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LESSON TEXT No. 34

STANDARD TUBE CIRCUITS FOR BROADCASTING TRANSMITTERS

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

To transmit speech by Radio, it is necessary to have a source of radio-frequency energy and a means of varying this energy in accordance with the variations in speech frequency. Controlling the radio-frequency energy in this manner is known as "modulation."

Two simple types of telephone transmitters are shown in Fig. 1, C is a variable condenser. L is an inductance coil,

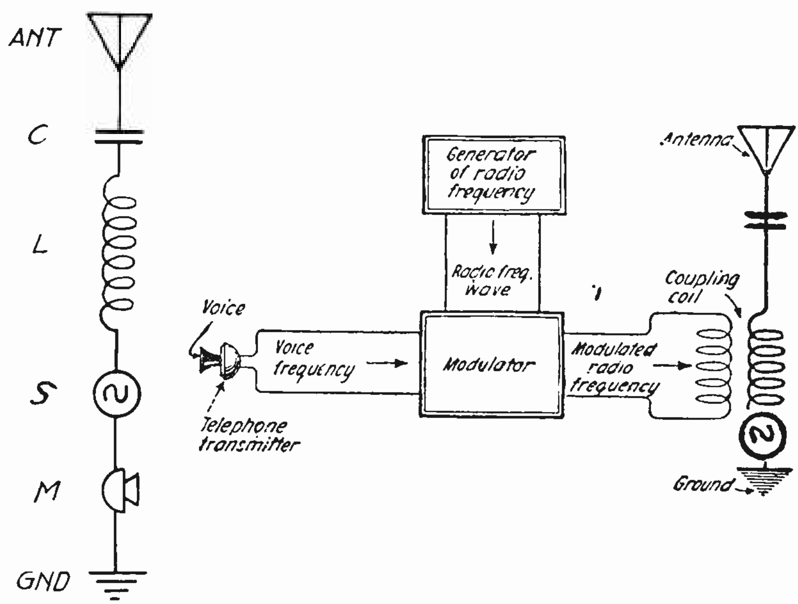

Fig. 1—The diagram to the left shows the parts for a simple type of Radio phone transmitter, while the picture above illustrates the actual apparatus installed in the Broadcasting Station.

S is a source of radio-frequency energy. M is a microphone, and GND the ground or earth connection. The microphone may be of the ordinary carbon granule type and since a clear understanding of its functioning is necessary in order to better understand the facts which are to follow, a description of the construction and functioning of this piece of apparatus will be considered at this point, in detail.

Figure 4 is a cross-sectional view of the carbon granule type of microphone. This diagram gives a good idea of the construction of the microphone when stripped of details. The elastic diaphragm, D is mounted on the rubber ring support AA, which in turn is held against the metal frame of the microphone case, B. The elastic diaphragm is mechanically connected to a carbon block, T_1 which is placed opposite another similar carbon block, T_2. The chamber between the carbon blocks is filled with small carbon granules, C. This chamber is sealed by means of the mica washer, E, and the insulating nut, F. The wall of the chamber containing the carbon granules is covered with a strip of paper, G. The two carbon blocks T_1 and T_2 are the electrical terminals of the microphone. If a source of emf. is applied to the two terminals of the microphone, a current will flow through the carbon granules. If the source is of constant polarity (D. C.) the flow of current will be unidirectional. If the source is of constantly changing polarity (A. C.) the current will flow first in one direction and then in the other. The value of the current will depend upon the potential applied and the resistance of the carbon granules. As long as the diaphragm remains in one position, the current will be constant but it is a property of these carbon granules in the microphone to vary in resistance as the mechanical pressure exerted upon them is varied. As the pressure is increased (an inward movement of the diaphragm), the resistance is decreased and as the pressure is decreased (an outward movement of the diaphragm), the resistance is increased. Hence, the current flowing through the microphone is increased or decreased. When speaking into the microphone, the diaphragm vibrates in synchronism with the frequency of the sound waves produced by the voice. The resistance varies in synchronism with the voice frequencies and it follows that the current flowing through the carbon granules within the microphone, varies in similar manner. The type of microphone just described is very sensitive to changes of pressure on the diaphragm. The current carrying capacity of such a device is very small due to the fact that a limit is soon reached where arcing occurs between granules, the contact points of which become red hot and the microphone becomes useless. The average resistance of a unit of this type is between 50 and 100 ohms. The current carrying capacity is about 0.1 of an ampere. The power capacity is a maximum of $.1^2$x100 or 1 watt. There are some special low resistance microphones (10 to 20 ohms) which have a current carrying capacity of .5 ampere and a maximum power capacity of $.5^2$x25 or 5. watts.

Going back to the circuit diagram shown in Figure 1. When the microphone is not being spoken into, the diaphragm remains stationary and exerts a constant pressure on the carbon granules, the resistance remains constant and the radio-frequency current in the antenna circuit is of constant amplitude as shown in Fig. 2. If the diaphragm of the microphone

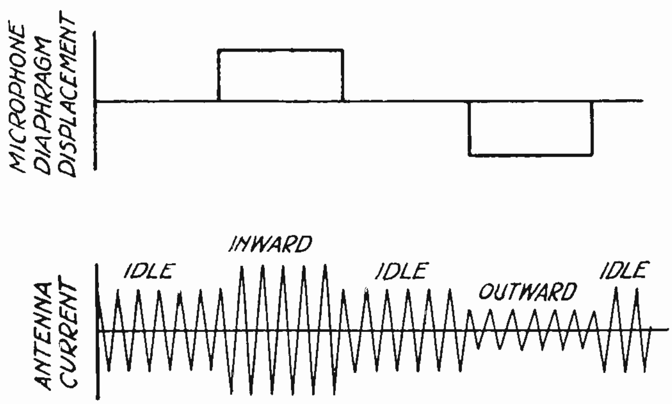

Fig. 2—This illustrates the change in amplitude for the Radio-frequency or carrier wave when the microphone diaphragm is moved inward and then outward by a fixed amount.

is depressed inward, the pressure on the carbon granules increases, the resistance decreases and the amplitude of the antenna current increases and remains constant at this value as long as the diaphragm is maintained in that position. When the diaphragm is released, the resistance will return to normal and the antenna current will return to its normal value. Again, if the diaphragm is pulled outward, the pressure decreases, the resistance of the carbon granules increases and the antenna current subsequently decreases and remains at this lower value as long as the diaphragm is held in the outward position. Then, of course, when the diaphragm is released, the resistance will return to normal and the antenna current will again reach its normal value.

For the sake of simplicity at this point in the discussion, let us assume that a 1,000 cycle tuning fork is set vibrating and placed in front of the microphone. Due to the sound waves from the tuning fork, the diaphragm of the microphone will vibrate at a frequency of 1,000 cycles. Looking at Fig. 3 if the line, NN, represents the normal position of the microphone diaphragm when idle, then the sine curve superimposed upon the straight line, NN, represents the action of the diaphragm when the tuning fork is placed in front of the mouthpiece. The diaphragm attains its maximum inward and outward positions 1,000 times per second and the resistance of the carbon granules will vary accordingly. The antenna current will go from maximum to minimum and back to maximum again 1,000 times per second and it follows that the radiated energy will vary accordingly.

The radio-frequency is the "carrier-frequency." The radio-frequency current is the "carrier-current." The frequency of the microphone diaphragm, which in this case is 1,000 cycles per second, is the "modulating frequency."

From the foregoing, it is obvious how it is possible to modulate the carrier current by the voice and transmit speech. Instead of placing the tuning fork in front of the microphone, it is simply necessary to talk into the mouthpiece. which in that case would vibrate in accordance with the complex air vibrations produced by speaking.

