across the grid and filament of the tube. But this is only the **looks** of the things. You must remember things are not always as they seem.

Let us see why it is a series circuit and not a parallel circuit. In the first place, you must realize that the voltage in the secondary coil is **induced** in it by the current in the primary input circuit. A magnetic field established by the current in the primary links the turns of the secondary winding and creates in the latter a similar alternating voltage. Now, whenever a voltage is **INDUCED** in a coil, it is always considered as in **series** with that coil. For this reason then the secondary circuit of figure 2 can be pictured as in figure 2A, where the voltage **induced** in the secondary is **represented** by the alternating current generator g. Then g, L and C are all in series, and we take the voltage across the terminals of the condenser, to operate the electron tube T.

The circuit shown in figure 2 is the one which is used in almost all radio frequency amplifiers. The way in which two tubes are joined together by means of this R. F. transformer, or **resonance transformer** as it is more properly called, is shown in figure 3; the batteries have again been omitted for simplicity. In studying the diagrams of radio frequency amplifiers, it must never be forgotten that the main circuits to consider are those which carry the radio frequency currents. For this reason it is more or less immaterial in what way the batteries are connected to the circuit, just so we keep the radio frequency circuits complete. Of course there are other things which we shall consider one by one as we come to them, but for the present the R. F. circuits are the main things.

It is on account of this that we have so far in this lesson omitted the batteries. We shall now consider the various ways in which the batteries are or may be connected to radio frequency amplifier circuits. Let us consider the "B" batteries first. In the first place what we require wherever we use an electron tube is that the plate be at a rather high positive potential compared with the filament, or rather, compared with the point of the filament to which the input circuit is connected. In figure 3 this point is "a." It is called the **grid return connection,** because, going over the input circuit starting at the grid, we leave the tube at the grid, pass around through the tuned circuit, and **return** to the tube at the point "a."

Now, we have said that what we require is that the plate be at a high positive potential compared with this point called the grid return point. How we obtain this condition of affairs is not so extremely important. You will see what we mean in a moment. Look at figure 4. In that illustration we have shown two radio frequency amplifier tubes, and these R. F. amplifiers are

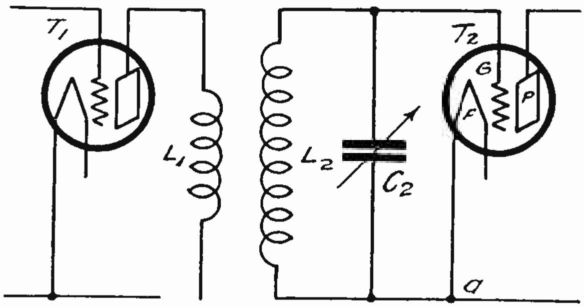


Fig. 3.

exactly the same in every respect as regards the circuits which carry the radio frequency currents. They differ only in the way in which we apply the potentials to the plates of the tubes; that is, in the way in which we connect the "B" batteries to the circuits.

In figure 4(A), for instance, we have connected the "B" batteries in series with the coil in the plate circuit, and we have connected a by-pass condenser across the battery. This by-pass condenser is fairly large, having a capacity of perhaps 0.006 microfarad or larger, so that the reactance or opposition it offers to the radio frequency currents in the plate circuit is very small. In fact, it is in most cases small enough to neglect. The radio frequency currents therefore pass around the plate circuit through the coil L and the condenser C, but do not pass through the "B" battery.

Now, in the circuit of figure 4(B) we have the "B" battery connected in series with a **radio frequency choke coil** marked Z, and the two connected directly to the plate and filament of the tube. The radio frequency choke coil offers very large reactance, or opposition, to the radio frequency currents which flow in the plate circuit of the tube, so that no radio frequency currents can flow through it or through the "B" battery. They travel through the coil L in the plate circuit.

So you see, as far as the radio frequency currents are concerned, the two circuits are exactly alike. In 4(A) the by-pass condenser C is connected across the "B" battery for by-passing the radio frequency currents, and in 4(B) the choke coil prevents the flow of radio frequency currents through the "B" battery. But in both cases the circuits of the R. F. currents are the same,

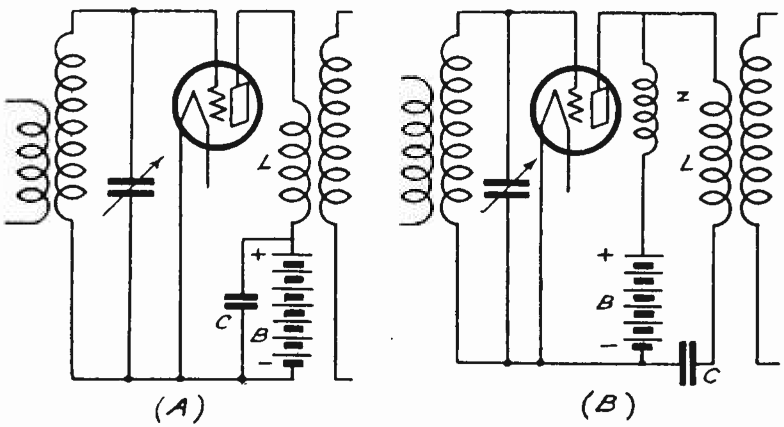


Fig. 4.

and also in both circuits we get the positive potential of the "B" battery on the plate of the tube, and the negative on the filament. You will note, however, that we have placed a condenser C in series with the coil L, in figure 4(B). If this condenser were not here, as far as the direct current coming from the "B" battery is concerned, the "B" battery would be short-circuited, and would be ruined. Therefore this **blocking condenser** C is required.

In order to show you how all this works out in a regular circuit, we have drawn the two circuits of a two-stage radio frequency amplifier in figure 5. Figure 5(A) uses the method employed in figure 4(A), and figure 5(B) uses that employed in figure 4(B). The first method is called the **series connection** and the second is called the **shunt connection.** It is clear why we use these names; in the first method we connect the "B" battery in series with the load (or coil) in the plate circuit, and in the second method we connect it in **parallel** with the load. Where it is in series figure 5(A) we must use a by-pass condenser. A by-pass condenser has been drawn in each stage; they are marked C1 and C2. But you must note that these two condensers, drawn

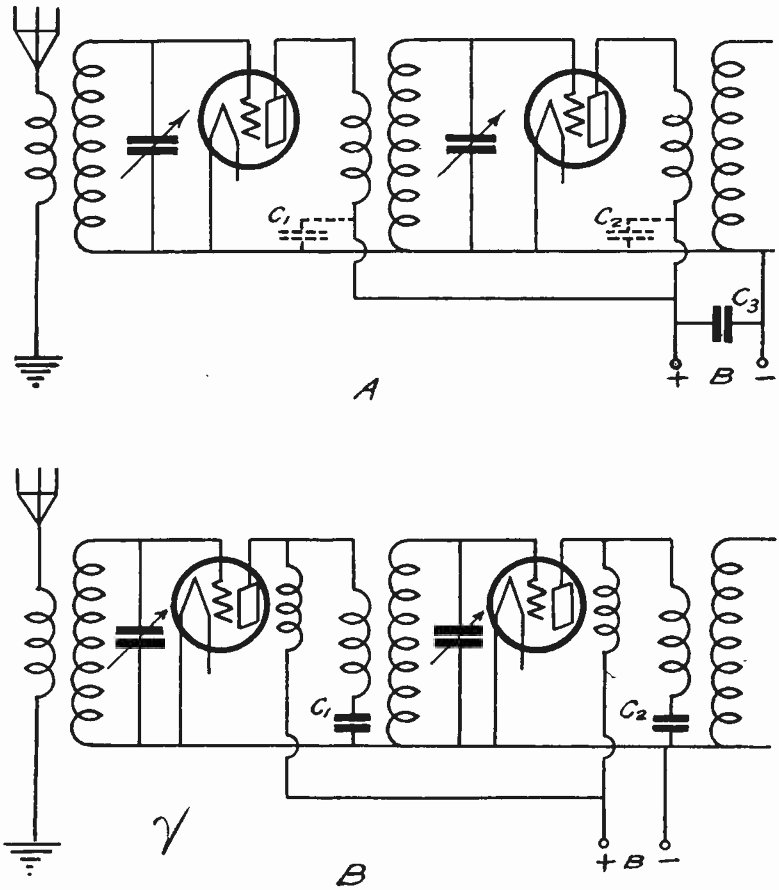


Fig. 5.

