NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

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Radio-Trician
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Lesson Text No. 17
(2nd Edition)

REGENERATION, OSCILLATION AND NEUTRALIZATION

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

CONCENTRATION ESSENTIAL

A Personal Message from J. E. Smith

Essential to effective study is concentration. The posture in which a person is best able to concentrate is the best posture for study so far as that person is concerned.

A similar state of affairs is discovered when one comes to consider the best time for study. There is no best time for study, for all students. The puritan view, still held to a considerable extent in some quarters, is that study can best be done in the early morning. However, there are persons who are especially fond of the early morning air and light and like to arise to enjoy them. Other persons reach their maximum effectiveness in study in the early afternoon. Still others, late at night. The thing is partly a matter of habit; partly, in all probability, a matter of one's nervous condition.

Most of us, of course, have to fit our study in with other work, we cannot arbitrarily set apart what hours we please for study. We can, however, exercise some choice among our spare hours. Most of us can at least determine to study either in the early morning or in the evening, whichever time we find by actual experience will be best suited to us.

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Radio-Trician's
(REG. U. S. PAT. OFF.)

Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

REGENERATION, OSCILLATION AND NEUTRALIZATION

A preliminary definition usually gives one a fair understanding of the subject to be dealt with. With this in view, the three definitions below are given before proceeding with a detailed study of the underlying principles of each.

Regeneration is the process of "feeding back," in proper phase, energy from the plate or output circuit of a vacuum tube, into the grid or input circuit so as to strengthen the oscillations in the grid circuit and gain additional amplification.

Oscillation or Oscillating as applied to a vacuum tube is the state or condition of a vacuum tube and its associated circuits where regeneration has been increased to the point where the tube and its oscillatory circuit act as a generator of self-sustained oscillations (alternating current).

Neutralization is the process of "feeding back" opposite phase energy from the output circuit, or from another circuit, into the grid or input circuit so as to decrease regeneration and prevent oscillation.

Read these definitions over several times so as to implant them in your memory forever.

THE ARMSTRONG REGENERATIVE FEED-BACK CIRCUIT

It is possible to take a simple vacuum tube circuit and make certain additions to it and by the proper adjustment to increase its sensitiveness several times. The special addition that is necessary is usually a plate coil which is in series with the plate circuit and in inductive relation with the grid circuit, so that any changes in the plate current will induce additional voltage into the grid circuit. This idea was developed and patented by E. H. Armstrong and is known to all as the "Armstrong Feed-Back Circuit."

One of the easiest ways of using the Armstrong idea is given in connection with Figure 1. It will be seen that this circuit is practically the same as some of the circuits previously given in the earlier texts with the exception that there is now an extra coil placed in the plate circuit. This coil known as the tickler coil is connected magnetically to the coil in the local tuned circuit L1 C1. By connecting magnetically, we mean that the two coils are placed in such position with respect to each other that when the magnetic field of one changes, it induces a voltage in the other.

HOW THE TICKLER COIL WORKS

A simple explanation of the action of the tickler coil and the effect produced in the tuned circuit L1 C1 is as follows: The signal current flowing in the antenna induces voltages in the local tuned circuit L1 C1 which is tuned to the signal frequency. Current is thus caused to flow in the L1 C1 circuit and it is to be remembered that this current is really caused to flow because of the effect of the changing magnetic field set up in L by the signal current, acting on coil L1 to produce voltage in L1. The grid potential will go up and down at the same frequency as the signal

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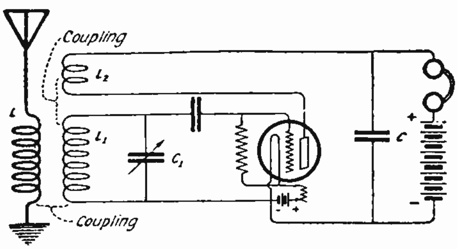

Fig. 1—Armstrong Regenerative Circuit.

current and so will cause the plate current to rise and fall correspondingly. This changing plate current flowing through coil L2 will give here a corresponding changing magnetic field which reaches out from L2 to L1 because of their proximity. This changing magnetic field in L1 from L2 will so act as to give a voltage in L1 which helps out the voltage induced in L1 by the signal current in the antenna. In other words, the changing plate current caused indirectly by the signal current in the antenna, so acts as to help the signal current in the antenna to produce bigger currents in L1 C1. It is the amount of current in L1 C1 which determines the strength of the signal heard in the telephones. The regenerative action, as it is called, is controlled in amount by the proximity or relative position of coil L1 and the tickler coil L2. The closer these coils are together, the greater is the regenerative action and the louder is the signal up to a certain limit. If the magnetic coupling of L1 and L2 is made too tight, the tube circuit may give all kinds of queer noises—sometimes a series of clicks at the rate of one or more per second or humming or squealing noises, depending principally on the size of the grid condenser and grid leak. If such noises are obtained, the coupling between the tickler coil L2 and L1 should be reduced until they disappear.

THE TUNED PLATE CIRCUIT

Another form of regenerative circuit is shown in Figure 2. In this case, it will be noted that instead of having a tickler coil magnetically coupled to the grid coil, we have two variable inductances in the form of variometers. One of these inductances (L2) is in the grid circuit so as to tune this circuit to resonance with that of the desired signal and make this circuit responsive to the same frequencies. The second variable inductance (L3)

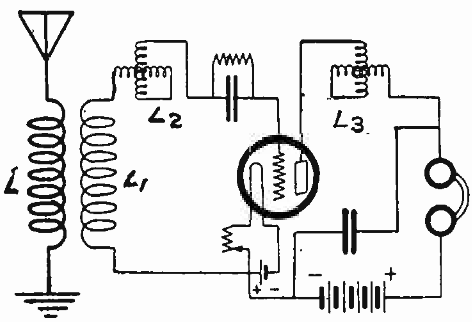

Fig. 2—Tuned grid and plate regenerative circuit.

is included in the plate circuit and by tuning this circuit to resonance with the grid circuit and incoming signal, regeneration can be accomplished as in the tickler feed-back method previously described. As the plate circuit of the tube is tuned and brought into resonance with the grid circuit, a feed-back of energy from the plate to the grid circuit takes place through the capacity existing between the grid and plate of the tube. It can be seen by looking at Figure 2 that the grid and plate act as the plates of a condenser with a potential applied to each plate and any fluctuations in the plate or grid circuit voltages will charge and discharge this condenser, causing a transfer of energy between these circuits. Therefore, then, as the plate circuit is tuned or brought into resonance with the grid circuit, a transfer of energy will take place between the two circuits and any change in voltage or current in the plate circuit will be impressed on the grid circuit. This, then, tends to increase regeneration by introducing into the grid circuit a voltage from the plate circuit, and, as this voltage is in phase with the voltage of the grid circuit, it strengthens and builds up the grid circuit oscillations resulting in regeneration.

HOW "FEED-BACK" INCREASES SENSITIVITY

The statement has been made that by feeding back a voltage from the plate circuit into the grid circuit, the oscillations will be strengthened and this in turn strengthens the plate current which passes through the head telephones or loudspeaker device and thus a louder response is heard. Let us go further into this subject and see just how this is accomplished and what takes place in the tube circuits when a voltage is fed back from the plate circuit into the grid circuit.

The following explanation of regeneration is based on the action of the resistance in an oscillatory circuit. It is the basis of the understanding of just what takes place in an oscillatory circuit and how regeneration can be accomplished.