Figure 3-A illustrates a modulated carrier-wave. When a letter is spoken into the microphone, it varies the amplitude of the carrier-wave (b); in other words, it cuts off the peaks of the radio-frequency waves; (a) represents the voice-frequency.

Each sound going into the microphone has a frequency or vibration all its own, and the part illustrated by (c) shows that the peaks of the radio waves have been chopped off according to the audio-frequency vibration of the microphone.

√ The oscillator tube in a broadcasting station sets up the carrier-frequency. This frequency is continuous and does not vary and it is governed by the amount of capacity and inductance in the oscillator circuit. For example, a 400 meter broadcast station, the carrier-frequency is 750 kilocycles.

√ The modulating frequency is that frequency impressed upon the carrier by the microphone and the modulator tube. This modulating frequency depends upon the nature of the sound being impressed upon the microphone, which may vary from as low as 30 cycles to as high as 10,000 cycles per second.

The ordinary range of the voice in frequency is from approximately 100 cycles to 5,000 cycles per second.

The complex vibrations of the microphone due to speech may be resolved into an infinite number of harmonic components of different frequencies, different amplitudes and bearing certain phase relations to each other. Theoretically, the number of these components is infinite, but practically, only those having a frequency of between 300 and 2,000 cycles per second have an amplitude great enough to be considered. The amplitudes of the others are so small that they are negligible.

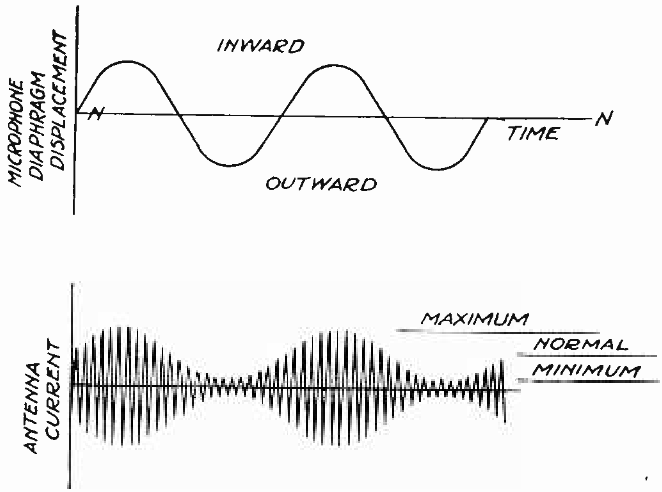

Fig. 3—This illustrates the change in amplitude of the radio-frequency waves when the microphone is acted upon by a tuning fork.

The following is a principle which is of very great importance in radiotelephony as well as wire telephony: As long as the amplitude of the harmonic components of the transmitting microphone diaphragm vibrations are reproduced in the receiving telephone diaphragm vibrations (bearing the same ratio to one another that they had at the start, without any reference whatever to phase relations) the speech, which caused the vibrations, will be faithfully reproduced in the receiver without any distortion.

We have seen from the foregoing that it was necessary, in order to transmit speech by Radio, to have a source of radio-frequency current of constant amplitude (C. W.), and a system of modulation. Of the various sources of radio-frequency, the following have been most generally used for radiotelephony:

The Alexanderson Alternator. The Poulsen Arc.
The Fessenden Alternator. The Vacuum Tube.

DIFFERENT TYPES OF VACUUM TUBE TRANSMITTING CIRCUITS

The vacuum tube may be used in many types of circuits to generate radio-frequency currents. *A discussion of the*

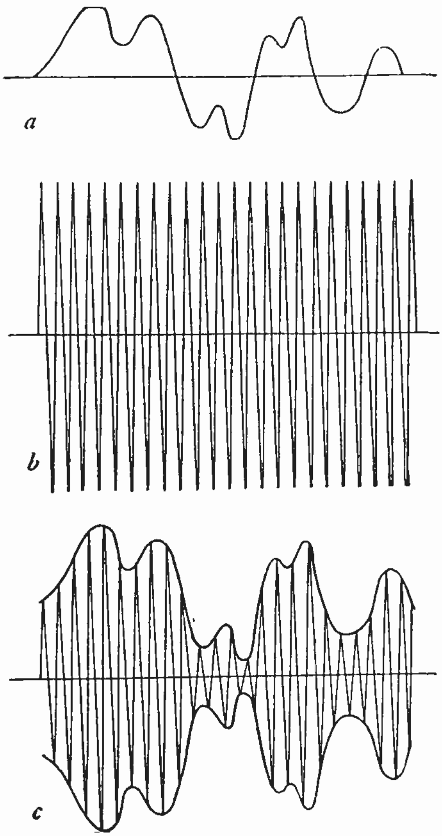

Fig. 3-A—The wave forms of Radio. "a" is the voice frequency from the microphone. "b" is the radio-frequency or carrier-wave from the generator unit. "c" is the resultant modulated radio-frequency (carrier) wave delivered to the aerial by the modulator unit.

fundamentals of the most important of the different types of oscillatory circuits follows. The various types are usually designated by the names of their inventors and fundamentally they are all the same. The circuits that we are going to consider at this time are of the self-excited type. The fundamentals of all of the oscillatory circuits of this type are, the vacuum tube; the power source ("B" battery); the load circuit (transmitting antenna), and a means of feeding back power to the grid circuit for its excitation. The circuits follow in the order of their importance.

MEISSNER CIRCUIT

The "Meissner" circuit is named after Dr. A. Meissner, of the Telefunken Company, of Berlin, and is shown in Fig. 5. The D. C. plate supply flows through the inductance, Lp. The constants of the plate circuit determine the frequency of the oscillations generated by the tube, namely, the inductance, Lp and the capacity, Cp, Cg and Rg are the grid con-

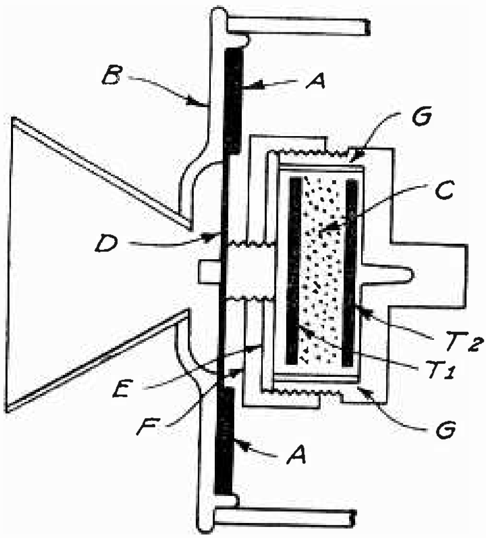

Fig. 4—This illustrates a cross-sectional view and the constructive features of a carbon type of microphone.

denser and grid biasing resistance, respectively. The former is of sufficiently high capacity to offer a low resistance to the flow of the radio-frequency currents being generated by the tube and is, therefore, a "by-pass" for these currents. It blocks off all D. C. in the grid circuit to such a point that it is necessary for this D. C. grid current to flow through the biasing resistance, Rg. There is a flow of direct current in the grid circuit due to the passage of electrons from the filament to the grid just as there is a flow of direct current in the plate circuit due to the flow of electrons from the filament to the plate. Of course, the grid current is much smaller than the plate current. This grid current flows through the resistance, Rg, towards the grid and there is a drop in voltage across this resistance as shown in the Fig. 5, the end of the resistance near the grid being negative and the other end positive. Since the positive end of the biasing resistance is connected to the negative filament lead, the grid has a negative bias, the amount of which depends upon the value of the biasing resistance and the grid current flowing in the circuit. Using a 250 watt tube, type UV-204, the grid resistance might be 10,000 ohms and the grid