in broken lines, are in parallel with each other; they are both connected across the B+ and B— terminals. Therefore it is not necessary to use both; we can use one by-pass condenser, C3, making it a little larger than we would if we used two separate condensers.

In figure 5(B) we have the shunt connection of the "B" battery circuit. In each stage we have to use a blocking condenser and a radio frequency choke coil. Which of the two methods you use in designing a set depends on the conditions in the receiver, and the amount of money you want to spend. The shunt connection is probably more expensive than the series connection, but it has advantages which we will learn of later on. One of these advantages is that the blocking condensers need not be large, rarely being greater in capacity than about 0.0005 microfarad, whereas in the series connections the by-pass condenser must be rather large; in practice this condenser may range anywhere from about 0.006 to 1 microfarad.

Now, as regards the connections of the "A" battery, the way in which it is connected depends upon the receiver. Generally the negative terminal of the "A" battery is connected to the grid-return, and the resistance which controls the filament cur-

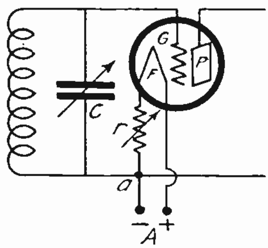


Fig. 6—Negative Bias.

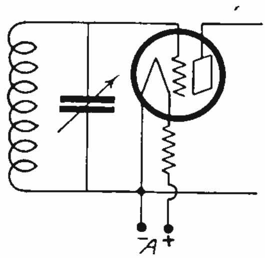
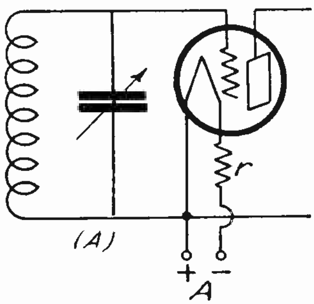


Fig. 7—Zero Bias.

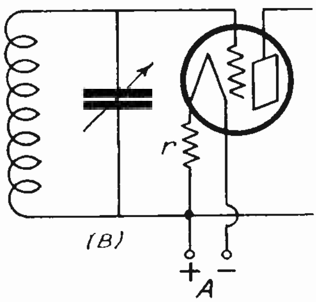
rent is also placed in this line from the "A" battery. The idea is illustrated in figure 6. The resistance r is the filament control resistance, or rheostat, and the grid-return is connected to the point a. The negative pole of the "A" battery is connected to the grid-return at a. The reason for this is that when we do this we have the grid G at a negative potential with respect to the filament F. That is, considering only the direct voltage which we get from the "A" battery, you will notice that the grid is connected directly to the minus of the "A" battery. The filament, however, is not connected directly to it. There is a certain drop of voltage in the rheostat. If we are using 201A tubes, the drop in the rheostat will be about 1 volt when we have it adjusted properly. There will be a negative bias on the grid therefore of one volt. By making the connections in this manner, the bias on the grid will keep the plate current low, and will make the receiver more sensitive. It becomes more sensitive because the negative bias on the grid prevents grid currents from flowing so there will be no power loss due to this cause.

There are many ways of varying the bias on the tube as illustrated in Figures 6, 7, 8. A zero or positive bias is very seldom used on amplifying tubes because it has a tendency to cause the tube to oscillate, while a negative bias decreases the tendency of the tube to oscillate. The amount of bias necessary to prevent oscillation will vary depending upon the type of circuit and tubes used.

In the illustrations given so far we have always shown two tubes connected together by means of a **radio frequency transformer,** generally known as a **resonance transformer.** In nearly all cases at the present time the secondary winding of the resonance transformer is tuned by means of a variable con-



Positive Bias.



Positive Bias.

Fig. 8.

denser. But it is not necessary to confine ourselves to this type of coupling. There are other ways of coupling two tubes together, just as you learned there were many different ways of coupling together two tubes in an **audio frequency** amplifier. The three main types of audio amplifier couplings were **transformer, impedance and resistance** couplings. In radio frequency amplifiers we may have the following types of coupling systems:

(a) Resonance transformer, which at present is generally tuned in the secondary.

(b) Impedance coupling; this is a special type of resonance transformer coupling, in which the resonance transformer takes the form of an autotransformer. **Choke coil** coupling also falls in this class.

(c) Resistance coupling, which at present is generally limited to wavelengths above 1000 meters.

You must remember that tuning must take place in the radio frequency amplifier stages and in the detector stage.

We cannot tune the audio frequency amplifier. The detector stage must be considered as a part of the radio frequency amplifier, for in all cases of class (a) and in most cases of class (b) the input of the detector is tuned, while the output is not. We shall see what this means as we go on.

A resonance transformer consists, as we have seen, of two windings, a primary and a secondary winding. It does not, as a rule contain an iron core, but has simply air for the core. The general circuit of a resonance transformer is shown in figure 9. At the left we have the input to the transformer circuit, where a voltage v is marked on the diagram. In the tube circuit this voltage v is the signal voltage which is developed in the plate circuit of the tube to which the resonance transformer is connected. In other words, we have a signal voltage applied to the input of the tube T1. This voltage is amplified in the first tube, and we have a larger voltage v developed in the plate circuit of T1. This causes a current to flow in the primary circuit (L1) of the resonance transformer, and this current **induces** a current in the secondary circuit. As the current flows in the secondary it establishes voltage across the terminals a and b of the condenser C2, and it is this voltage which operates the second tube T2.

We want the current in the secondary to be as great as possible, for this will make the voltage input to the second tube (that is across ab) large, as we will then have quite a lot of amplification in the system. In order to do this the secondary circuit is tuned to resonance by adjusting the variable condenser C2.

As we have said before, generally, only the secondary circuit is tuned, but there are circuits used occasionally which also have a condenser C1 in the primary of the resonance transformer circuit. We shall see why later on. You must note that when a condenser is placed in the primary circuit it is necessary to use the **shunt feed** method of connecting the "B" batteries (see figure 4B) whereas when there is no condenser in the primary you must use the series method (see figure 4A).

Now, in the circuit of figure 9, the closer we get the primary and secondary coils, L1, L2, the greater will be the amount of energy transferred from the primary circuit to the secondary. Or, what amounts to the same thing, we should use as great a primary winding as we can. A fair example of a resonance transformer as generally used would be a single layer of wire on a tube 3 inches in diameter having about 60 turns; the primary may be wound on a tube which just slips into the other, and may have perhaps 10 turns of wire. The wire might be No. 20 B. & S. gauge. Actually these dimensions may not always be used in any receiver; the number of turns and diameters of the coils differ considerable from one receiver to another. We only give these figures to give you an idea of their size.

