SECTION 2

ADVANCED PRACTICAL RADIO ENGINEERING

TECHNICAL ASSIGNMENT

OSCILLATOR AND NEUTRALIZING CIRCUITS

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OSCILLATOR AND NEUTRALIZING CIRCUITS

OSCILLATOR AND NEUTRALIZING CIRCUITS

INTRODUCTION.—It was stated in a preceding assignment that, "An oscillator is a brute force device; if a tube will operate at all it can be made to oscillate." That is true, but there are many types of oscillations and oscillator circuits. A circuit designed specifically as an oscillator may be critical and difficult to adjust for stable efficient operation; on the other hand, a radio frequency amplifier in which oscillations cannot be tolerated, will sometimes, due to the physical arrangement of the circuit, develop oscillations at the operating frequency or spurious high frequency oscillations, the elimination of which may be very troublesome. In order to be able to design an efficient oscillator circuit, or to design a circuit in which the tendency to oscillate is very remote, it is necessary to thoroughly understand the circuit conditions which facilitate self-oscillation.

A vacuum tube oscillator is a device consisting of a vacuum tube and complementary circuit, by means of which a direct current input is converted into an alternating current output at the desired frequency. In general the frequency of the a-c output is a function of the circuit constants. Alternating current power can be developed very efficiently at the lower (power) frequencies by means of a motor driven generator. In fact, frequencies up to the lower radio frequency range of about 30 kilocycles have been developed with large power output by motor-generators. However, at such frequencies the generator must operate at extremely high rotating velocity (in some cases as high as 20,000 r.p.m.) the installation is very expensive, cumbersome, and subject to all the troubles of power installations on a greatly magnified scale.

In contrast, the vacuum tube oscillator can be made to oscillate at practically any desired frequency, most conventional types of tubes oscillating easily and efficiently at frequencies up to 30 megacycles (30,000 kilocycles). As explained in an earlier assignment, special tubes have been made to oscillate at frequencies in excess of 2,200 megacycles. In further contrast with the motor-generator, the higher the frequency, the more simple the vacuum tube oscillator becomes of the reduction in the dimensions of circuit constants.

CONDITIONS FOR OSCILLATION.— A vacuum tube circuit is said to be oscillating when energy in the form of an alternating voltage is transferred from the plate circuit and applied between the grid and filament of the same tube, in such magnitude and polarity that the variations of voltage on the grid cause like variations in the plate voltage, which in turn transfer more energy back to the grid, etc. The circuit will oscillate *when sufficient energy is transferred from the plate circuit to the grid circuit to exceed the losses in the grid circuit.*

Consider the case of a vacuum tube with tuned circuits, resonant to essentially the same radio frequency, connected to the grid and plate; a change is to be made in any part of the circuit or in one of the circuit voltages; assume for example that the plate voltage is suddenly applied. This causes a rush of electrons to the plate, a flow of plate current through the external circuit, and some energy transfer to the plate r-f circuit.

In an oscillating circuit it is necessary to have some means of coupling between the plate and grid circuits. Thus part of the initial impulse of energy is transferred to the grid circuit, establishing a difference of potential between the grid and filament, this in turn causing another plate current variation, etc. Three conditions can now exist: First, the energy transferred back from the plate to the grid circuit can just equal the energy lost in the resistance of the grid circuit, in which case if the initial impulse is strong, oscillations will be sustained indefinitely so long as conditions remain unchanged but will not build up in amplitude. Second, the energy transferred back can exceed the energy lost in resistance, in which case the grid circuit energy will increase and the oscillations will build up in amplitude until the tube is operating as an oscillator at its maximum output. Third, the energy transferred back can be less than the amount lost in grid circuit resistance, in which case the grid circuit energy will die out and oscillations will not start.

The latter condition in radio receivers is called regeneration. A signal from an antenna being transferred into such a grid circuit will die out, but more slowly than if plate feed-back were not present. Oscillations will not start. If instead of a single impulse from the antenna, a continued train of impulses or a number of cycles of energy is transferred into the tuned grid circuit, these cycles of energy adding to the energy transferred back from the plate circuit, being correspondingly amplified and a still greater amount of energy being fed back, will cause in a short time a tremendously amplified signal.