Fig. 4-A—A Microphone transmitter as used in Radio broadcast stations.

current about 30 milliamperes, consequently there would be a drop of 300 volts across the biasing resistance and the grid would be 300 volts negative. The grid coil, Lg, is inductively coupled to the plate coil, Lp, and it is by this means that energy is fed back to the grid for its excitation. Due care must be taken to have the proper phase relation in obtaining this feed-back for the grid excitation or the feed-back action may tend to block oscillations rather than maintain them. If either the grid coil or the plate coil is reversed from the position it should be in, the alternating current fed back to the grid will be 180 degrees out of phase with the pulsations in the plate circuit and there will be a bucking action rather than a boosting action, hence oscillations will not be maintained. The grid circuit as shown is simply an untuned pick-up circuit but may be tuned to the frequency of the plate circuit by shunting a capacity of the proper value across the grid coil, Lg. The antenna coil is inductively coupled to the plate circuit and is tuned to the frequency of that circuit. This circuit is very flexible and by means of the coupling between the plate circuit and the antenna circuit, the transfer of power from the tube to the antenna circuit can be taken care of. The adjustment of the feed-back is conveniently made and does not depend upon the voltage drop across a reactance in the load circuit as in the case of the Hartley and Colpitt's circuits.

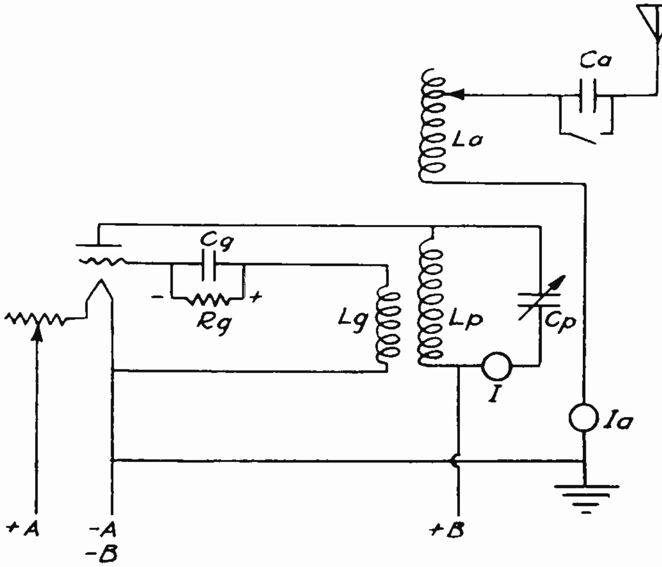

Fig. 5—Wiring diagram for the Meissner transmitting circuit.

TICKLER-COIL CIRCUIT WITH INDUCTIVE PLATE COUPLING

In Figure 6 the "Tickler" coil circuit with inductive plate coupling is shown. The antenna circuit consists of the antenna, the series condenser, Ca, the inductance, La, the ammeter, Ia and the ground. The plate is connected to the positive side of the high voltage plate supply through the inductance, Lp. The grid radio-frequency circuit is coupled to the antenna circuit through the condenser, Cg. The grid leak circuit is composed of the radio-frequency choke coil, Xg, and the grid biasing resistance, Rg. The choke coil keeps the radio-frequency currents out of the grid leak circuit. Without this choke coil, there is a lost of 20 watts in a 5,000 ohm grid leak when using a 250 watt tube, which is 8 per cent. of the normal power. This loss is due to the passage of radio-frequency currents through this biasing resistance. When the choke coil, Xg, is used, the loss is decreased to .5 watts which is .2 per cent of 250 watts. The amount of grid excitation is determined by the capacity, Cg, and the point at which the grid is tapped on the coil, La. The coupling between

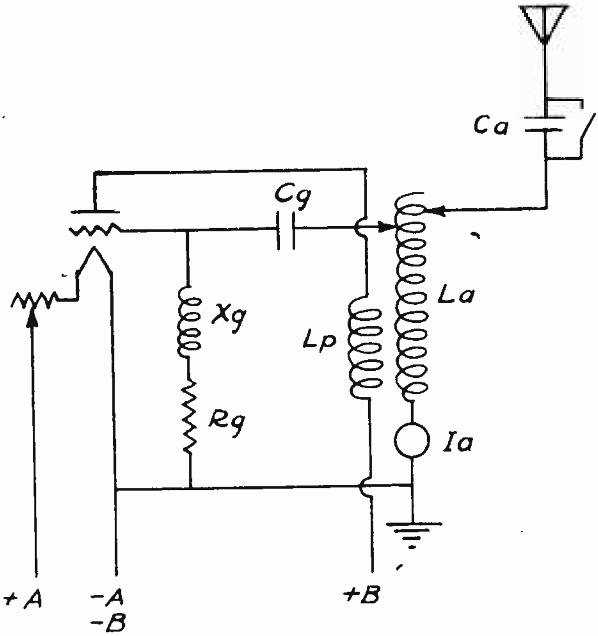

Fig. 6—Transmitting circuit diagram for the tickler coil type of circuit with inductive plate coupling.

plate and grid due to the coil, Lp, maintains the oscillatory condition. The constants of the antenna circuit determine the frequency of the oscillations generated by the tube.

TICKLER-COIL CIRCUIT WITH INDUCTIVE GRID COUPLING

In Figure 7 the "Tickler" coil circuit with inductive grid coupling is shown. The antenna circuit shown here is the same as in the previous case. The plate potential is supplied through the radio-frequency choke coil, Xp. The purpose of this coil is to isolate the radio-frequency in the plate circuit from the high potential plate supply. The plate is connected to the antenna coil, La, through the blocking condenser, Cp. The purpose of this condenser is to keep the inductance coil, La, from short circuiting the D. C. plate source. Rg and Cg are the grid biasing resistance and grid condenser, respectively, and function as previously described. The grid excitation is derived by means of the grid coupling coil, Lg. The grid circuit as shown in the figure is an untuned pick-up circuit but may be tuned to the frequency of the antenna by shunting a capacity across the coil, Lg. Obviously, these last two circuits described are not as flexible as the Meissner circuit which was described first.

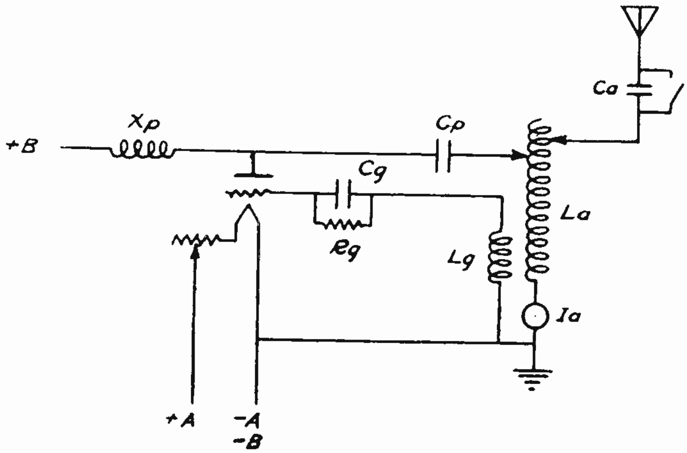

Fig. 7—Transmitting circuit diagram for the tickler-coil type of circuit with inductive grid coupling.