If we want to increase the coupling between the primary and the secondary circuits, we may use more turns on the primary coil or place the primary coil L1 closer to the secondary coil L2. But there is something which will not permit us to use any number of turns we choose, but must use a certain number of turns in each receiver, and this something is called **regeneration.** We will learn about this before we finish this lesson.

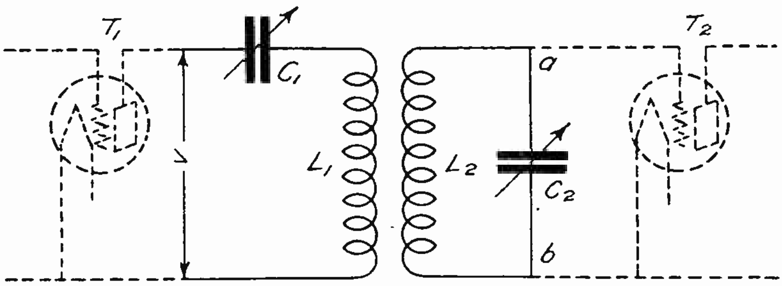


Fig. 9.

In the ordinary circuit, such as we see in figure 10, L1 is the primary coil of the resonance transformer coupling the two tubes. As this coil is made larger and larger by increasing the number of turns of wire, the **inductance** of the coil increases. At the same time, as we increase the inductance, the amplification increases and increases, until finally we reach a point where we hear a whistle when we try to receive a signal. When this happens the receiver is no longer acting as a receiver, but is acting as a low-power transmitter. The electron tube circuits of the receiver have begun to **oscillate.**

The oscillations thus established in the receiver interfere with the incoming signals, which you are trying to receive, and as a result, instead of hearing the incoming signals, all you hear is a loud whistle. This is called a **heterodyne** whistle, and is a **beat note** caused by the interference of the oscillations in the receiver and the oscillations of the incoming signal.

It is clear that the receiver must not be allowed to oscillate. For that reason we must keep the number of turns of wire in the primary so small that oscillations will not occur. This is what limits the design of the resonance transformer in the ordinary radio frequency amplifier.

The next question to answer, for we know you will ask it, is "What causes this increase of amplification, and why do the circuits oscillate?" The reason for these things is that the electrodes in the tube form little condensers. As you know, a condenser is formed by any two pieces of metal near each other. In the tube, for instance, we have the grid and the plate; these two are separated by a small distance. They form a small condenser. Likewise the grid and filament form a small condenser,

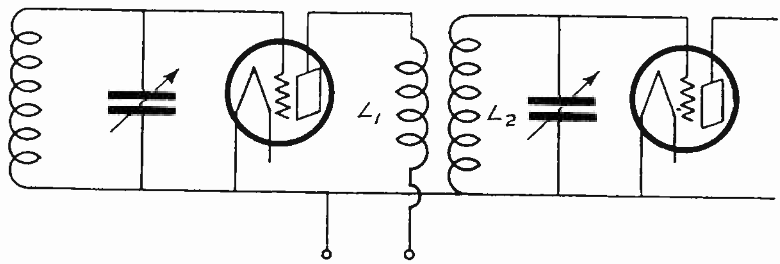


Fig. 10.

and again, the filament and plate form a small condenser. In other words, looking at figure 11, we have the effect in the tube, indicated by the condensers drawn with broken lines.

The most important of these small condensers formed by the electrodes of the tube is the capacity between the grid and the plate, for this capacity forms a connecting link between the output circuit and the input circuit of the tube. In the **ideal** tube there would be no such connecting link between the input and the output circuits. The alternating signal voltage impressed on the grid or input of the tube would **control** the alternating voltage of the plate circuit, but there would be no path by which power from the plate circuit could get back to the grid circuit.

On account of the amplification in the tube there is much more power in the plate circuit, so that some of this power can be **fed back** to the input circuit through the small condenser formed by the grid and the plate. Now, you remember that the input circuit, consisting of a coil and tuning condenser, has a certain amount of resistance, and therefore loses some of the power of the signal. The energy **fed back** from the plate circuit to the input makes up for part of this loss, so that the input circuit acts as if it were receiving more power from the signal. Consequently the amplification goes up.

Under some conditions the power fed back from the plate circuit to the input circuit may actually be greater than the power due to the signal. When this happens the receiver oscillates and becomes a transmitter instead of a receiver. The greatest amount of amplification occurs when the power fed back just about, but not quite, equals the power input to the tube.

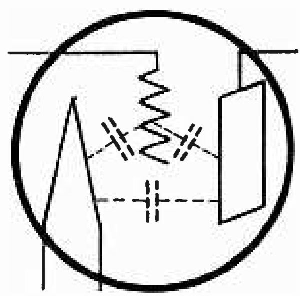


Fig. 11—Illustration showing the capacity effect between the elements in a vacuum tube.

This is called the **critical point** in the amplification. The whole process is called **regeneration,** up to the point where oscillation begins.

Now it happens that the more inductance we have in the plate circuit of the tube the greater is the regeneration, or the tendency to oscillate. When the inductance (that is, of the primary coil of the resonance transformer) becomes great enough it is impossible to stop the tube from oscillating except by special means which we will learn in a little while. Also it is found that the circuits oscillate more easily when tuned to the lower wavelengths (higher frequencies) than when tuned to the longer wavelengths (lower frequencies). As a result, receivers which employ regeneration to make them sensitive, generally are more sensitive when tuned to the short wavelengths than when tuned to the long wavelengths.

These effects occur naturally in all tube circuits unless special means are employed to counteract them or to control them. If it were not for these things all radio frequency amplifiers would be built alike, but in order to control these things a great many different arrangements have been tried, and it is on account of this that we have the great number of so-called radio receiver circuits. We are going to study some of these circuits in this lesson before we finish it.

The simplest way in which to prevent self-oscillation of the circuits is to increase the power losses in the input circuit. By doing this it makes it necessary to have more power fed back from the plate circuit than it can feed back, so that although we can have a regenerative effect and an increase of amplification, the circuits cannot start oscillating. And the simplest way of increasing the power losses in the input circuit is to introduce resistance in this circuit. Thus, in figure 10 we could so design the coil L2 that it had quite a lot of resistance; then the power loss in the input circuit of the second tube would be more than the power fed back from the plate circuit of that tube through the tube capacity. But this is a poor way of doing it; when the tuning circuits have a lot of resistance the tuning becomes broad and the receiver becomes less sensitive.

Another way of accomplishing the same result is to build the primary coil L1 in figure 10 so as to have little inductance. This also is not a good way of doing it, for it limits the amount of energy that can be transferred from the primary circuit of the resonance transformer to the secondary circuit. Although it is not a very good method it is widely used, for it is the simplest and cheapest method. The same effect can be obtained by keeping the primary and secondary coils sufficiently far apart, that is, by keeping the coupling loose.

Another means of doing the same thing is to place a resistance, not in the tuning circuit, but connected directly to the grid of the tube. This is indicated in figure 12 where the resistance is marked r. This is a little better than placing resistance in the tuned circuits, for the resistance r, does not decrease the sensitivity quite as much or make the receiver tune quite as broadly. The idea of this resistance r, is that as the power is fed back from the plate circuit it encounters the difficulty of passing through the resistance, so that only a little power can go back as far as the tuned circuit. At the same time, since there is very little current due to the signal, which flows from the grid to the filament of the tube, the loss of signal power in the resistance is not very great. In this way the resistance r decreases the feed-back and the tendency to oscillate but does not cause as much loss of signal power as occurs when there is resistance in the tuned circuits.