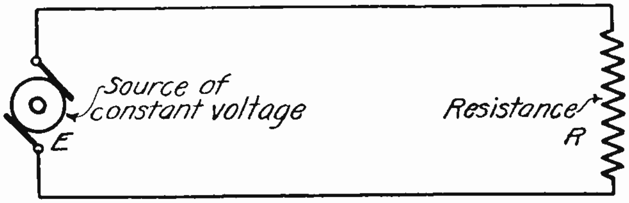

Fig. 3—Constant voltage forcing current through a resistance.

In order to bring out the exact condition and just what takes place in this circuit, it will be necessary to review some of the elementary circuits and see what happens in them and then apply the principles learned to the circuit under consideration at the present time.

Figure 3 represents an electric circuit containing a source of voltage E, and a resistance R connected in series. If the voltage is constant in value, a current also constant in value will flow through the circuit and the value of the current will be limited by the resistance. The smaller the resistance, the greater the current and vice versa. In this case, maximum current value is reached almost instantly. There is nothing to retard the flow of current except the resistance and the voltage instantly forces the current through this resistance.

If the same constant potential is applied to a circuit containing resistance and inductance in series, as in Figure 4, the current does not reach its maximum value immediately, but gradually rises from zero to its final value. The reason that the current takes some time to reach its final value is that the inductance in an electric circuit behaves as an inertia and retards the growth of current. Such a circuit is said to have a time constant which depends upon the value of the inductance and resistance. This time constant is a measure of the length of time it takes for the current to build up to its final maximum value.

If in the above circuit containing an inductance and resistance, there is a current flowing and the impressed voltage is removed, the current will gradually drop to zero. When the voltage is removed, the current that is flowing has all its energy dissipated in the resistance in the circuit and since there is no longer an impressed voltage to maintain this current, it dies down to zero. The greater the resistance, the less time it takes for the

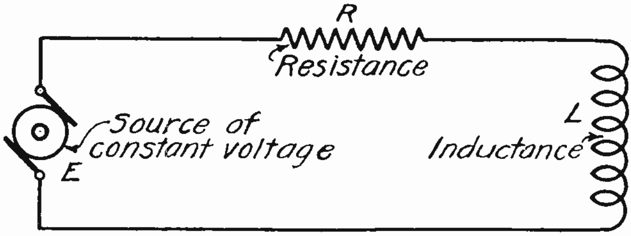

Fig. 4—Constant voltage forcing current through a resistance and inductance.

current to die down to zero; the less the resistance, the more time it takes for the current to die down to zero. Suppose that while the current is still flowing, the resistance, by some means, is reduced to zero. What happens? At the instant the resistance is reduced to zero, the current has a definite value. Since there is now no resistance to consume the energy of the current and there is no resistance to oppose the flow of current, the latter will continue to flow in the circuit regardless of the presence of the impressed voltage. This is a very important fundamental truth and should be mastered so that the following statement can be understood. If the impressed voltage is removed at the instant the resistance of the circuit decreases to zero, then the current will continue to flow for a certain time and at that value which it had at the instant the impressed voltage was removed.

Let us now consider oscillating current circuits, as in Figure 5; namely, circuits containing resistance, inductance and capacity. The principles and facts outlined previously for direct current hold here also, except for these changes; in the first place, the current is oscillating or alternating. When the oscillating voltage is applied, an oscillating current flows and builds up in the circuit gradually. As with direct current, it takes an appreciable time for the oscillating current to build up to its maximum value. The time it takes is again determined by the time constant of the circuit which, in this case, is determined by the value of the inductance, capacity and resistance.

This current which builds up in value when the voltage is impressed is called "forced oscillation," since the existence of the current depends solely upon the presence of an applied external voltage. The frequency of this "forced oscillation" is the same as the frequency of the impressed voltage, regardless of what the natural frequency of the circuit is.

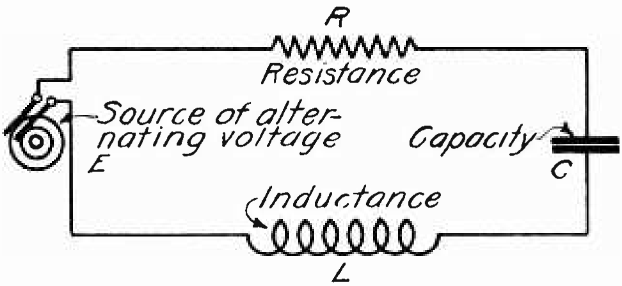

Fig. 5—Oscillatory circuit with an A. C. voltage applied.

When this applied alternating voltage is removed, the forced oscillating current decreases to zero exactly as in the case of direct current and for the same reason. The time it takes for the current to drop to zero depends largely upon the value of the effective resistance in the circuit. The greater the resistance, the less time it takes for the energy of the current to be consumed and hence the less time it takes for the current to drop to zero and vice versa. When the current drops rapidly to zero, it indicates that the effective resistance is extremely high. The circuit is then said to be "highly damped" and the circuit has a high decrement and vice versa.

Thus far the action of the oscillatory circuit is the same for alternating current as the action of the previously described circuit for direct current. We now come to an important difference. An oscillatory circuit has a natural frequency of vibration or oscillation of its own. This natural period is determined by the value of inductance and capacity in the circuit. If an instantaneous electrical impulse of any sort is applied to such a circuit, it will vibrate—i. e.; an oscillatory current will flow through it and the frequency of this oscillation will be the same as the natural frequency of the circuit. Such an oscillation is called a "free oscillation." This free oscillation dies down to zero after the voltage pulse is removed for the same reason and in exactly the same way as the forced oscillation when the impressed voltage is removed.

Thus when an external alternating voltage is applied to an oscillatory circuit, two oscillations result; one, a forced oscillation having the same frequency as the applied voltage, in which the oscillations last as long as the voltage is impressed; two, a free oscillation having the same frequency as the natural frequency of the circuit. While the forced oscillation persists during the time the voltage is impressed, the free oscillation dies out. The forced oscillation overcoming the free oscillation.

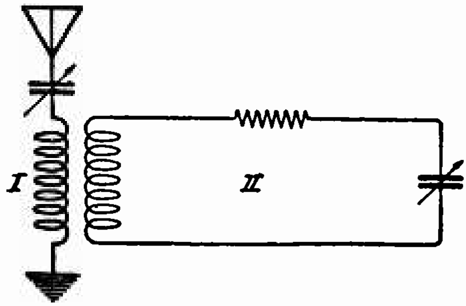

Fig. 6—Applying the antenna signal voltage to an oscillatory circuit.

In place of the alternating current generator applying the impressed voltage to the circuit, you may consider the generator replaced by an antenna circuit inductively coupled to an oscillatory circuit as shown in Figure 6. In this case, the voltage impressed on the oscillatory circuit will be that due to the voltage induced in the circuit by the signal voltage in the antenna circuit. The forced oscillation in circuit II will have the same frequency as the signal voltage in the antenna circuit I and the free oscillation will have the frequency of circuit II. The value of these oscillations will be a maximum, however, when the two circuits are in resonance—i. e., when the frequency of the antenna circuit I and circuit II coincide.

In this case, the forced and free oscillations will have the same frequency. This is the general case in all Radio circuits, since Radio circuits coupled to each other are generally tuned to each other.

In the general case here described, it is the forced oscillation which is of the greatest importance and the free oscillation which is of negligible importance as far as the production of signals is concerned. The free oscillation, while it lasts a finite time is practically instantaneous and dies down to zero, while the forced oscillation persists as long as the applied voltage (which is the received signal in the antenna) lasts, which is many times longer than the free oscillation.