REVERSE FEED-BACK CIRCUIT

The Armstrong tuned plate or reversed feed-back circuit named after its inventor, Mr. E. H. Armstrong, is shown fundamentally in Fig. 8. In this circuit, the oscillatory condition, feed-back from plate circuit, is obtained by means of the small capacity coupling between the plate and the grid within the tube itself. This small condenser is formed by the grid and plate electrodes. It is important to note that the plate and grid coils are not inductively related but may be widely separated from each other. The only coupling between the plate and grid is the capacity coupling within the tube. The feed-back effect increases as the wave-length is shortened and depends upon the value of the grid plate capacity. The action may often be improved and controlled by connecting a variable condenser of small capacity (.0001 mfd.) between the plate and the grid. The principle of this circuit is different from any yet described. The important advantage of the Armstrong circuit is that the oscillations occur when the plate circuit is in resonance with the grid circuit. The frequency of these oscillations depends mainly upon the constants of the grid circuit but the constants of the plate circuit do have some effect upon the generated oscillations. This is an important point because by connecting the antenna to the plate circuit as shown in Fig. 9, the change in the antenna capacity due to swinging will not materially affect the frequency of the radiated oscillations as in those circuits where the antenna circuit

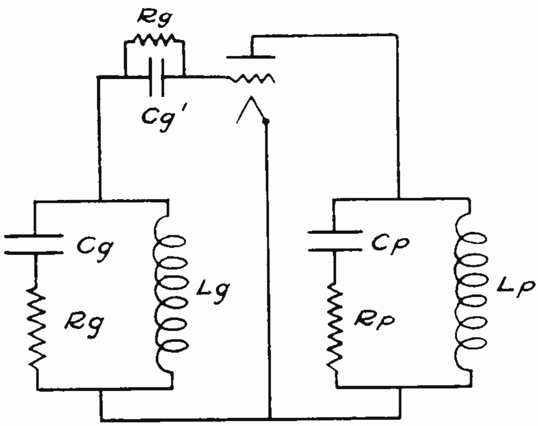

Fig. 8—The Armstrong tuned plate or reversed feed-back elementary circuit.

is directly associated with that circuit whose constants determine the frequency of the oscillations generated. The constant frequency advantage of the master-oscillator system is embodied to some extent in this circuit. Figure 9 shows the method of connections for transferring energy, generated by a tube in a circuit of this type, to an antenna. The tuned plate circuit shown in Fig. 8 is replaced by its equivalent, an antenna circuit of inductance, La, series capacity, Ca, and resistance. This circuit is tuned to the frequency of the grid circuit. The radio-frequency choke coil, Xp, functions as usual, to prevent the short-circuiting of the output circuit by the plate source. The blocking condenser functions conversely, to prevent the short-circuiting of the plate source by the output circuit.

COLPITTS CIRCUIT

The Colpitts circuit is shown fundamentally in Fig. 10 and is named after its inventor, Mr. E. H. Colpitts, of the Western Electric Company. The frequency of the generated oscillations depends upon the inductance, L, and the two capacities, Cp, and Cg, in series. These elements, together with the resistance, R, constitute the load circuit. The grid excitation is determined by the voltage drop across the condenser, Cg, the smaller the condenser, the greater the voltage drop and the greater the grid excitation. The grid excitation varies with the power capacity of different tubes. If a 1 k.w. tube were

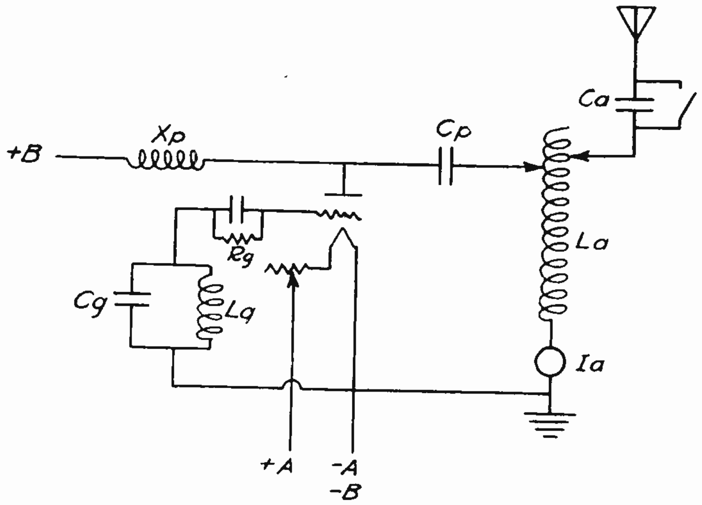

Fig. 9—The Armstrong tuned plate circuit showing its connection to the antenna.

used in this circuit, the values of inductance and capacity should be so chosen that, with 1 k.w. dissipated in the circuit, the total reactive voltage (that between the points x and y) would be 7,500 volts. The proper grid excitation for this tube is 1,000 volts, so the proper values for the condensers Cp and Cg are determined by the relation, Cg/Cp equals 6,500/1,000; then, Cg equals 6.5 Cp. Thus when the grid condenser, Cg, is 6.5 times as large as the plate condenser, Cp, the voltage drop across the grid condenser, Cg, will be 1/6.5 of the voltage drop across the plate condenser, Cp, giving 1,000 volts across the grid condenser and 6,500 volts across the plate condenser and 7,500 volts across the two.

Figure 11 shows the application of the Colpitts circuit to an antenna, with the addition of grid choke, Xg, grid leak, Rg,

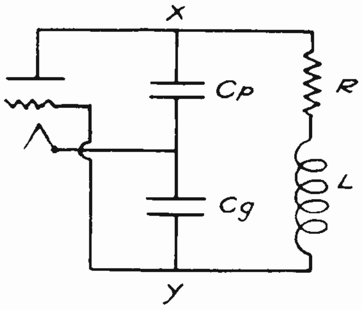

Fig. 10—Fundamental diagram for the Colpitts circuit.

grid blocking condenser, Cg, and plate choke, Xp, which function as previously described. This circuit is the same as the fundamental circuit shown in Fig. 10 with the exception that the plate capacity, Cp, has been replaced by the antenna which functions as a capacity. No plate blocking condenser is

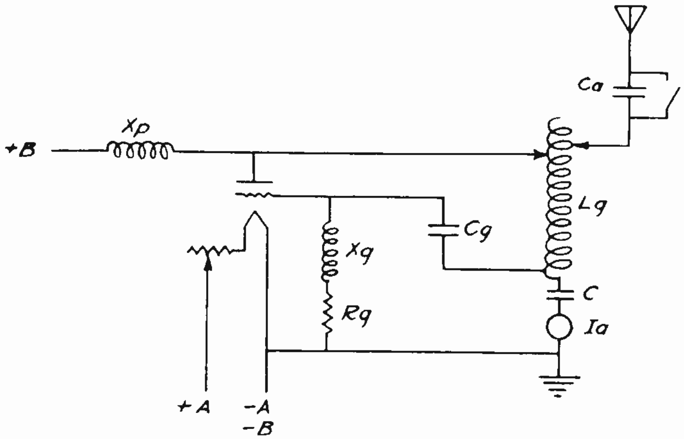

Fig. 11—Diagram of Colpitts circuit showing antenna connection.

necessary in this circuit, since, due to the load circuit arrangement, there is no possibility of the plate supply being short-circuited by the output circuit.

HARTLEY CIRCUIT

The Hartley circuit is named after its inventor, Mr. R. V.