Resistance may be introduced in the tuned circuits in other ways. For instance, any way of absorbing power from the tuning circuit will have the same effect. If the coil is placed close to any large metallic surface, as the tuning condenser, the metal may absorb some of the power. Or, if another circuit is coupled to the tuned circuit it may absorb power from it, especially if it is tuned to the same wavelength. This idea is illustrated in figure 13, where an **absorption circuit** (A) is **coupled** to the secondary of the resonance transformer. This absorption circuit consists merely of a small coil and a variable condenser connected together as shown.

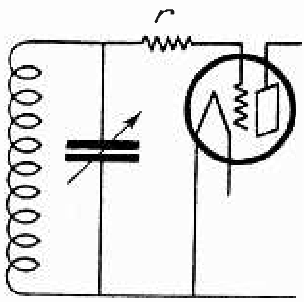


Fig. 12.

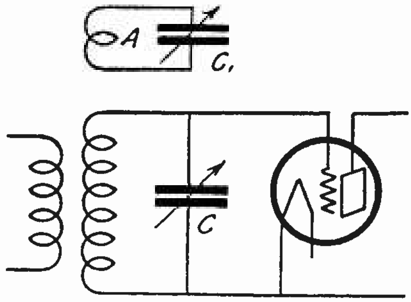
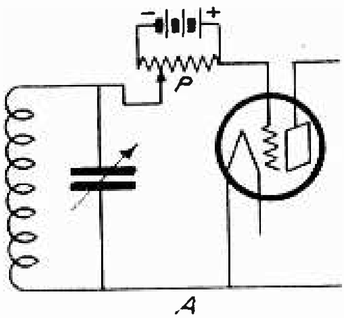


Fig. 13.

When methods of controlling the tendency to oscillate like that shown in figure 13, are used, where we are able to make the adjustments while we operate the receiver, it is clear that we can make it oscillate or not, as we please. For instance, as we tune the condenser C, bringing the receiver into resonance with the signal we wish to listen to, we can adjust the condenser C1 so that it absorbs a little power or a lot of power. When we adjust it to absorb little power the receiver may oscillate, which makes it useless as a receiver. Then we can change the adjustment a little, so that the oscillations just stop. This is the condition under which the receiver is most sensitive. Then, we can adjust the condenser C1 so that the receiver is considerably "below" the point of oscillation.

When such adjustments as these are on a receiver, there is a tendency for the operator to make the adjustment so that the receiver **will** oscillate, for this enables him to find the station he is trying to tune to very easily, by means of the whistle which it causes in the loud-speaker. This is not a very good way of "hunting" for stations, as these whistles are **radiated** by the receiver and may cause whistling and howling in other receivers in the neighborhood. So when you operate such receivers keep this in mind, and do not join the army of "bloopers" as they are called. Always keep the receiver "below" the oscillation point when you are tuning.

The next way of causing a power loss in the input circuit which we will consider is the **potentiometer** method. This is illustrated in figure 14(A) (B).



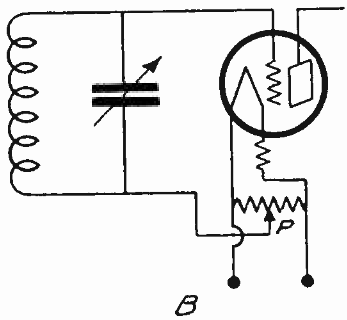


Fig. 14.

The reason why a potentiometer is used is to enable us to control the tendency to oscillate **at will.** In order to obtain the greatest amount of amplification, different values of bias are required at different wavelengths (or frequencies), so it is to our advantage to be able to make the necessary adjustments. You will note that in figure 14(B), instead of adding another battery to the circuit, we are making the "A" battery do the double duty of lighting the tube and at the same time supply the bias for the grid of the tube.

As we have said before, it is possible to control the tendency to oscillate by keeping the inductance in the plate circuit of the tube below a certain critical value. A little while back, when we were discussing the resonance transformer, we stated that the closer the coupling between the primary and secondary coils, the greater would be the amount of energy transferred from the one circuit to the other. Now, when any amount of energy is transferred from the primary to the secondary, it is clear that the secondary must exert a certain influence upon the primary.

But we must go a little further and explain that the higher the frequency of the current being carried by the transformer windings, the greater is the effect of the secondary on the primary. And we also must remember that the higher the frequency becomes the smaller becomes the critical amount of inductance that we can have in the plate circuit of the tube before oscillations set in.

In other words, as the frequency becomes higher (or the wavelength shorter) we have the critical amount of inductance

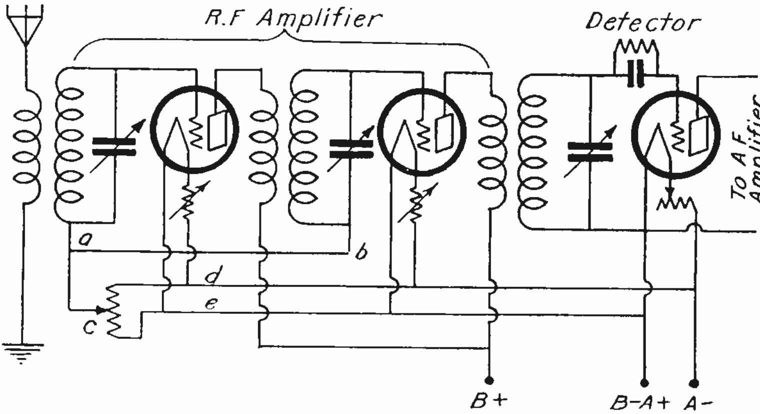


Fig. 15—Circuit diagram of two stages of tuned radio frequency and detector.

decreasing and the apparent primary inductance of the transformer decreasing also, so that if they decreased at the same rate everything would be fine and the circuits could be adjusted easily so that they would not oscillate. Unfortunately, the primary inductance does not decrease rapidly enough as the frequency becomes greater and greater, and although we might adjust the circuits so that they would not oscillate when tuned to the longer wavelengths (lower frequencies) they generally oscillate easily when tuned to the shorter wavelengths (or higher frequencies). On the other hand, if we adjust the circuits so that they do not oscillate at the higher frequencies, we shall find, in many cases, that the receiver is "dead," or relatively insensitive at the lower frequencies. This is a general failing of receivers of the **tuned radio frequency** (abbreviated T.R.F.) type which do not have adjustable means of controlling the regeneration, such as potentiometers, or absorption circuits.

On account of this difficulty there have appeared on the market receivers which **vary the coupling** between the primary and secondary as the tuning condenser is rotated in order to tune to the various wavelengths. They all operate on the same principles, so that when we describe one we describe all. First we have the secondary coil wound in a single layer, in the form of a solenoid. Then we have the primary coil, which is wound on another piece of tubing which can be rotated either inside the secondary coil, or at its end.