Now as the effective resistance in the circuit decreases, the oscillating current for a given voltage increases. When the effective resistance reaches zero, the current has reached a very large value. If now the impressed voltage is removed, the current continues to flow in the circuit at the value it had when the voltage was removed. Once the current has been started in a circuit and the effective resistance reduced to zero, this current will continue to flow, regardless of the presence of an external voltage, since there is no resistance to consume this energy or damp the cur-

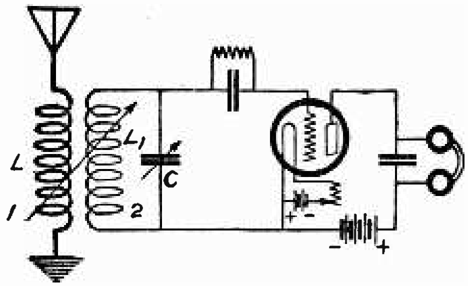

Fig. 7—A non-regenerative vacuum tube circuit.

rent. As there is now no impressed voltage and current flows, this current may be regarded as free oscillation.

Let us now consider the application of the above outlined principle to the regenerative receiver. Figure 7 is a circuit diagram of a simple Non-Regenerative receiver. The signalling voltage in the antenna is impressed by induction on the secondary circuit 2 consisting of L1 C1 and a free and forced oscillation will, therefore, flow in the secondary circuit. The free oscillation dies out in a very short period of time, as explained above, while the forced oscillation builds up in value until its further growth is limited by the resistance of the secondary circuit. As a result, the audibility will be limited in the same way. If it were now possible to introduce some means whereby the resistance of the secondary circuit could be gradually decreased, there would result a corresponding increase in the oscillatory current, thus producing louder signals. This is the effect that occurs in the regenerative receiver.

To understand how this is accomplished, suppose we connect in series with the telephones in Figure 7 a coil T whose position may be altered with respect to the secondary coil L such as in Figure 8. This coil T called the tickler, produces regenerative action. Suppose the position of this coil is such that it has no effect on the coil L, thus its axis may be perpendicular to the axis of coil L or it may be at a considerable distance from coil L so that in either case there is no transfer of energy from one coil to the other by induction. In this case, conditions will be practically the same as for the circuit in Figure 7; i. e., the signal is just simply limited, for a given received voltage, by the circuit resistance.

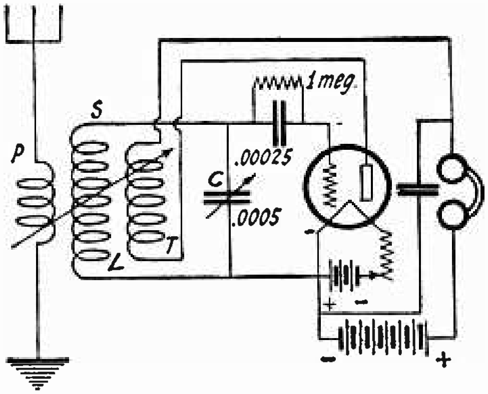

Fig. 8—Coupling a tickler coil to the grid coil to secure regeneration.

Now suppose that the tickler coil T in Figure 8 is changed in position so that it is either moved up closer and closer to coil L, or it is located so that its axis is more and more parallel to the axis of coil L. The coupling between the coils is thus increased, and due to this increased coupling, there will be a greater transfer of energy between the two circuits. A voltage will be induced in coil L by the current in tickler T, and as the coupling increases, this induced voltage will also increase. This induced voltage will have the effect of overcoming or counteracting the opposing resistance reacting on the entire circuit, thus resulting in increasing the oscillation current over its original value. The more the tickler coupling is increased, the larger is the voltage induced in coil L and the more is the circuit resistance counteracted, with the result that both current and signal strength become greater and greater. In other words, the effect of regeneration is to decrease the effective resistance of the oscillatory circuit by introducing additional voltage of the same frequency and phase, thereby, resulting in large increases in current and greater audibility of the signal. As the regeneration increases, we see that in effect the resistance of the circuit is made to decrease.

Hence, from the principles explained earlier in this lesson, it will take a longer time for the free oscillations to die out, for the smaller the resistance in the circuit, the less the damping of the circuit. Now suppose the coupling between the tickler and coil L is made so close that the voltage induced in coil L is sufficient to counteract entirely the effective resistance. In this case, the resistance of the circuit will in effect be reduced to zero. Since there is no effective resistance now to impede the flow of current, the free oscillations will continue to flow. However, when the effective resistance of the circuit drops to zero, the circuit becomes unstable and hence slight variations in filament current, plate voltage, or in the circuit will result, generating self-sustained oscillations, which will destroy any amplification. These self-sustained oscillations will have a paralizing effect on the tube, and will drown out any other oscillations which may be present.

This, then, is the limiting condition of regenerative amplification. So long as the tickler coupling does not result in completely nullifying the circuit resistance, regenerative amplification can be obtained. As soon as the coupling becomes great enough, resulting in reducing the circuit resistance to zero, the free oscillations persist and destroy any amplification of signal voltage which may have been secured.

What, then, regenerative amplification accomplishes is this: It reduces the circuit resistance from a high value to an extremely low value, but higher than zero, and thereby increases the current to a very large value; hence, also, the increase in audibility.

SUPER-REGENERATION

Apparently, further amplification which might be obtained by a continued increase in regeneration—i. e., a continued decrease in circuit resistance below zero to negative values, is prohibited by the introduction of self-oscillation. It is obvious that if this decrease in circuit resistance could be effected without the introduction of self-sustained oscillations, amplification of enormous values would be obtained.

In this case, we would have a circuit with a negative resistance. We learned how a positive resistance had the effect of limiting the value of forced oscillation current, and damping out the free oscillation current. We also learned that when the resistance in the circuit was reduced to zero, the forced oscillation current was maintained at the value it had when the resistance became zero, while the free oscillation was not damped out, but continued to flow at the value it had when the resistance became zero. When a circuit has a negative resistance, not only is there no resistance to limit the value of the forced oscillation

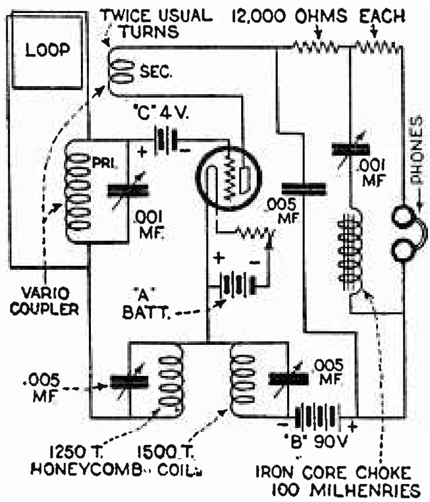

Fig. 9—A typical super-regenerative circuit.

current or to damp the free oscillation, but an exactly opposite effect is had—namely: whatever free oscillation current there is in the circuit at the time the resistance should become negative, steadily increases in value and approaches infinity.

In the case of the circuit having a positive resistance, it was noted that it was the forced oscillation which was of dominant importance, most of the energy being in the forced oscillation. However, in the case where the resistance is negative and the free oscillation steadily increases in value, it is this free oscillation which is of major importance and the forced is of minor importance. Furthermore, this free oscillation has the property of starting with a value which is proportional to the applied voltage (in the case of the signal, it is proportional to the antenna voltage), and during any finite period of time the free oscillation maintains this proportionality. Hence, it will be seen that since the free oscillation in a negative resistance circuit may rise to enormous values, and since this value is proportional to the applied signaling voltage, it will repeat the transmitted signal with tremendous amplification, provided the circuit does not break into self-oscillation which will destroy any amplification.

As in regeneration, so in this case, it is the self-oscillations, which are generated when the circuit resistance becomes unbalanced, that destroy the amplification which would otherwise be obtained. If some means could be devised to prohibit the generation of these paralizing self-oscillations, the tremendous amplifying effect of the free oscillations could be secured. This is precisely what is done in the Armstrong Super-Regenerative receiver.