L. Hartley, of the Western Electric Company and is shown in Fig. 12. The frequency of the oscillations generated depend upon the constants of the load circuit. The grid excitation is obtained by means of the voltage drop between x and y. As is the case in the Colpitts circuit, the grid excitation depends upon the voltage drop across a reactance in the load circuit, but in the Hartley circuit the reactive drop is across a coil, whereas in the Colpitts circuit the reactive drop is across a condenser. The greater the number of turns between x and y, the greater the voltage drop and the greater the grid excitation. As in the previous case, if a 1 k.w. tube, type UV-206 were used in this circuit, the total drop from x to z should be 7,500 volts and the drop from x to y 1,000 volts, thus leaving 6,500 volts from y to z. Figure 13 shows the application of this circuit to an antenna system. The fundamental change between the circuit shown in this figure and the one in Fig. 12

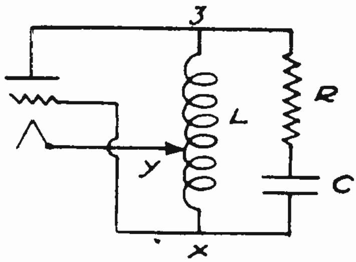

Fig. 12.—Fundamental diagram of the Hartley circuit.

is the replacing of the load circuit lumped capacity and resistance by the antenna circuit which has distributed capacity and resistance. This circuit, although not considered the best for direct application to an antenna system, has many useful applications both in transmitting and receiving, notably as a master-oscillator circuit for transmitting and as a local oscillator for heterodyne reception.

In the Hartley circuit, the voltage fed back by means of variations in the plate current, which excite the grid and cause it to vary, depends upon the reacting drop across the coil. This is an inductive effect and is the result of the current passing through an inductance; whereas, in the Colpitts circuit, the grid voltage or excitation depends upon the voltage drop or potential across a condenser.

From the preceding paragraphs, you have learned that it is necessary to cause the grid to have a varying voltage applied to it and in the case of the Hartley type of transmitting circuit, this voltage is obtained by means of an inductance, whereas in the Colpitts type, the voltage is obtained from the potential of a condenser.

COUPLING OSCILLATING CIRCUITS

U. S. Government regulations require the inductive type of coupling between the closed oscillatory system and the antenna system of a transmitter.

The oscillation transformer consists of the primary and secondary coils, which are mutually related and are mounted as one unit. Sometimes, in some installations, it is desirable to place the complete antenna system with coils outside of the building. In such installations it is necessary to connect the closed oscillatory circuit to the antenna system with a link circuit or feeder line as it is somtimes called, this coupling between the two circuits is effected either by inductive or capacitative coupling.

Whenever either of these two arrangements are used, the antenna inductance, antenna ammeter and ground connections are all in series; therefore, no part of the radiating system enters the building where the transmitter is located, only the feed wires connecting from the transmitter to the antenna.

This type of coupling is very often used to good advantage for short wave transmission becaue it reduces to some extent the length of the lead-in wires from the antenna to the set. It is also used advantageously in many high-power broadcasting stations.

THE MASTER-OSCILLATOR CIRCUIT

All of the foregoing types of oscillatory circuits described have been of the self-excited type; that is, they were of the type that supplied their own grid excitation. Now we come to the master-oscillator system which is the separately excited type of circuit. From an electrical viewpoint, this type of circuit is superior to any of the self-excited type. It is far more flexible than the latter and is less susceptible to frequency changes. This last feature is of special importance. The fundamental circuit shown in Fig. 14 is composed of two tubes. One is the "master-oscillator" used for generating the desired radio-frequency output and the energy thus obtained is used to excite the grid of another tube which is termed the "power amplifier" tube. The power amplifier tube in turn can feed into the antenna system, or, if there are several power tubes in the transmitting assembly, they can

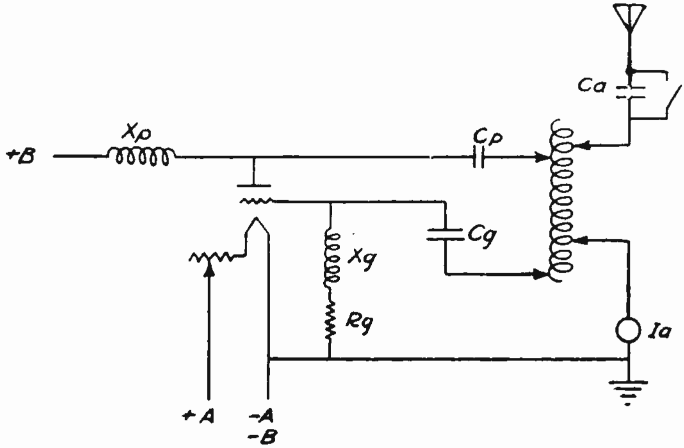

Fig. 13—Diagram of Hartley circuit showing antenna connection.

all be used in successive stages of amplification. The constants of the master-oscillator circuit determine the frequency of the energy to be radiated from the antenna. Due to the fact that the master-oscillator is not directly coupled to the

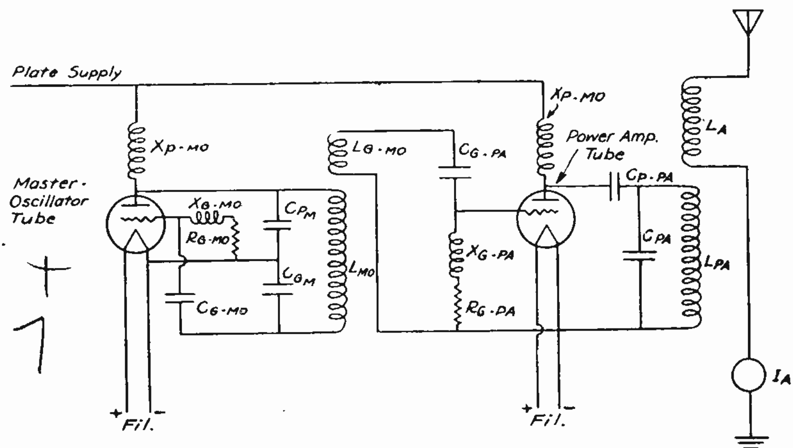

Fig. 14—Diagram of the Master-Oscillator circuit.

antenna system, this arrangement is free from frequency changes, in the course of transmission caused by a swinging antenna, etc. The master-oscillator tube simply has to be of sufficient size to supply the losses in its own oscillatory circuit and the losses in the grid circuit of the power amplifier tube. The losses in the grid circuit of the power tube would probably be between 2 per cent. and 10 per cent. of the total capacity of the tube, hardly ever over 10 per cent. The oscillatory circuit for the master-oscillator is of the Colpitts type and has already been described. The grid circuit of the power amplifier tube instead of being coupled to its own output circuit as in the case of the self-excited types, is inductively coupled to the master-oscillator oscillatory circuit inductance, Lmo. The grid of the power amplifier tube is supplied with the proper amount of grid excitation by varying the coupling to the master oscillator. The grid-blocking condenser, Cg-mo, grid choke, Xg-mo, and grid biasing resistance, Rg-mo, function as previously described. The plate circuit of the power-amplifier tube is tuned by means of the inductance, Lp-pa, and the condenser, Cp-pa, to the frequency of the oscillations generated by the master-oscillator. The antenna circuit is inductively coupled to the plate circuit of the power amplifier by means of the coupling coil, La. The adjustment of this system is simple. The master-oscillator is first set at the frequency desired. The power amplifier plate circuit is then tuned to resonance with the frequency of the master oscillator. The grid excitation of the power amplifier is adjusted for maximum efficiency. The antenna circuit is then tuned to the same frequency and its coupling to the power amplifier varied until maximum efficiency is obtained. On ships at sea, during heavy storms, the ship rolls and the antenna swings from side to side and is constantly changing in capacity. If a type of circuit were used in which the antenna circuit were directly associated with that part of the circuit whose constants determined the frequency of the radiated energy, the frequency would change, due to the change in antenna capacity, and the frequency of the radiated signals would vary in synchronism with the swinging of the antenna. This condition is unfavorable because signals of this type are difficult to understand at the receiving station. They would be strong one minute and the next minute would be weak due to the change in wave-length. Obviously, it would be impossible to vary the tuning of the receiver in synchronism with the variations in the frequency of the incoming signals. This condition is not only true of ship antennas but might likewise be true of shore-station antennas which are subjected to a strong wind. The master-oscillator system eliminates this condition due to a swinging antenna. In the case of the master-oscillator, the frequency is fixed by the constants of the master-oscillator circuit and there is no reaction from the antenna. The only thing that changes as the antenna capacity changes is the efficiency. As the antenna swings out of tune, the current in that circuit will decrease.