The idea of the contraption is to make the primary coil move away from the secondary coil just the proper amount as the condenser is tuned to the shorter wavelengths. A cam attached to the condenser moves the primary coil, so that as the condenser

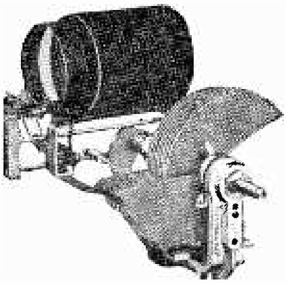


Fig. 15-A—Typical Radio frequency transformer attached to a variable condenser.

is turned the primary coil turns also, always keeping the proper distance from the secondary coil so that the circuit always operates just below the critical point, where the greatest amount of amplification is obtained.

Of course the shape of the cam is a peculiar one; there is no way of determining the shape by calculation; it must be determined by actual trial. There are various mechanical arrangements which permit this to be done, but the one shown in figure 15-A will illustrate the principle.

There are still other ways in which regeneration may be controlled in a tuned radio frequency amplifier; another simple way is to place a resistance in the plate circuits of the amplifiers. Figure 16 shows how this is done. In figure 16(A) we have the plate resistor applied to a circuit where the "B" battery is connected by the **series** feed method. The resistance R is connected right in the B+ line, so that when we introduce resistance in the circuit we are merely lowering the plate voltage of the r. f. tubes. This will effectually control the tendency to oscillate.

In figure 16(B) we have the plate resistor connected in a circuit which employs the **shunt feed** method of connecting the "B" batteries. In this circuit the plate voltage remains constant, and the resistor R introduces resistance into the primary circuit of the resonance transformer, which carries high frequency current. The effect of the resistance in this circuit is to introduce

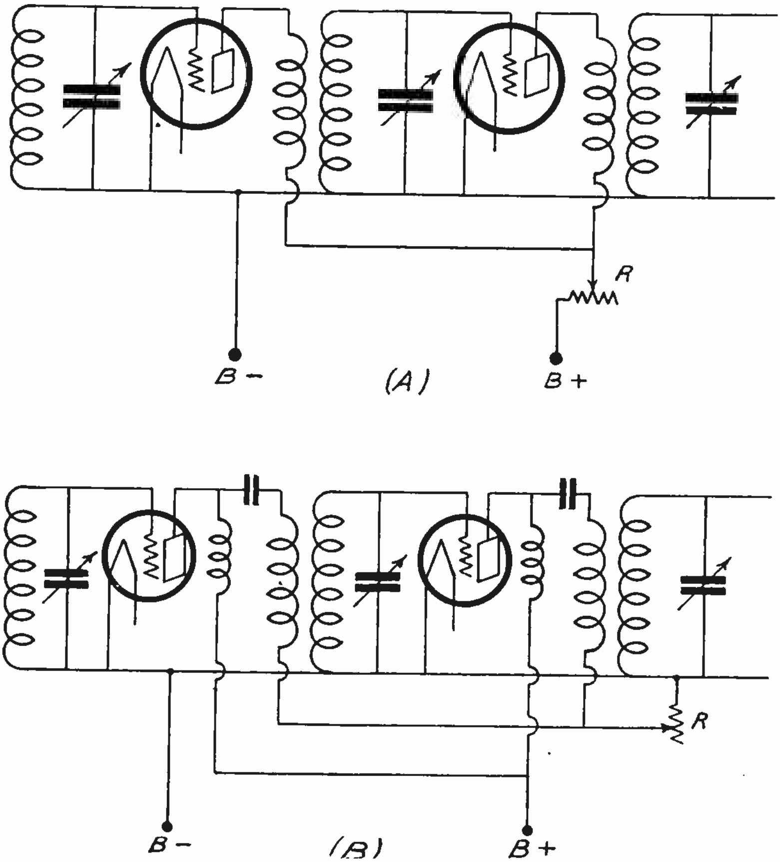


Fig. 16.

power losses in the plate circuit, which will prevent the circuits from oscillating. The same thing is true of these circuits as is true of other regenerative circuits. The greatest amount of amplification is obtained by making the adjustments so that the set is operated just slightly below the critical point at which oscillations occur. In the circuit of figure 16(A) the resistor R may have a maximum value of several hundred thousand ohms and in the circuit of figure 16B, R must have a maximum value of something like 100,000 ohms.

There are many other ways in which such receivers can be controlled, but it is not possible at the present time to study all of them. They all work in the same way; they introduce power losses into the circuit in some way or another, so that the effect of the feed-back can be reduced so the circuits will not oscillate.

Next we come to a type of receiver in which the regenerative effect is **balanced** out. You will remember that in the T.R.F. type of circuit the feed-back is accomplished through the capacity between the grid and plate of the electron tube. If this capacity were not present in the tube there would be no feed-back. So, since we cannot remove this capacity, if we could find a way of counteracting its effect, there would be no feed-back in the circuits. This is what is done in the **bridge type** of receivers.

All of these receivers are based on the Wheatstone bridge. We will briefly review the operation of a Wheatstone bridge, so that you will have it fresh in mind. Look at figure 17. Suppose at G, in figure 17, we have an alternating current generator. The rest of the circuit contains four resistances, r1, r2, r3 and r4, arranged in a square or bridge form. The alternating current generator is connected to two opposite corners of the square, and a pair of phones is connected across the other two corners of the square.

Now, there will be a certain current flowing through the various branches of this network. At the corner marked (a) the current coming from the generator will divide. Part of it will flow through the branch r1 to the point (b). The rest of it will flow through the branch r2 to the point (c). At the point (b) part of the current may go through the phones or through the branch r3 to the point (d). Then at the point (c) the current coming down through the phones will join the current coming through r2 and the total will flow through the branch r4 to the point (d) and thence back to the generator.

In other words, there will, in the general case, be a current flowing through all the branches of the network, and upon placing the phones to the ears a sound will be heard corresponding in pitch to the frequency of the generator. But supposing, instead of making it a general case, we make it a special case; suppose we take special precautions to adjust the resistances of the various branches in a certain special manner. Or, suppose we adjust the resistances so that the current flowing through r1 when multiplied by r1 will be equal to the current through r2 multiplied by r2. By this we mean that we are going to make

$$r_1I_1=r_2I_2$$

Now, since the resistance multiplied by the current gives us the voltage drop in the resistance, it is clear that the voltage drop across r1 must be the same as the voltage drop across r2. It is then clear that there can be no difference of potential (or voltage drop) from the point (b) to the point (c).

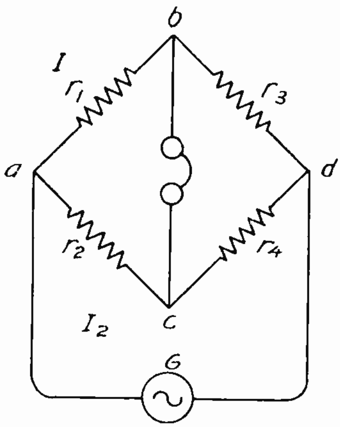


Fig. 17—A Wheatstone Bridge for measuring unknown resistances.

This might be explained in a simpler manner. Suppose the potential of the point (a) is 10. Then suppose we so adjust the resistances that the voltage drop in the branch r1 is 4. Suppose we also adjust the branch r2 so that the voltage drop in it is 4. It is plain then that the potential at the point (b) is 10—4 or 6, and likewise the potential at the point (c) is also 6. In other words, the potential at (b) being the same as the potential at (c), there is evidently no **difference of potential** between (b) and (c). This is the same thing as saying that there is no voltage across the phones, and consequently, when we have made this adjustment, we will hear no sound in the phones, and there will be no current flowing through them. The bridge is then said to be **balanced.**

This is the principle of the Wheatstone bridge. Although. in order to simplify the explanation we have supposed that there were only resistances in the various branches of the network, it is possible to connect various combinations of capacities, inductances and resistances instead of simply resistances, and the bridge can still be made to **balance.**

Now, you will remember that the feed-back in a T. R. F. amplifier is the current flowing from the plate to the grid within the tube. What we do in the bridge systems is to furnish another path for current to flow in the opposite direction so that this other current **neutralizes** the effect of the feed-back current. Let us see how this can be done.