Armstrong discovered that if a regenerative circuit having a negative resistance is made positive at intervals so that the circuit is alternately positive and negative, the circuit will not generate self-sustained oscillations which will paralize amplification. It takes a certain finite time for a negative resistance circuit to break into self-sustained oscillation. Up to the instant when the circuit is ready to generate the undesired oscillations, the circuit resistance is negative and hence the enormous amplification possible with this circuit is secured. At the instant when the circuit is ready to oscillate on its own, it is made to have a positive resistance, thus restraining the tendency to oscillate and the amplification secured is, therefore, not destroyed. In Figure 9, we have a circuit diagram of a typical Armstrong Super-Regenerative receiving set.

OSCILLATION

By referring to the definition of Oscillation or Oscillating Vacuum Tube as given in one of the earlier pages of this lesson, it can be understood that under certain conditions a vacuum tube can be caused to act as a generator of alternating current.

In reality, of course, a vacuum tube does not act as a generator of alternating current because it has a direct current applied to its plate circuit and, therefore, it in reality acts as a converter of power and changes direct current into alternating current of a definite frequency.

From the preceding explanation of regeneration, it was seen that when the feed-back voltage from the plate into the grid circuit becomes great enough to make the resistance of the oscillatory circuit zero, then, the tube will act as a generator of self-sustained oscillations. Thus, oscillation is merely a step further in regeneration, or it is over-regeneration because regeneration increases up to the point where the induced voltage reduces the oscillatory circuit resistance from a positive value almost to zero and then beyond this point regeneration is known as oscillation.

By referring to Figure 8, it is noticed that a tickler coil is placed so as to feed back some voltage from the plate circuit to the grid circuit. It was not stated previously that before regeneration can take place a certain condition must be met. This condition is that the connection to the plate or tickler coil

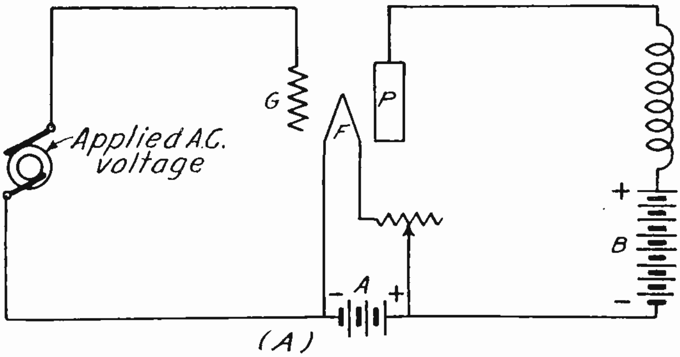

Fig. 10A—Alternating current applied to the grid circuit of a vacuum tube.

must be such that the voltage induced in the grid coil will be in phase with the voltage in the grid coil and assist it to build up the oscillatory circuit voltage. If the induced voltage be out of phase with the oscillatory circuit voltage so that it is directly opposed to it, then the induced voltage will not be assisting the voltage in the grid circuit and it will not build up the oscillations but will diminish and decrease them. From this, it can be seen that the magnetic field set up by the tickler coil must be such that the induced voltage will be in phase with the voltage in the grid circuit. If this magnetic field of the tickler coil caused by the variations in the plate current induces a voltage of opposite phase in the grid circuit, then oscillation and regeneration will not take place. This magnetic field can be reversed by reversing the connections to the tickler coil, because the plate current flows only in one direction and merely varies in magnitude.

Let us go further into the action of the vacuum tube as a generator of alternating current and see what happens in the plate circuit. Steady quantities of plate current, plate voltage and grid voltage do not enter into consideration except as they fix the plate circuit resistance, etc. The plate current of an oscillating tube can then be regarded as an alternating current. (The student should bear in mind that actually, of course, the plate current is a fluctuating one, and that it never reverses its direction of flow but is regarded as an alternating current because the variations in the plate current follow the variations in the alternating voltage applied to the grid). Under ordinary circumstances, we can treat the plate current as if it were a purely alternating current because it fluctuates in a positive and negative direction above and below its average value and follows all the laws of an alternating current, but it must be borne in mind that this is a varying plate current and not a strictly alternating current which periodically reverses its direction of flow.

The voltage which produces the alternating component of the plate current is impressed on the grid; this alternating grid voltage produces changes in the plate current just as though an alternating voltage had been introduced directly in the plate circuit. But, the grid voltage is much more effective in controlling the plate current than would be the same voltage introduced directly into the plate circuit, and is greater by the amplification factor of the tube. We can, then, consider a three element oscillating vacuum tube, having an alternating voltage impressed on the grid and filament and compare it to another vacuum tube having an alternating voltage in the plate circuit equal to the grid voltage applied to the first vacuum tube but greater than this by the amplification factor of the tube. We, then, forget the grid of the tube exists, except when it is necessary to consider the amount of current taken by the grid, but this sometimes has an important effect on the operation of the tube.

This viewpoint is illustrated in the diagram shown in Figures 10A and 10B. In Figure 10A is shown the actual circuit, with the B battery forcing the plate current to flow. This current is made to increase and decrease by the action of the alternating voltage applied in the grid circuit. The equivalent circuit is shown in Figure 10B and this is the one we use in deriving the relation of current and voltage of the oscillating tube. We suppose there is an alternating current generator between the filament and plate, generating a voltage greater than the voltage which was applied to the grid circuit of the tube in Figure 10A by the amplification factor of the tube and that the internal resistance of this generator is equal to the internal resistance of the three element tube. This plate resistance depends for its value on the steady voltages used in the grid and plate circuits.

Actually in a three element vacuum tube the value of the plate resistance varies with the magnitude of the plate current (alternating component), not only increasing when too much current is drawn from the tube, but actually varying during the cycle. It can be noticed by referring to Figure 10B that the alternating current generator will increase and decrease the voltage which is applied between the plate and filament of the tube

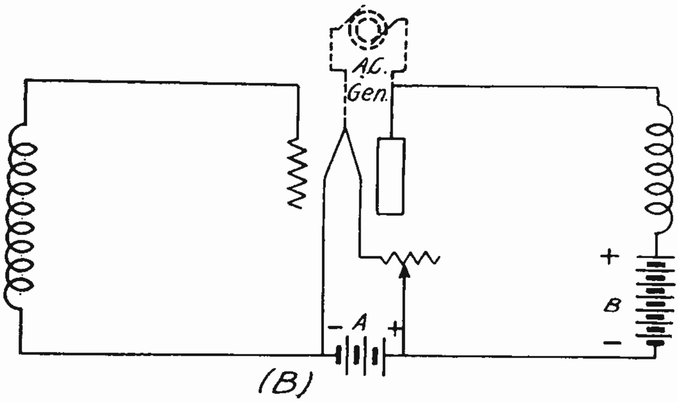

Fig. 10B—Theoretical circuit for illustrating alternating component of plate voltage and current.

and this increase and decrease of voltage will cause an increase and decrease of plate current accordingly. Therefore, then, we have an alternating component of plate current which rises and falls from a steady value and this rising and falling is in exact accordance with the alternations of the generator.

It can then be understood that an alternating voltage applied to the grid circuit of a tube produces an alternating component on the plate current which rises and falls according to the alternations applied to the grid.

Since there is no time existing between the application of the grid voltage and the change produced in the electronic stream and plate current, therefore, the plate current is in phase with the grid voltage. Now let us see what happens in regard to the plate voltage and grid voltage. Due to the fact that an inductance is inserted in the plate circuit, making it necessary for the plate current to flow through this inductance, we find that this inductance throws the plate current and plate voltage out of phase. The actual relation is that the alternating component of the plate voltage is 180 degrees out of phase with the plate current. This is an important factor which must be borne in mind and which will be made use of later on.