MODULATION SYSTEMS

Now that we have a source of radio-frequency energy, we must have a system of modulation. The function of the modulating system is to vary the radio-frequency output current in accordance with the low-frequency variations of the sounds to

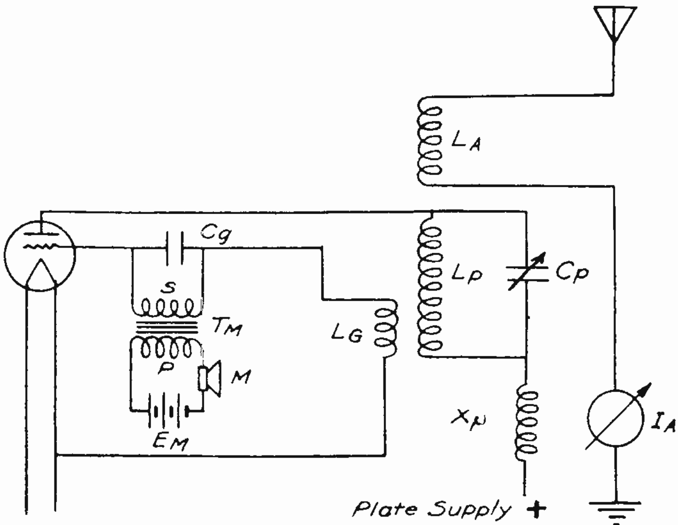

Fig. 15—Diagram showing method of modulation by the variation of grid voltage.

be transmitted. The different schemes of modulation operate principally by three fundamental methods, namely:

1. Variation of the resistance of the antenna circuit.
2. Variation of the grid voltage of the oscillator tube.
3. Variation of the plate supply to the oscillator tube.

The *first* of these methods has already been touched on and is shown in Figs. 1 and 4. This method shows very clearly the fundamental operation of a radiotelephone transmitter, but as far as its practical application is concerned, it is almost obsolete. In fact it is obsolete where any power over 5 watts is used. Fair results can be obtained with this method when the output of the transmitter is 5 watts or less. However, the method is inherently a poor one both as to quality and efficiency.

The *second* method listed above depends upon the variation of the average grid voltage (biasing voltage) of the oscillator tube. Figure 15 shows the application of this method of modulation using a typical oscillatory circuit. The functioning of this type of oscillatory circuit has already been described so the method of modulation only will be considered at this time. The microphone circuit is composed of the microphone, M, a 6 volt storage battery, Em, or any 6 volt battery capable of supplying 200 or 300 milliamperes, and the primary of the microphone transformer, Tm. The secondary of the microphone transformer takes the place of the grid biasing resistance and is connected across the grid condenser, Cg. When the microphone is spoken into, the resultant action that takes place is the varying of the grid biasing voltage, in accordance with the variation in the microphone displacement. As mentioned before, the result desired is to have the amplitude of the antenna current vary exactly in accordance with the microphone displacement. This desired result is not entirely obtained with this system of modulation due to the following facts: the relation between the grid biasing voltage and the antenna current is not linear (and it should be for good modulation) that is, a certain percentage variation in grid biasing voltage does not produce a relative percentage variation in antenna current. In fact, if a circuit condition has been obtained at which point the oscillations are stable, the antenna current is only slightly effectual throughout a relatively wide range of variation in the grid biasing voltage. Obviously, these conditions are not favorable for good modulation and by "good modulation" is meant the faithful reproduction of speech vibrations in the varying of the amplitude of the output radio-frequency current. By very careful adjustment, however, fairly satisfactory operation is possible.

The *third* method of modulation, which depends upon the variation of the plate supply to the oscillator tube, is far more efficient than either of the other two methods mentioned above. By variation in plate supply is meant, either the variation of the plate voltage, the plate current, or the plate power. This method excels the first due to the fact that there is no waste in the oscillatory power (as there is in the first), which might logically be called the "absorption" method. It excels the second method due to the fact that the relation between plate supply and antenna current is fairly linear over a wide range. In this method a voice voltage (one which varies in accordance with the frequency and amplitude of the sound waves due to speech which actuate the microphone diaphragm) is superimposed upon the D. C. voltage in the plate circuit of the oscillator tube, thus causing the plate current, and subsequently the plate power, to vary at speech frequencies. A complete variation from zero current to double the normal current of the oscillator tube entails an amount approximately equal to that supplied to the oscillator during normal operation. By normal operation is meant the functioning of the oscillator tube as a generator of radio-frequency currents with a constant plate supply, hence with no superimposed variations due to speech. The modulating device must be capable of supplying this power to the

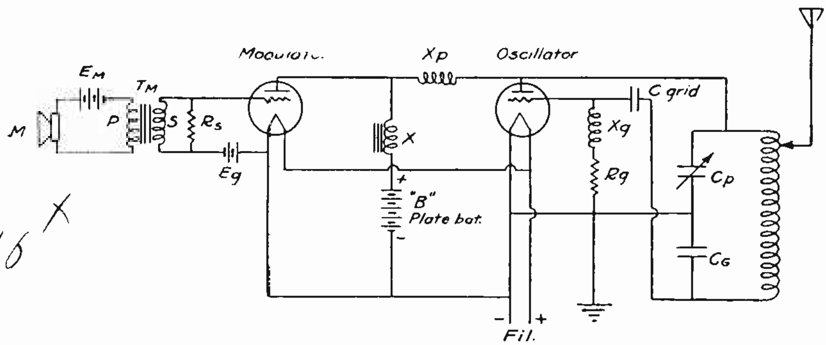

Fig. 16—This diagram illustrates the Heising system of modulation.

oscillator tube or of controlling its supply from the plate source. The microphone, due to its low capacity rating (100 milliamperes) is incapable of controlling the plate supply to the oscillator tube directly, but must effect its control indirectly and it does this through the medium of an auxiliary tube called the "modulator" tube.