First we start out by having the input, or tuned circuit, connected to the points (a) and (d), just as in figure 17. You can see this in figure 18. It is clear then that the points (a) and (d) must be the grid and filament of the tube, for the tuned circuit is connected to these, as shown in the upper corner of figure 18. Now, across the other two corners of the bridge (b) and (c), we must have the output of the tube, and therefore one of these points must be the plate of the tube. Let us say it is the point (b). Now we have the plate, grid and filament assigned to three corners of the bridge, so we have two arms of the bridge already furnished for us. These are the capacities within the tube itself; they are marked Cgp (meaning capacity between the grid and plate) and Cfp (meaning capacity between the filament and plate). In order to complete the bridge we must furnish two other arms, viz., the arm between (a) and (c), and the arm between (c) and (d). These may just as well be fixed condensers, as shown at C1 and C2 in the bridge. They may be about the same size, since Cgp and Cfp are about the same size.

The complete circuit is shown alongside the bridge arrangement. The two differ only in the way they are drawn. The capacity between the grid and filament does not enter into the bridge circuit for it is across the points (a) and (d), and therefore can be considered as merely in shunt with the tuning condenser. In the circuit diagram the capacities within the tube have been drawn in broken lines so that you can see their location in the circuit. This is one form of bridge circuit in use today. So far as known no particular name has been given it.

The neutralizing effect can easily be seen in the bridge circuit of figure 18. Suppose we have in the output circuit (between b and d) some energy or power which is trying to get back to the grid at the point (a). It flows in one direction from the plate to the grid (that is, from b to a) and flows in the opposite direction to the grid through C1 (that is, from c to a). The two currents coming to the point a (the grid) from opposite directions, neutralize each other, or cancel out, so that none of the feed-back current can enter the tuning or input circuit. The diagrams show only one stage of the r. f. amplifier. Several of these may be connected in cascade in the usual manner. On studying the circuit you will notice that there is no continuous path from the plate to the filament. This path is broken by the condenser C2. It is clear therefore that the "B" batteries cannot be connected by the series feed method, but must be connected by the shunt feed method. In connecting up this circuit the two condensers C1 and C2 may be of small capacity, say about .0001 mfd. or 100 mmf. One of these may be fixed and the

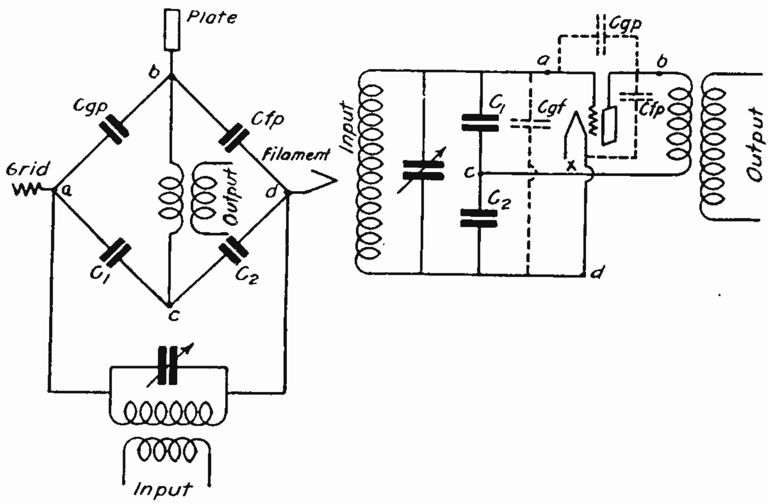


Fig. 18—Capacity bridge alongside a vacuum tube circuit.

other may be variable. The adjustment of the circuit is made as follows:

A very strong local broadcasting station is tuned in very accurately. Then the tube in one of the R. F. stages is taken out of the socket, and a piece of paper is fastened to the filament prong of the tube which is not in the bridge circuit. This is the side of the filament marked x in the circuit diagram of figure 18. Then the tube is put back into the socket, and the filament will not light up since the piece of paper breaks the circuit. Then the variable condenser C2 is adjusted until the sounds **completely disappear** in the loud-speaker. Then this particular stage is exactly neutralized. The same procedure is followed in neutralizing the other radio frequency stages.

A neutralized receiver of this type will not generally oscillate. There have been discussions as to whether or not there is regeneration present, although there is little doubt that there is some regeneration when the amplifier is not neutralized accurately. There are also some types of bridge circuits which can be accurately balanced or neutralized when tuned to other frequencies or wavelengths. Bridge circuits which have condensers in all four arms of the bridge will generally stay neutralized at all frequencies no matter at what frequency they are neutralized, but bridges which have coils in some of the arms may not stay as well balanced at all frequencies. The reason for this seems to be that the inductances of the coils vary somewhat as the frequency changes and this variation is not the same in all the

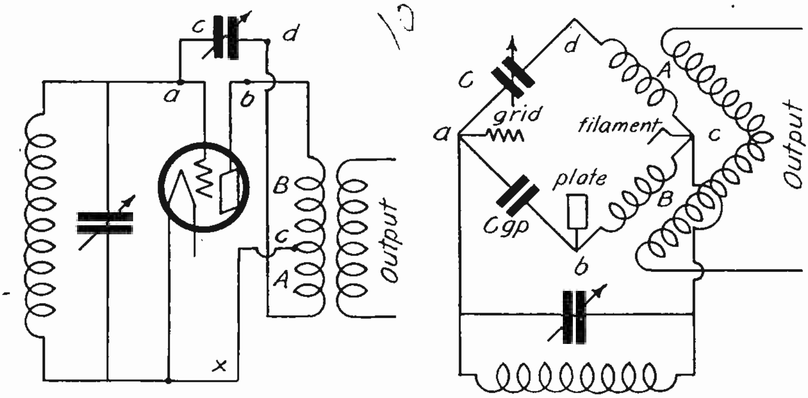


Fig. 19—Neutrodyne Bridge Circuit.

coils in the bridge. Consequently the inductance in a certain arm of the bridge which contains a coil will not be the same at one frequency that it is at another frequency. On the other hand, the capacity of condensers does not change with the frequency, so that it is easier to keep a good balance in a bridge circuit which has condensers in all of its arms.

Of course, a little regeneration due to a slight unbalance of the bridge may not do any harm; in fact, it may do some good by increasing the sensitivity of the receiver. But it is always good to have the balance as close as possible, for the gain due to the regeneration may not be worth the loss of good quality of reproduction which it may cause.

Another bridge circuit is shown in figure 19. This circuit is widely used at the present day. This circuit is a simple form of the **neutrodyne** circuit. The primary coil has a tap at a certain distance from one end. This is the point c in the diagrams. A neutralizing condenser of very small capacity, marked C, forms one arm of the bridge. The two parts of the primary coil, A and B, form two other arms of the bridge, and the grid-plate capacity in the tube forms the fourth arm of the bridge. The bridge is balanced as described above, by adjusting the neutralizing condenser C when the filament is not lighted. The secondary coil is coupled to both parts of the primary coil. Since there is a direct unbroken path from the plate to the filament, it is possible to use the series connection for the "B" batteries, which may be connected at x in the diagram.