In order for a vacuum tube to operate efficiently as a generator of alternating current power, it is necessary that certain conditions must be fulfilled. One of these requirements is that there must be some sort of load or resistance in the plate circuit which is equal to the plate resistance of the tube. It is also necessary to have such reactions occurring in the circuit to which the tube is connected so that when the plate current undergoes variations, the plate potential and grid potential both undergo the same variations of potential in opposite phases, and that the relative magnitude of these two potential variations be properly adjusted for the tube being used. The fundamental requirements of the problem can be readily specified. There must be a coupling between the plate circuit and the grid circuit so that variations in the plate current produce voltage variations in the grid circuit. This coupling between the two circuits must be such that the voltage induced in the grid circuit is in phase with the grid voltage and will assist any oscillations occurring in this circuit. Also, the voltage introduced into the grid circuit must be of such an amount that it will change the normal voltage of the grid and thus react and cause variations in the plate current accordingly; the plate current can then react and introduce further variations in the potential of the grid.

Since any variations in the potential of the grid cause similar variations in the plate current and then the plate current reacts on the grid voltage, it seems that there is some limit to this cycle or else we would have a continually increasing potential applied to the grid circuit. The limiting factor in this case can be determined, of course, from the fact that the plate current can never reverse its direction of flow. The variations in the grid voltage, no matter how great, can never cause a reversal in the flow of the plate current and the most that can be done is for the grid to become so negative that it will actually cut off any flow of current in the plate circuit. When this condition is reached, then the capacity of the tube is reached and further increases in the variation of the grid voltage will not cause any further variations in the plate current, because the plate current is cut off entirely for a certain amount of time. The reason why the plate current is cut off for a certain length of time, of course, is due to the effect on the electronic stream flowing between the filament and plate of the tube when the grid becomes negative. Since this electron stream flows in one direction only, therefore, the plate current can only flow in one direction only, and since the negative values of grid potential produce a decreasing plate current, then the limiting factor of oscillation is for the grid to become so negative that it will actually stop the flow of any plate current at all.

RECEPTION OF UNMODULATED CONTINUOUS WAVES

If an unmodulated continuous wave signal is impressed upon the grid circuit of a non-regenerative detector, there will not be any response in the headphones or loudspeaker. This is due

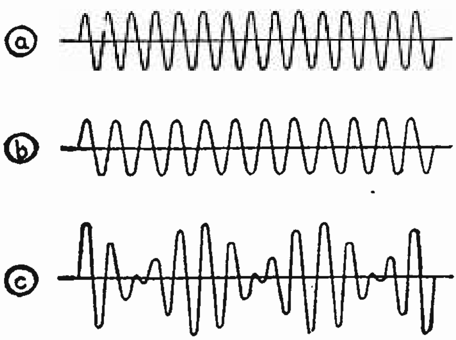

Fig. 11—Graphical representation of the "beat" principle.

to the fact that the radio frequency potentials applied to the grid cause corresponding radio frequency variations in the plate current and if the amplitudes of these variations do not change in an audible manner, then the headphone or loudspeaker cannot make a sound because there is no audio frequency variation and the diaphragm on the loudspeaker cannot respond to the radio frequency variations of the plate current and if it could, the human ear would not respond to such high frequency variations. This has previously been explained under "Detection" and the necessity for modulation or varying the amplitude of the radio frequency wave was brought out.

Since most radiotelegraph stations now use continuous waves instead of damped waves, some means must be provided whereby it is possible for a vacuum tube detector to detect the presence of these signals. Radio invention, therefore, borrowed from the musical science and other sciences some principles which have long been known in these sciences. One of these principles is the adaptation of "beat" or the combination of two different frequencies in order to produce a frequency entirely different to either of the two.

We are not all musicians but most of us have had the experience of listening to some kind of a musical instrument. Take for example a piano. If one key of the piano is pressed, a certain note is heard. If another key is pressed, another note is heard. Now, if two keys are pressed at the same time, the combination of the sound produced is entirely different from the sound produced when either of the keys were pressed separately. This is due to the fact that each string of the piano which was caused to vibrate by the touching of the key had a definite frequency and vibrated at this definite frequency. When the two keys were touched, we had two different strings vibrating at different frequencies and each emitting sound waves of a different frequency. These different vibrations when received by the ear produced a third vibration which was equal to the difference between the two vibrations. In the first case, suppose that the first key which was touched caused the string to vibrate at a frequency of 1,000. If the second string vibrated at a frequency of 800, then the third frequency produced by the combination of these two frequencies was 200, which is equal to the difference between the frequencies of the two strings. When such a condition exists and a third frequency or sound is generated, caused by the combination or the mixing of two other frequencies or sounds, it is referred to as a "beat" or "beat frequency."

Similarly, if two sources of undamped electrical oscillations of constant amplitude act simultaneously upon the same circuit, one having a frequency of 1000 kilocycles and the other a frequency of 1001 kilocycles per second, we will also have a beat frequency existing in the circuit having a frequency of 1 kilocycle. The amplitude of the resulting beat frequency will successively rise to a maximum and fall to a minimum at the rate of 1000 times per second, the difference between 1000 kilocycles and 1001 kilocycles. If these two frequencies be impressed on the input circuit of a detector tube, the variation of the resulting beat frequency will produce an audible note having a frequency of 1000 cycles (1 K. C.) in the plate circuit of this detector tube. If one of the two frequencies is the received signal in the antenna, and the other is generated locally, we have "beat" or "heterodyne reception." In the receiving telephone, a musical note is heard whose pitch is readily varied by a slight variation of the frequency of the local generating circuit.

Figure 11 illustrates graphically this principle, (a) represents the incoming oscillations impressed on the antenna by the approaching wave; (b) represents the locally generated oscillations that are impressed also on the input circuit of the detector tube, and (c) represents the resultant beat frequency that exists and becomes audible in the headphones or the loudspeaker.

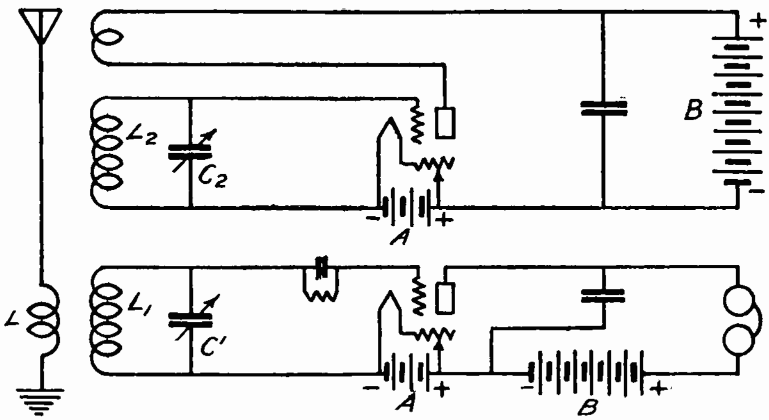

Fig. 12—Circuit diagram using a separate Heterodyne.

It will be noticed by close observation that the waves of (a) and (b) differ slightly in frequency and that as the peaks of (b) come in phase with the peaks of (a) and coincide with these peaks, that the peaks of the wave (c) gradually rise. When the peaks of (b) do not coincide with the peaks of (a), then the peaks of the wave (c) are at a minimum.