The practical application of the plate modulation system which is called the *Heising method of modulation* after Mr. R. A. Heising, is shown in Fig. 16. The oscillatory circuit shown here is of the Colpitts type. When the microphone, M, is idle there is a constant plate supply, both to the oscillator and the modulator tubes. It follows then that the radio-frequency currents in the antenna circuit are of constant amplitude (C. W.) and the output is "unmodulated." When the microphone is spoken into, its diaphrgam follows the speech frequency variations and subsequently its resistance varies accordingly. The direct current in the microphone circuit goes through similar variations and we now have a pulsating direct current flowing in this circuit. Alternating emfs. are set up in the secondary winding of the microphone transformer, Tm, due to the pulsating currents flowing in the primary winding, and are applied to the grid of the modulator tube. This causes the plate current of this tube to vary accordingly. There is an iron-core choke coil, X, in the common plate supply to the modulator and oscillator tubes, which is of very high inductance. It is the inherent property of an inductance to oppose any change in the current flowing through it, therefore, the choke coil in the plate circuit tends to keep the value of the current flowing through constant. If, at any instant the grid of the modulator tube goes positive, the plate current of this tube increases and since the choke coil tends to keep the total flow of current to both tubes constant, the modulator draws current away from the oscillator tube and the current to the oscillator tube decreases. Conversely, when the modulator grid goes negative, the modulator plate current decreases and the oscillator plate current increases due to the fact that the total supply of current to both tubes is maintained constant by the choke coil. The average plate current to the oscillator tube is varied at an audio-frequency rate (speech frequency) and the amplitude of the radio-frequency antenna current is correspondingly varied.

This explanation may seem a little hard to understand at first reading, but looking at Fig. 16 again, you will see that the Heising system of modulation employs two vacuum tubes. One is used to generate radio-frequency power to apply to the antenna. This is connected as an oscillator; the other tube is employed as a modulator tube. Both tubes are fed from a common plate supply source through a large iron-core coil. The reactance of the choke coil X is so great that the current through it is practically constant and cannot vary at speech frequencies or higher. frequencies. When the transmitter is working, the current from the source is constant. For this reason, the Heising system is sometimes known as the constant current modulating system.

The oscillator works steadily and the radio-frequency is coupled into the antenna circuit. A radio-frequency choke coil Xp keeps the high-frequency current from leaking back into the modulator and supply circuit. The load which the modulator tube takes varies. As the grid voltage of the modulator tube is changed at speech frequencies, the plate current is made larger and smaller accordingly. We have a high-frequency carrier-wave completely modulated with a speech envelope.

With the aid of Figure 17, this action can be made clearer. Here the modulator plate filament circuit has been represented by a variable resistance, Rm, due to the fact that its average grid voltage varies at a speech frequency rate. The oscillator tube plate filament circuit has been represented as a constant resistance, Ro, since its average grid voltage remains constant. The plate source is shown at B and the iron-core choke at X.

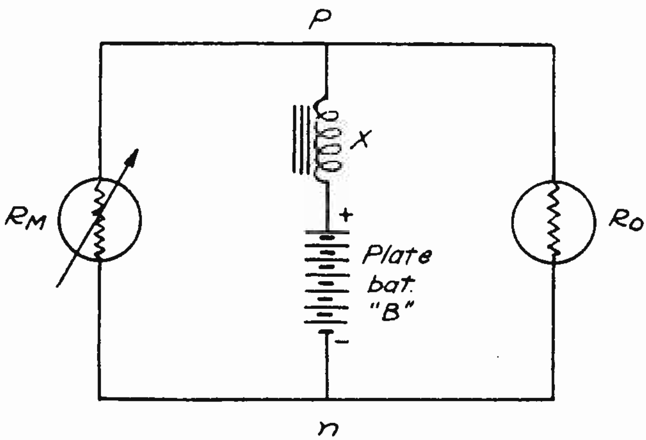

Fig. 17—Theoretical diagram of the Heising system of modulation.

For the sake of simplicity in the discussion, let us assume that a 1,000 cycle tuning fork is set vibrating in front of the microphone, producing a sine wave of sound. The modulator grid voltage and consequently, plate current, will go through similar variations of the same frequency as the tuning fork. This will make the plate circuit of the modulator tube function as a variable resistance connected across the plate supply. If we assume that the modulator plate current changes from zero to twice its normal value and by normal value is meant the value of the plate current flowing when the microphone is idle, then it follows that the oscillator plate current must increase and decrease about its normal value to the same extent, since the choke coil functions to maintain the total plate current approximately constant.

Obviously, if the value of the oscillator plate current is varied at the rate of 1,000 cycles per second, the amplitude of the radio-freqeuncy antenna current will be varied at the same rate. Since the resistance of the oscillator plate current is varied at the rate of 1,000 cycles per second, the amplitude of the radio-frequency antenna current will be varied at the same rate. The resistance of the oscillator plate filament circuit is considered constant. The current through this resistance is changing from zero to twice the normal value. The power expended in this resistance must change from zero to four times the resistance. The power is equal

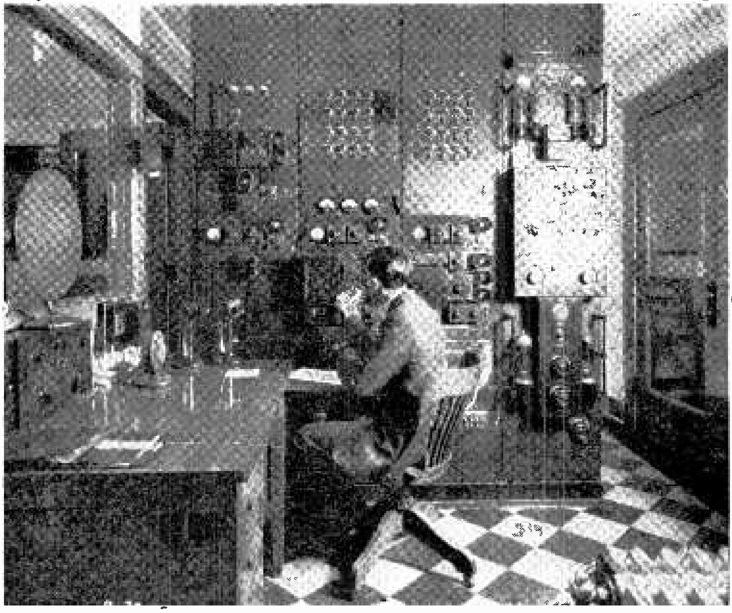

Fig. 18.—This is an inside view of a Broadcasting Station, showing the operator adjusting the proper control units.

to the voltage across the resistance times the current through it and since the power changes as the current, the voltage across the oscillator resistance and hence the voltage across the points, n and p, in Fig. 17 must change to twice its normal value. It has been mentioned that the choke coil in the plate feed circuit tended to maintain the total plate current approximately constant. If it held the plate current absolutely constant, it would be untrue that there was any change in voltage across the points, n and p. However, the inductance of the choke coil is so high and the current flowing through it is varying at an audio-frequency rate (1,000 cycles per second in this case) only a slight change in the value of the current flowing through the coil would cause a large change in the voltage across it. The following are some actual figures from Radiophone sets using this type of modulation:

Average value of total plate current	.08	amperes
Inductance of choke coil, X	2.	henries
Plate voltage	300	volts

In this case, if there was a maximum variation of 20 per cent. in the current through the choke coils, at a modulating frequency of 1,000, the maximum voltage drop across X would be equal to 2nfLI, where f is the frequency in cycles and L the inductance and I the change in current. Writing this out mathematically we would have:

2x3.1416x1000x2.x(20 per cent of .08)=200 volts. The voltage across the points, n and p, would vary from 300-200=100 to 300+200=500. It can be said that the oscillator plate voltage and the amplitude of the antenna current varies in accordance with the microphone diaphragm displacement. This is due to the sounds impinged upon it.