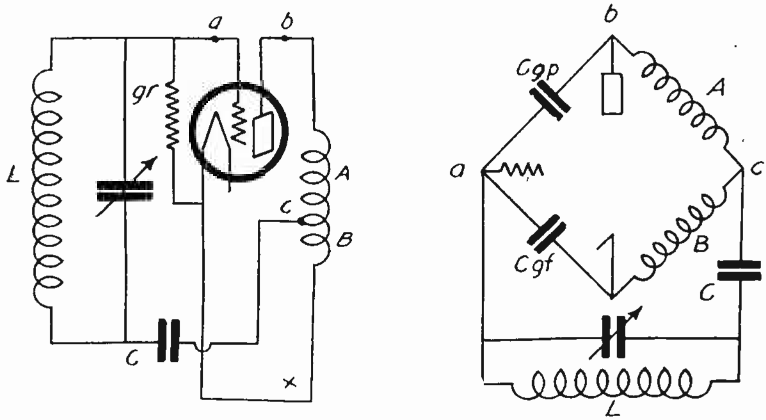


Fig. 20.

In figure 20 we have still another form of the bridge circuit. The plate coil is tapped as in the previous case, and this time the capacities Cgp and Cgf form two arms of the bridge. The two parts of the coil form the other two arms. The "B" batteries can be connected by the series method at the point marked x. It will be noted that a large blocking condenser is connected at C in the diagram. This condenser is required in order to keep the high positive voltage from the "B" batteries off the grid of the tube.

This brings up another point in connection with many bridge circuits. You will note that by placing the blocking condenser in the circuit, we have broken the path from the grid to the filament, which passes around through the coil L. As a consequence the grid is left "free" and is quite likely to become highly charged negatively. In order to let this charge leak off the grid we have to furnish a "leakage" path. In the present circuit it is difficult to do this, as any leakage path we might connect in the circuit might allow a high positive or negative voltage from the "B" battery to be placed on the grid of the tube. In either case this is bad. What might be done, however, is to place a grid-leak resistance as shown at gr. This may have a resistance of about 3 megohms. This particular bridge circuit is not adjustable. The balance or **neutralization** is only approximate, and is made by adjusting the tap (c) on the coil to the point of balance with the tube not lit, when building the receiver. When tubes are changed the adjustment will change slightly, but although there may be some regeneration, there is not much likelihood of oscillations being started.

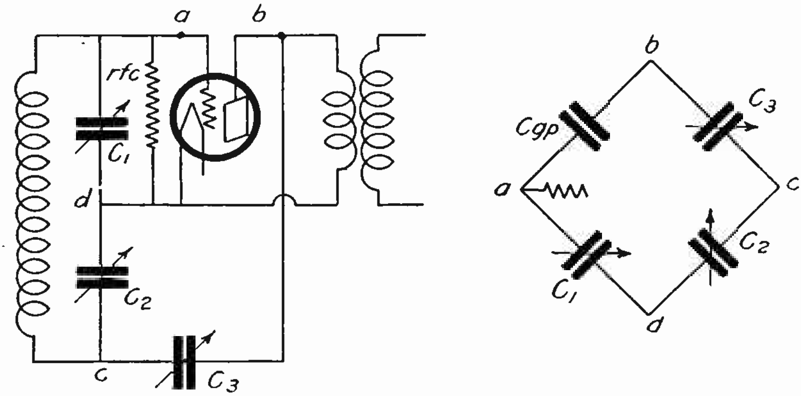


Fig. 21—Isofarad Bridge Circuit.

In figure 21 we have still another form of bridge circuit. This is known as the Isofarad circuit. The two condensers C1 and C2, forming two arms of the bridge, are rotated together, so that the capacity of one always bears the same relation to the capacity of the other. The grid-plate capacity forms another arm, and the fourth arm is formed by the neutralizing condenser C3. On account of the fact that the connection shown would leave the grid of the tube "free," a radio frequency choke coil rfc is connected between the grid and filament.

You, no doubt, have noticed that up to this time we have illustrated many drawings showing the connections from vacuum tubes to batteries. Therefore, it is advisable at this time to know the difference between circuits using D.C. tubes and A.C. tubes.

In Figures 22 and 23, we have shown a standard 2-stage

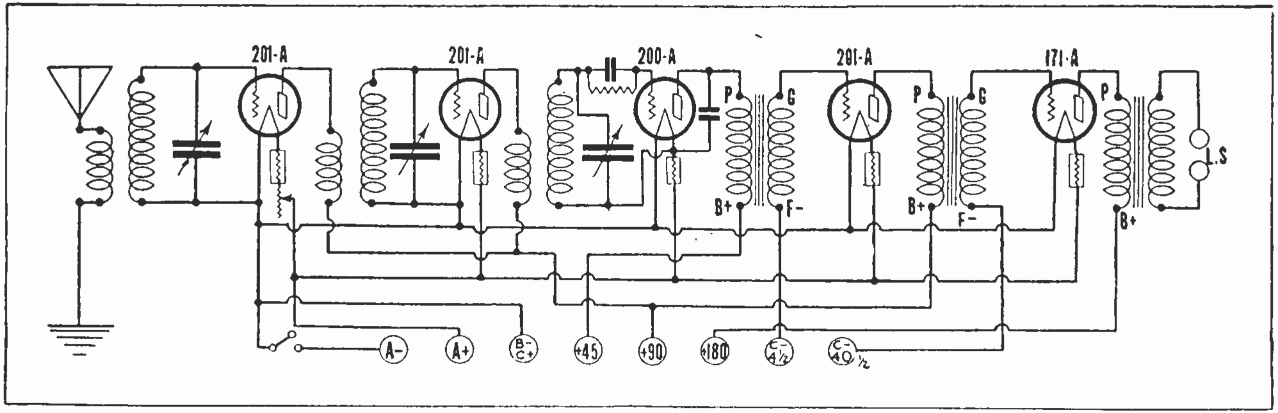


Fig. 22—The circuit diagram of a 5-tube Receiver using two stages of T.R.F., detector and two stages of A.F. amplification for battery operation is shown above.

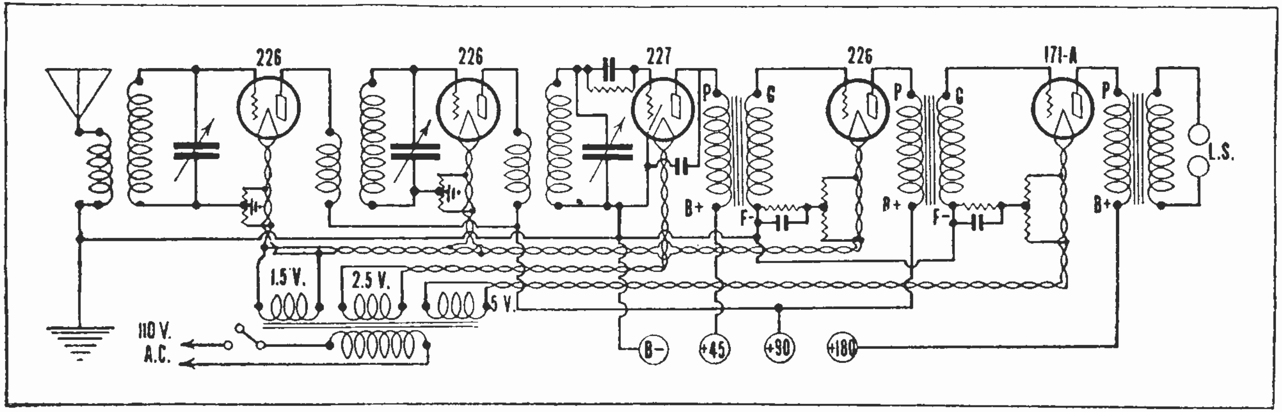


Fig. 23—Circuit similar to Fig. 22, using A.C. tubes operated from filament transformer and B power supply.