From the foregoing, it can be seen, then, that in order to create this beat frequency, it is necessary to have some form of generator of high frequency alternating current. From the foregoing explanation of the action of a vacuum tube as an oscillation generator, it can be seen that an additional tube could be used and this tube caused to act as a generator of oscillations. If such a second tube and circuit is placed near the detector so that the oscillatory circuit of the local generator is in inductive relation with the tuning circuit of the detector, then by varying the frequency at which the local generator is oscillating, the two frequencies can be impressed on the grid or input circuit in order to create the beat frequency.

In Figure 12 such a combination of circuits is shown. By varying the capacity of condenser C2, the frequency of the oscillations generated in the circuit L2 C2 is varied and the beat frequency existing in the circuit L1 C1 is caused to vary. This variance between the frequency of the two circuits can be made any desirable amount. If the oscillations generated in the local circuit L2 C2 have a frequency of 1100 kilocycles and the incoming frequencies impressed on the antenna and oscillating circuit L1 C1 have a frequency of 1000 kilocycles, then a beat frequency exists which is equal to the difference of these two frequencies

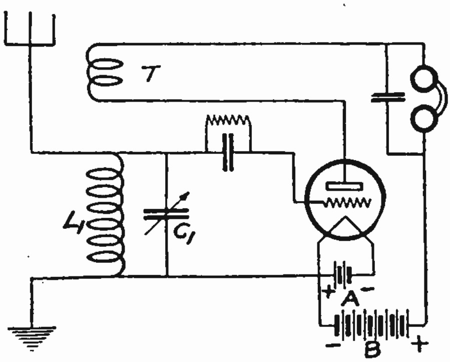

Fig. 13—The Autodyne circuit is simply a regenerative circuit.

or 100 kilocycles. As this beat frequency is not within the audible frequency limit, it is, therefore, necessary at all times to adjust the circuit L2 C2 so that it is generating a frequency which will beat with the incoming frequency and the difference between these two frequencies will create a third frequency which is within the audible band of frequencies which usually lies between 30 and 10,000 or 15,000 cycles. In most cases, the beat frequency usually corresponds to approximately 800 to 1000 cycles because the human ear is usually most sensitive to approximately 1000 cycles.

In the case just described where a separate source of locally generated high frequency oscillations is used to be impressed on the detector circuit, the scheme is generally known as "heterodyne reception" and the separate generator of oscillations is sometimes referred to as the "heterodyne oscillator" or simply as a "separate heterodyne." We shall now see how it is possible to produce the same results and eliminate this separate heterodyne oscillator or source of local oscillation.

When one vacuum tube is used to generate the source of high frequency oscillation and at the same time receive the incoming signal and the two are mixed in order to create the beat frequency, this form of reception is referred to as the "Autodyne" method.

In Figure 13, we have a simple form of the ordinary regenerative type of receiver using the tickler feed-back method of regeneration. Previously in this lesson it was stated if the coupling between the tickler coil T and the inductance L1 was increased to

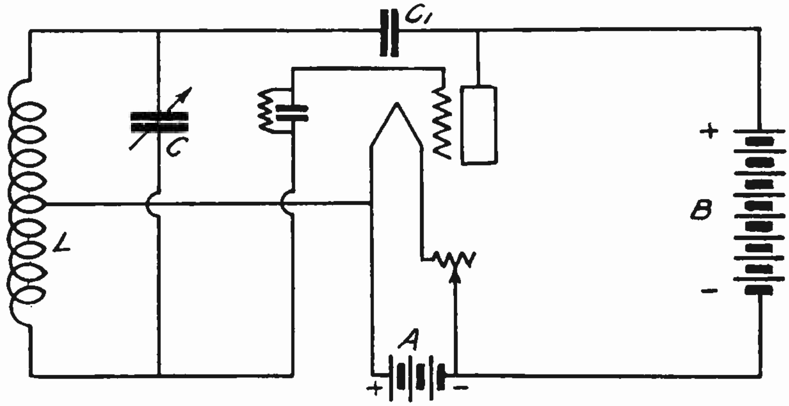

Fig. 14—Circuit diagram showing the Hartley Circuit.

the point where the feed-back voltage induced in the circuit L1 C1 was enough to reduce the effective resistance of this circuit to zero, then the tube would act as a generator of self-sustained oscillations. Therefore, we have one of the requirements necessary for beat reception; the generator of local oscillation.

By adjusting the tickler coil so that the detector circuit acts as a generator of self-sustained oscillations, and by varying the capacity of C1 so that the L1 C1 tuning circuit is adjusted to a slightly different frequency from that of the incoming signal, we have the other requirement for beat reception. Suppose that the incoming oscillations impressed on the antenna and L1 C1 circuit have a frequency of 1000 kilocycles. By adjusting the capacity of condenser C1 so that the L1 C1 circuit responds or is tuned to 1001 kilocycles, the 1000 kilocycle oscillations impressed on the antenna circuit will also be impressed by conduction on the L1 C1 circuit, but since this circuit is tuned to a slightly different frequency, the current in L1 C1 will not be as strong as if this circuit was tuned to exactly 1000 kilocycles. Nevertheless, the result of the incoming oscillations will cause oscillatory currents to flow in L1 C1 even though they are of slightly less amplitude and these oscillations will mix with the other oscillations in this circuit which are caused by the tube acting as a generator. Therefore, then, we have the second requirement for beat reception and that is, that we have the local generator circuit and also the tuning circuit. Since these two

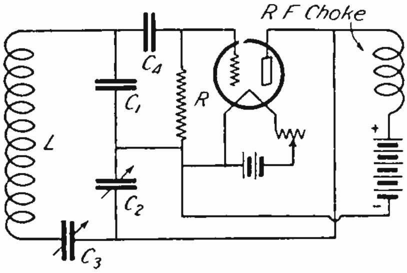

Fig. 15—The Colpitts oscillator circuit.

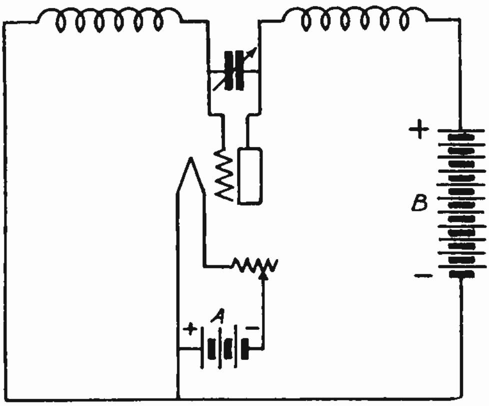

Fig. 16—A type of oscillator circuit proving very popular.

frequencies introduced in L1 C1 are different by 1000 cycles or 1 kilocycle, we have identically the same results and the same oscillations impressed on the grid of this circuit as we have in the case where a separate oscillator or heterodyne was used. The variations impressed on the grid circuit will rise and fall at a frequency of 1000 cycles per second and will cause changes in the plate current and the variations in the plate current will rise and fall at an audio frequency also and these are detected and reproduced by the loudspeaker or headphones.

It has been stated that the tickler coil connections could be reversed and the effect of oscillation or regeneration could be increased or decreased. There is a definite rule for the connections to the tickler coil in order for oscillation to take place.

Suppose that the grid coil and the tickler coil were both wound on the same winding form and the turns were wound in the same direction—then, in order for the tube to oscillate, it would be necessary that the grid be connected to one of the outside end terminals and the plate to the other outside end terminal, or that the plate be connected directly to the inside end of the plate coil and the grid be connected to the inside end of the grid coil.