If the feed-back for regeneration is increased to the point where it is just sufficient to cause a cancellation of the grid circuit losses, the effect will be that of a zero resistance circuit; if the antenna signal energy is removed the circuit will continue to oscillate. If the feed-back coupling is increased beyond the point of zero resistance, the circuit assumes a condition of "negative resistance", that is, an initial impulse of energy transferred into the grid circuit, instead of gradually dying out due to circuit losses, actually builds up to a point of maximum tube output. Under this condition, oscillations when once started will be maintained by power supplied by the d-c plate supply.

Thus a tube circuit can possess positive resistance, in which case it will not oscillate; zero resistance, in which case oscillations can be sustained but will not build up in amplitude; negative resistance, in which case oscillations can be started by any disturbance in the circuit and build up, the rapidity with which the oscillations build up depending upon the amount of the negative resistance. It will be seen that the effective resistance of the entire tube circuit is a function of the feed-back coupling, decreasing with an increase of coupling.

In most practical oscillators

a high degree of negative resistance is desired so that oscillations will build up to a maximum amplitude quickly. This means close coupling between the grid and plate circuits. An oscillator employing a tube and resonant circuit arranged for feedback between grid and plate circuits is normally operated at relatively high efficiencies. This means that the tube will be operated Class C. Therefore, the tube will be operated under the same conditions as a Class C amplifier. In fact, the oscillator may be readily compared to a Class C amplifier since the essential difference between the two is only in the method of supplying the grid circuit losses. In the Class C amplifier, the grid losses are supplied by the driving amplifier, in the oscillator the grid losses are supplied from its own plate circuit by returning some of the energy to the grid in the proper phase.

A good mechanical analogy which will assist in gaining a picture of oscillator operation is that of the pendulum clock. The oscillating circuit in the clock is the pendulum, the power supply is the main spring and the escapement is the tube. The energy is supplied in spurts, i.e., the escapement supplies a pulse of energy in the proper phase to the pendulum, the fly-wheel of the pendulum translates this pulse of unidirectional energy into a smooth and steady flow of bidirectional energy. If the pendulum were initially displaced from its position of rest and then allowed to return to that position, it would oscillate at a constant frequency (provided the angle of displacement were small) and the amplitude of oscillations would decrease at a constant rate with the final amplitude zero. This is characteristic of a free oscillation. If, however, the pendulum is supplied, at some point in the swing, with a pulse of energy to replace that smoothly dissipated, then the oscillations would be of constant amplitude which is characteristic of forced oscillations. The initial energy stored in the pendulum will be many times in excess of the energy dissipated per cycle which will air in stabilizing the clock. This is done by using as frictionless a suspension system as possible and by using a relatively large pendulum bob. This improves the system stability but has no effect on the frequency.

Many students of radio get the impression that the tube is the oscillator. This conclusion is erroneous. The tube is but one of the important parts of any oscillator. Of equal importance is the "tank" circuit. And of just as great importance is the power supply. The tube is properly connected with respect to the tuned circuit so that the power supply can deliver energy to the tank circuit (in spurts) to make up for that dissipated per cycle. Of great importance in this function is to properly connect the tube to produce the 180° phase relation between grid and plate circuit.

Before a discussion of the instantaneous relations of voltages and currents in the oscillator, a consideration of fly-wheel action in the tuned circuit is desirable. Suppose that the capacitor in Fig. 1 has been fully charged and that it is then allowed to discharge through the inductance. This discharge current must flow through the coil. At the instant the current starts to flow it is *changing* at the *greatest* *rate*. Hence the greatest counter electromotive force will be developed across the coil. This c.e.m.f. will, at any instant be equal to the voltage across the capacitor but opposite in phase, opposing the discharge current of the capacitor. The capacitor, in causing the initial flow of current, has used up some of its energy (voltage) which results in a decrease in the potential difference between the plates. The voltage of opposition existing across the inductance has also decreased to always be equal but opposite to the capacitor difference of potential. The discharge of the capacitor manifests itself in a flow of electrons (current) from the negative plates to the positive plates to establish equilibrium between them. The energy in the system was originally stored in the capacitor in the form of an electrostatic field. The total energy of the system is all in the capacitor at point "a" in Fig. 1. At point "b", the current has reached a maximum and the capacitor is completely discharged. The potential across the capacitor is zero and all the energy is stored in the electromagnetic field about the inductance. At all instants of time between points "a" and "b" there is a transfer of energy from the electrostatic field of the capacitor to the electromagnetic field of the coil. At point "b" the transfer is complete. The energy in the capacitor is static or potential, in the coil the energy is dynamic or kinetic. At point "b", the voltage has instantaneously become zero, but the maintainance of the electromagnetic field requires a flow of current. Since there is now no potential difference in the system to sustain the flow of current the field will collapse. This it does, but by Lenz's Law it induces a voltage in the coil in a direction to sustain the current. The flow of electrons is in the same direction from "b" to "c"