tuned radio frequency amplifier, detector, and 2-stage audio frequency amplifier for both D.C. and A.C. operation. In the D.C. operated set, the filament power is obtained from a storage battery, while in the A.C. operated set, the power for the filament is obtained from the 110-volt light source, through a step-down transformer. To furnish the correct operating voltage to the various types of A.C. tubes and the power amplifier tube, the step-down transformer must have besides its 110-volt primary winding, three other windings, namely, a 1.5-volt supply for the 226's, 2.5-volt supply for the 227 and a 5-volt supply for the 112-A or 171-A type of power tube.

In battery operated receivers, the return side of the secondary coil, whether it be in the tuner or amplifier, ultimately returns to one side of the filament; the same is true with A.C. tubes with the exception of the heater or 227 type of tube, where this connection can be made direct to the oxide coated element (cathode). However, it is not practical to make direct connection to either side of the filament when using 226 A.C. tubes or power tubes operated from a transformer for the reason that a disagreeable hum would be produced. To eliminate this hum, it is necessary that the midpoint of the tube be connected to the return side of the secondary coil. Mechanically, this is impractical in tubes now available because it would necessitate the actual connection to the center point of the filament.

The problem can be solved in a more simple and direct manner. Merely by shunting the filament terminals of the 226 A.C. tube and power tube sockets with a center tapped resistor, a satisfactory return connection is obtained when connection is made to the midpoint of the resistor unit. Where it is desired to obtain the proper C bias without the aid of external C batteries, it is simply necessary to insert in the return connection a resistance unit of the value which has been predetermined to give the correct C bias to the tube.

The A.C. amplifying tubes, the 226's, are of the standard 4-prong base. The 227 or detector tube, however, has 5 connections or 5 prongs at its base and, therefore, requires a 5 terminal socket. These sockets usually have terminals marked as follows: G for grid, P for plate, H-H for the heater terminals to which is supplied the filament voltage, and C (cathode) to which is attached the return side of the secondary circuit of the tuner coil. Figure 23 shows how this tube socket is connected in the circuit.

You will notice in Figure 23 that the filament leads are twisted together This is done so as to prevent the alternating current flowing through the filament leads from acting magnetically on the coils or grid leads which may cause a hum. This effect may be prevented also by keeping the filament leads as far away as possible from the other wires and also by shielding the filament leads.

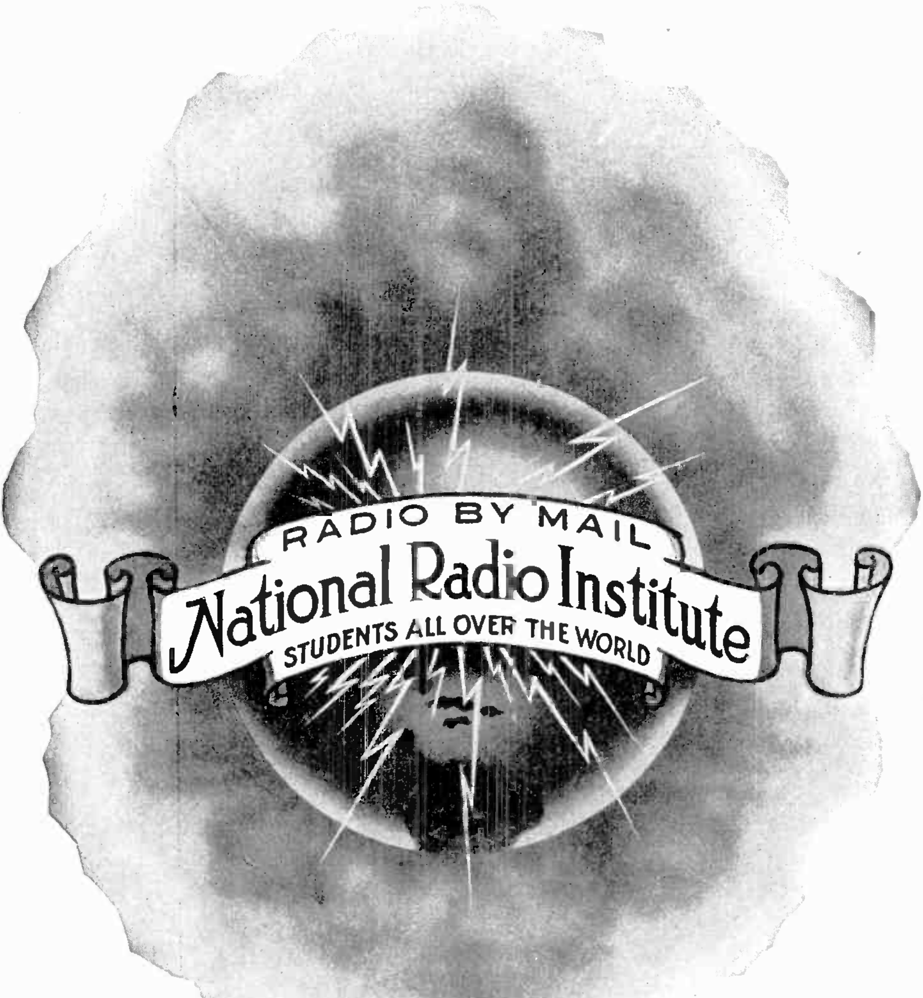
The plate voltages applied to both D.C. and A.C. tubes may be obtained from standard B batteries or a regular B eliminator, the latter being preferable.

As the student has probably guessed by this time, the study of radio frequency amplifiers is an enormous one. We can hope in these lessons to give you only a fair idea of what it is all about, and can introduce you to only a limited number of circuits. By learning carefully what has gone before you will have a very good knowledge of the subject we will take up in detail in advanced text books A.C. receivers. Having learned this lesson it will be easy for you to read what is written on the various circuits in the radio magazines **and future text books**; as a matter of fact, you will not be in a fair position to understand what you read about them until you have thoroughly digested this lesson.

TEST QUESTIONS

Number Your Answer Sheet 13-2 and add your **Student Number.**

1. What is the purpose of using a radio frequency amplifier ahead of the detector circuit?
2. Draw a diagram of a two stage radio frequency amplifier.
3. Show by diagram how an "A" battery can be connected in the filament circuit so we can obtain a negative bias on the grid of the tube.
4. State the advantage of placing a negative bias on the grid of an amplifying tube.
5. Name the various coupling systems used in radio frequency amplifiers.
6. How is the secondary circuit of a tuned radio frequency transformer tuned to resonance?
7. How can we increase the coupling between the primary and secondary circuits using radio frequency transformers?
8. What causes a receiver to oscillate and become a small transmitter?
9. Explain what is meant by a critical point in the amplification of a tube.
10. Draw a simple form of Neutrodyne Bridge circuit.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