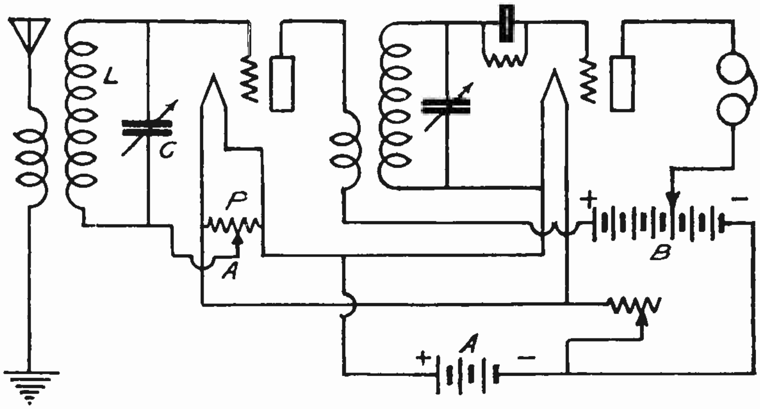

Fig. 17—Potentiometer control of grid bias.

This will keep the two magnetic fields in such relation that the induced voltage will be in phase with the grid circuit voltage. If these connections are reversed, regeneration and oscillation will not take place.

By referring to Figure 14, we have another form of circuit which is used considerably when an oscillating vacuum tube circuit is desired. It can be noticed that in this case only one coil is used and the grid connected to one end of this coil, whereas the plate is connected to the other end and the filament is connected to a center tap on the coil. This form of oscillator circuit is commonly referred to as the "Hartley" type. It will be noticed that the condenser C1 is connected in series between the plate and one end of the coil. This condenser can either be a fixed or variable type and its main purpose is a blocking condenser to keep the D. C. plate voltage off of the inductance L and the grid of the tube. If it is a fixed condenser and of the proper capacity so as to allow the correct amount of feed-back to take place, then the circuit will act as a generator of alternating current. If it is a variable condenser and of the correct capacity, the amount of feed-back can be controlled and regeneration accomplished just as in the tickler type where the amount of induced voltage fed back was regulated by the magnetic coupling between the two circuits. In this case, the coupling is controlled by varying the capacity instead of varying the magnetic coupling. The condenser C controls the frequency at which the tube oscillates. There are two other types of oscillators shown in Figures 15 and 16 and later on in one of the advanced text-books, these circuits will be taken up in detail.

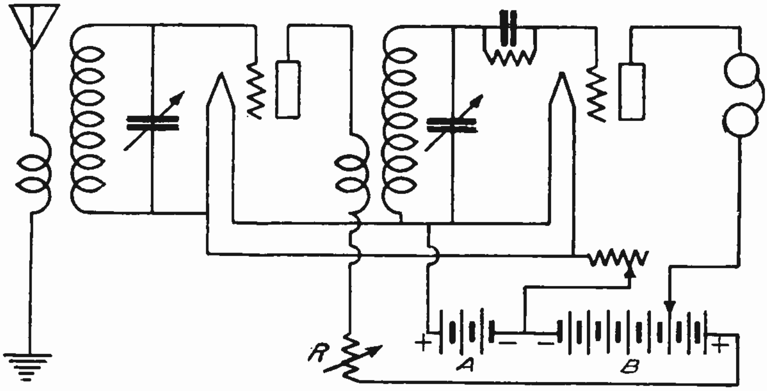

Fig. 18—Reducing the plate voltage by a variable resistance, reduces the tendency to oscillate.

NEUTRALIZATION

From our definition of "Neutralization" and what has already been explained, it can readily be seen how some forms of neutralization can be accomplished. Under the explanation of oscillation, it was shown that if the induced voltage was in opposite phase to that of the voltage in the grid circuit, then regeneration and oscillation could not take place because the induced voltage would not assist the oscillations in the grid circuit and cause them to build up, but would decrease these oscillations.

After broadcasting became popular and it was necessary to use stages of radio frequency amplification preceding the detector circuit, considerable difficulty was experienced due to the feed-back between the elements of the tubes themselves. In this case, the plate circuit, of course, was not tuned. However, it is not necessary to have both the grid and plate circuits tuned; a tuned grid circuit with sufficient inductive reactance in the plate circuit, may set up oscillations with no other coupling than that between the elements of the tube. This becomes increasingly likely as the oscillator circuit is made more efficient (less resistance) and as the circuit is adjusted for higher frequency. Thus, a radio frequency, transformer coupled, tuned amplifier, may operate well at the larger values of the tuning condenser (lower frequencies); but if the capacity is varied, causing the circuit to respond to a higher frequency, the tuning becomes sharper, denoting to one skilled in Radio the presence of regenerative action. As the higher frequencies are approached, the oscillations occur easier and these are set up in the tuned circuit. For the re-

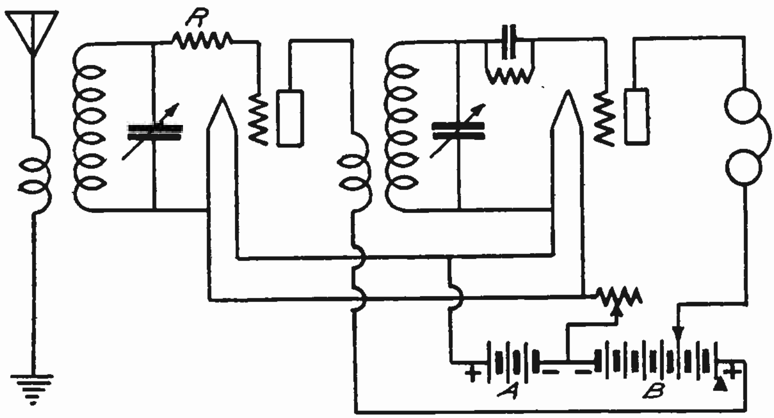

Fig. 19—Resistance inserted in the grid circuit to prevent oscillation.

ception of broadcast signals, the amplifier becomes useless due to the distortion caused by the circuit generating self-sustained oscillations.

Various schemes have been devised to control these oscillations in tuned amplifiers, in which the resistance of the oscillatory circuit is sufficiently increased at the higher frequencies to offset the tendency of the tube to generate oscillations. The first scheme used for the control of such undesirable oscillation is shown in Figure 17. This scheme is often referred to as potentiometer control, stabilizer, or a losser method. A high resistance potentiometer (200-400 ohms) P is connected directly across the "A" battery and the tube input circuit, L-C, is connected at the filament end to the sliding contact A. Thus the average grid potential (grid bias) can be given any value between that of the negative end and that of the positive end of the "A" battery.

Figure 18 illustrates another method for controlling regeneration and oscillation, in which a variable high resistance is connected in the plate circuit of the tube so as to regulate the amount of current and voltage applied to the plate. By lowering the voltage applied to the plate, the tendency to oscillate is decreased.

Another method for controlling oscillation under the losser scheme is shown in Figure 19. This scheme is used in some of the later receiving sets and the resistance (R) in the grid circuit merely introduces enough loss and raises the resistance of this circuit; hence the feed-back occurring between the elements of the tube never decreases the effective resistance of the tube circuit to the point where self-sustained oscillation can take place.

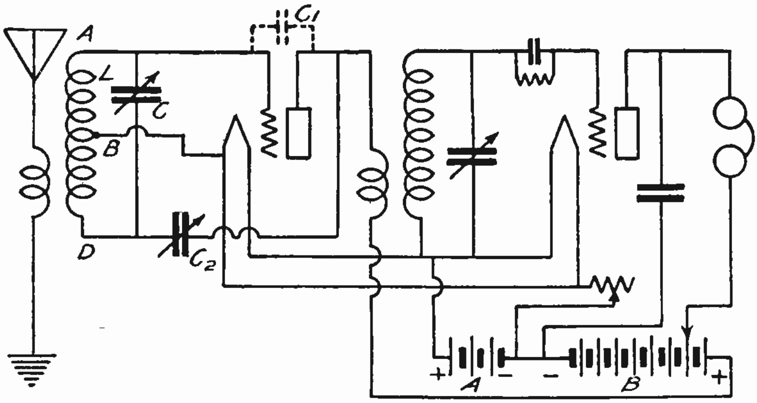

Fig. 20—The Rice or grid form of neutralization.