GENERAL RELATIONS IN RADIOTELEPHONE TRANSMITTER CIRCUITS USING PLATE MODULATION

A Radiotelephone set using plate modulation is a more or less complicated network in which three classes of currents coexist—radio-frequency, audio-frequency, and direct. In Figure 19 is shown schematically a typical Radiotelephone transmitter set, analyzed for purposes of discussion into four distinct units. At the extreme right is the radiator unit, which joins up the transmitter with the distant receiving station. The signal depends upon the nature of the wave form of current in this radiator unit. It is independent of the process by which that current is produced. The useful currents in this circuit are of radio-frequency. The modulating mechanism may cause slight audio currents to flow in the radiator unit. These produce practically no effect except at near-by stations. Such audio currents result from the audio current flowing in the lead to the tube, O, which is inductively coupled to the antenna or radiator circuit. During speech the radio-frequency current is of variable amplitude, and is known as modulated radio-frequency. For the purpose of explaining the general operation of the transmitter, it is not necessary to analyze completely the wave form of this current.

The Radio generator unit is to the left of the radiator unit. This contains electron tubes which, from the functions performed by them, are known as oscillator tubes. They also contain the other electrical equipment essential to the production of radio-frequency power from whatever power is supplied at the input b+ and b— terminals of this unit. An important part of any generating unit in Radiotelephony is a device such that the radio-frequency voltage across the input terminals is small compared with other voltages of lower orders of frequency In the present case, this device is a condenser Cb, the reactance of which for radio-frequencies is low compared with the ratio of average plate voltage of the oscillator tubes to the average plate current. In any continuous wave transmitter, a device of this nature is required in case the radio impedance of the system supplying the plate power is so high that otherwise considerable radio voltage variations would occur across the input terminals, limiting the useful power output. In the present case, the condenser Cb may be thought of as an electrical valve which prevents radio-frequency power working back into the part of the network to the left, but which does not interfere with the lower frequency power entering the generating system. This particular type of generating circuit is known as the Meissner circuit. It is classified electrically as one with plate and grid both inductively coupled to the radio-frequency circuit. Series power supply is used with the same radio-frequency current flowing through the plate coupling coil as through the tube. In place of such a circuit, any of a large number of other types might be used. In the generator unit all three types of electrical currents exist. The power entering the unit during operation is direct power and audio power. The output through the antenna and ground terminals, A and G, is modulated radio-frequency. While a tube in continuous wave telegraphy may be thought of as a converter of power from direct to radio-frequency. In a radiotelephone set, the generator tube converts power from direct and audio to modulated radio-frequency.

To the left of the generator unit is the modulator unit. Its function is to supply audio and direct power to the generator unit, the audio power being controlled by the operator speaking into the microphone. In the case shown, an electron tube is shunted across the input terminals of the generator unit, the two in parallel being supplied with direct power from a direct current source through the iron-core choke coil, Lb. The tube in this case is a speech-controlled resistance in which the instantaneous resistance, or ratio of plate voltage to plate current, is determined largely by the instantaneous grid voltage. On account of the functions it performs, it is known as a modulator tube. Mechanically, it is usually the same as the oscillator tube.

When tubes are paralleled, approximately as many modulator tubes are used as oscillator tubes. The modulator tube is a converter of power from direct to audio-frequency and the audio current and voltage output of the modulator tube is a more or less faithful reproduction of the audio voltage impressed upon the grid of the modulator tube by the use of a microphone and transformer. The modulator tube, therefore,

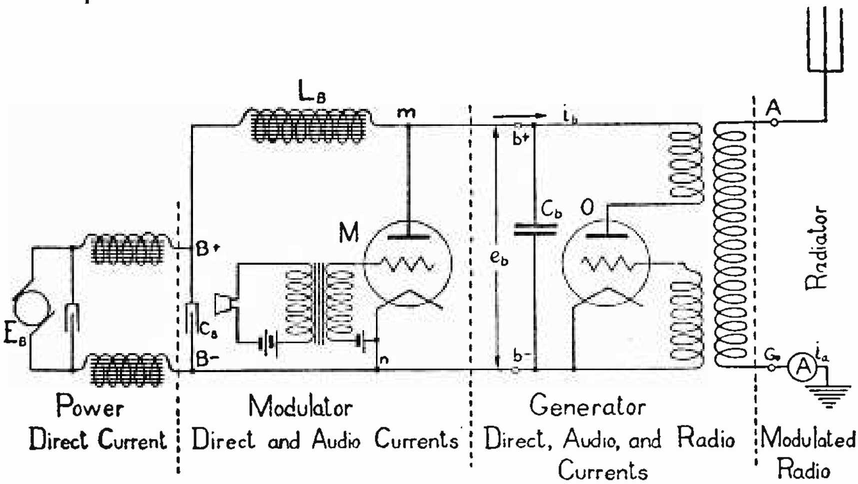

Fig. 19—Analysis of a radiotelephone transmitter set.

functions as an aperiodic power amplifier. The audio power output may be tested, for example, by connecting a suitable resistance and stopping condenser in series across m and n of Fig. 19, instead of the generating circuit. The power which is manifested by the heating effect upon the resistance, during speech, is entirely audio power, converted from direct power from source Eb through the agency of the modulator unit. Tubes for modulating are usually designed to operate with a negative average voltage on the grid, which in the case shown is obtained by the use of a battery in the grid lead. The choke coil, Lb of the modulator circuit partially performs the same function for the modulator unit as does the condenser Cb for the generator unit. It prevents audio currents produced by the unit from working back through the input terminals B+ and B—, and in this it is aided by the condenser, Cb. It performs, however, another important function.

If a fixed impedance and a variable impedance be connected in parallel and placed across a direct power source of zero internal impedance, then variations of one impedance will not disturb the current to the other unless the two in parallel are supplied with power through a common line impedance. The generator unit may be thought of as the fixed impedance and the modulator tube as the variable impedance in parallel, both being supplied with power through the common impedance Lb.

Fig. 20.—This shows the picture of an N. R. I. graduate making changes in the tube transmitter which he operates.

Without this impedance, practically no variations in the audio-frequency voltage across the b+ and b— terminals could occur. The impedance of Lb is usually high for the average speech frequency of 800 cycles per second in comparison with the impedance given by the ratio of the direct voltage across the B+ and B— terminals to the direct current constituent flowing through the choke coil. Choke coils for this purpose are usually built with an air-gap in the magnetic circuit and with a large number of direct current ampere-turns per unit length of the magnetic circuit.

To the left of the modulator unit is the direct power supply unit. In this case it consists of a direct current generator provided with filter circuits to prevent voltage due to commutation from existing across the terminals B+ and B—. The condenser Cb functions doubly as a part of the filter network and as a device which by-passes any audio-frequency current which may flow through the choke coil.

To summarize, tracing from left to right, the primary power supply to the set is direct current delivered to the B+ and B— terminals of the modulator unit. By an audio-frequency variation of the modulator tube impedance, audio power is produced and, together with direct power, is supplied to the b+ and b—input terminals of the generator unit. As a result, the amplitude of the radio-frequency output current of the generator unit is varied at speech frequencies and a wave form emitted. which upon reception gives rise again to speech currents.

TEST QUESTIONS

Number your answer sheet 34 and add your Student Number

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Illustrate by drawing a modulated carrier-wave.
2. Explain the difference between the carrier frequency and the modulating frequency for a 400 meter Broadcasting Station.
3. What two factors determine the R. F. generated by the tube in the Meissner circuit shown in Fig. 5?
4. State the reason for using the coil Xg in the grid leak circuit of Fig. 6.
5. What is the one important advantage of the Armstrong circuit shown in Fig. 9?
6. Why can the plate blocking condenser be eliminated in the Colpitts circuit Fig. 11?
7. Make a diagram of the Master Oscillator circuit.
8. What is the essential difference between the Hartley and the Colpitts circuits?
9. Draw a diagram showing control of modulation by varying grid voltage.
10. Explain briefly by aid of a diagram the Heising system of modulation.

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