TRUE NEUTRALIZATION

It is evident from previous explanations that if the grid potential is not allowed to change, due to the change in plate potential, feed-back or regenerative action could not occur. Another opposing voltage may be introduced in the grid circuit by an electromagnetic coupling between the grid and plate circuits. Such an expedient can be expected to work over a comparatively narrow frequency band. However, as it is not possible to just balance a capacitive feed-back by a magnetic feed-back throughout a wide range of frequencies, the magnetic feed-back must be made adjustable if such a scheme is to be most effective, and the receiving set operator will have to change the magnetic coupling as he changes the tuning capacity. The better scheme is to utilize another capacitive feed-back between the plate and grid circuits and so arrange the circuits that the voltage impressed on the grid through this added condenser is just equal and opposite to that impressed on the grid through the plate-grid capacity. It will be seen that this scheme involves the selection of a suitable point in the grid circuit and connecting this point to the plate through the added balancing condenser, or the selection of a suitable point in the plate circuit and connecting this point to the grid through the balancing condenser. In case the circuit arrangement is such that the suitable point called for cannot be located, it may be necessary to add another coil in one or the other circuits, or to seek a point in a circuit coupled to the grid or plate circuit.

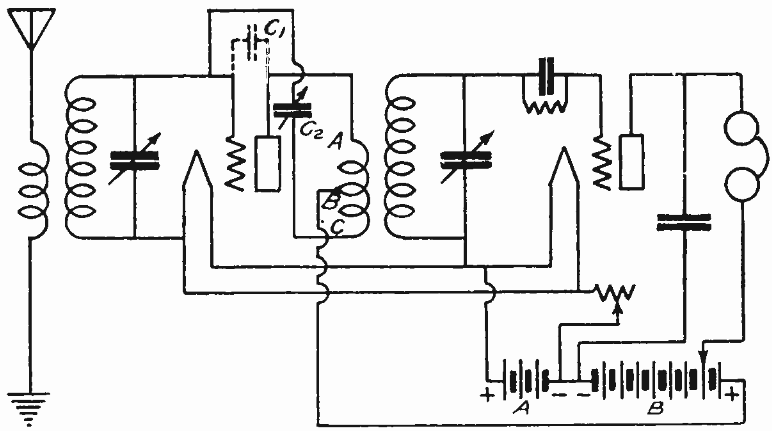

Fig. 21—The so-called "plate form" of neutralization.

Many sets have been put on the market in which this balancing scheme has been employed; some of them neutralized from grid circuit to plate and others neutralized from plate circuit to grid.

In Figure 20 is shown one method of applying neutralization, this being of the grid form. This scheme is also referred to as the Rice system of neutralization. The filament is connected, not to the end of the coil, A-D, of the input circuit, but at an intermediate point B which may be the middle. Then condenser C2 is connected as shown, and, if point B is the midpoint of coil A-D, then condenser C2 is given the capacity equal to the grid-plate capacity of the tube, indicated in Figure 20 by the condenser C1. Merely by inspection, it can be appreciated that any tendency to make the L-C circuit oscillate, due to voltage from the plate being impressed on the point A through condenser C1 will be nullified by the equal and opposite voltage impressed on point D through C2. Thus, a change in plate voltage cannot start oscillations in the L-C circuit. It will be further appreciated that any disturbance set up in the L-C circuit cannot affect the plate voltage as condenser C1 and C2 will produce equal and opposite effects on the plate for any current circulating in the L-C circuit.

It is not necessary to have point B (Fig. 20) in the middle of coil L at all; it might be anywhere in the coil and the scheme will

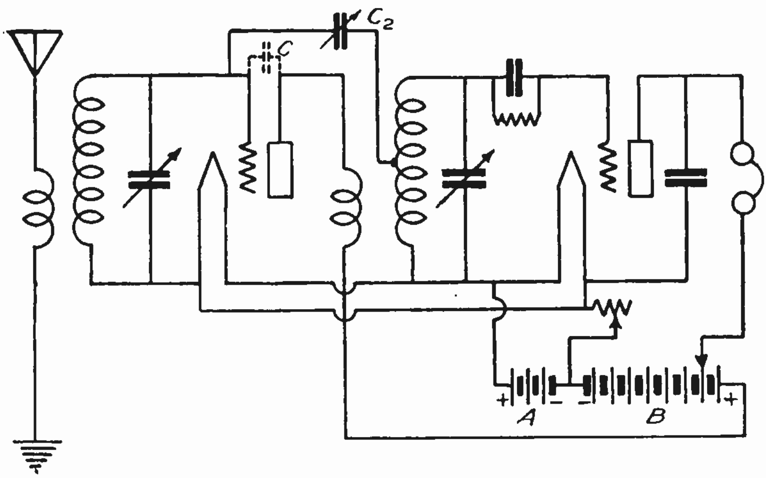

Fig. 22—The Hazeltine system of neutralization.

still work providing the capacity of condenser C2 is properly chosen. It will be appreciated that to get equal and opposite voltages on the plate, the ratio of condensers C1 and C2 must be fixed by the ratio of voltages across B-D and B-A. But condenser C1 cannot be altered as it is inherent in the tube, so condenser C2 is the one that must be changed to effect neutralization. This is so adjusted that the ratio of C1 to C2 is the same as the ratio apparent from D-B to B-A. The fewer turns there are in coil L from B to D, the larger must be C2 to balance the effect of C1.

In Figure 21 is shown one arrangement for effecting neutralization from the plate side of the vacuum tube. As it is normally impossible to find a point directly in the plate circuit which has the opposite potential to that of the plate, we have recourse to the same expedient as used in Figure 20. Instead of making the B plus connection to the end of the plate coil at C, we connect it at a midpoint B. Then, point B will go up and down in potential in phase opposite to the potential of the plate, just the same as in Figure 20, point D and A have opposite voltages. In Figure 21, the neutralizing condenser C2 is connected between point C and the grid. If point B is not the midpoint of coil A-C, then C2 will have a different capacity than C1, its value being greater as the turns from B-C are fewer.

In Figure 22 is shown the Hazeltine scheme of neutralization. Here the point of potential opposite that of the plate is found in the secondary of the plate circuit transformer—that is, in the input circuit of the next tube. In Figure 22, the point is shown as an intermediate one on the secondary coil but this point may, of course, be the end of the coil. In this scheme, it is important that the primary and secondary coils of the plate transformer be connected with proper relative polarity, otherwise this point will have a voltage of the same phase as that of the plate and then, of course, the neutralizing circuit will act to help the normal regenerative action of the tube.

TEST QUESTIONS

Number your Answer Sheet 17-2 and add your Student Number.

1. What is regeneration?
2. Draw a circuit diagram of the Armstrong regenerative circuit.
3. What is the meaning of neutralization?
4. What determines the natural frequency of an oscillating circuit?
5. When will a vacuum tube act as a generator of self-sustained oscillations?
6. Is it possible for the plate current to reverse its direction of flow?
7. Draw a circuit diagram of a receiver that can be used for the reception of unmodulated continuous waves.
8. Draw a circuit diagram illustrating the Hartley type of oscillator.
9. Do oscillations in a radio frequency amplifier occur easier at high or low frequencies?
10. In Figure 20 is it necessary to have point B in the middle of coil L?

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