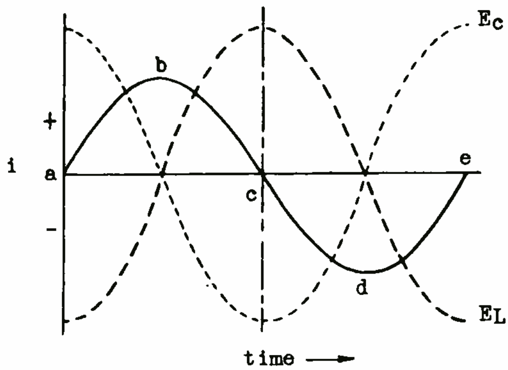

Fig. 1.—Energy relations in L-C tank circuit.

as from "a" to "b". At the instant the electromagnetic field starts collapsing the current flow into the capacitor is a maximum, as the field continues to collapse the potential difference across the capacitor increases since the capacitor is now receiving a charge. At point "c" the charge in the capacitor is maximum, the current has become zero, the magnetic field about the coil is zero and the energy exchange between the coil and capacitor is once more complete but with this important difference: the capacitor is charged to the opposite polarity from its original condition.

It is seen that one complete interchange of charge on the capacitor has taken place. From "c" to "d" and from "d" to "e" a complete reversal of conditions will now take place and one period or cycle will be the result. At "e" the capacitor will now be charged identically as it was at "a" and the whole sequence or cycle will again occur. The so-called "fly-wheel" of the free-oscillation results in this interchange of energy and the development with respect to time of a sinusoidal voltage across the circuit. If there were no losses in the circuit, this would continue indefinitely. However, no circuit is without loss and energy is constantly being dissipated in the circuit resistance. This results in a constant energy loss and is manifest in the familiar damped oscillation. This is characteristic of free-oscillation. The oscillations of a free oscillator are always damped, i.e., they gradually die away. A pendulum will gradually come to rest since it is a free-oscillator if the excapement supplies no energy to the system in the proper phase. Similarly, a resonant circuit oscillation will die away.

If, however, energy is supplied to the circuit at the proper time, the oscillations will continue at constant amplitude. This is characteristic of forced oscillations. A forced oscillator must be supplied with energy to replenish that expended per cycle. If more energy is supplied than dissipated per cycle, the amplitude of oscillation will build up indefinitely, if supplied with less energy than dissipated, they will die away, if supplied with just as much energy as dissipated, the oscillations will remain constant.

This fly-wheel action is very important in properly understanding the operation of Class B and Class C r-f amplifiers and, of course, oscillators. It is because of this fly-wheel effect that almost pure sinusoidal voltages may be developed by resonant circuits, even though these circuits are supplied with energy at discrete intervals. The fly-wheel on a single cylinder gasoline engine receives its energy not continuously but in "spurts" but it delivers this energy relatively smoothly to the load. The tank circuit of any r-f amplifier is quite similar in operation since it too receives energy in spurts from the power supply and delivers the energy continuously to the load. The smoothness with which it delivers its energy and the maintainance of a sinusoidal voltage across the tank depends upon the value of the fly-wheel of the tank circuit. It will be developed later in this assignment that the fly-wheel is a direct measure of the ratio of energy stored (called volt-amperes) to the energy dissipated per cycle (called watts), the ratio being expressed as the va/w ratio.

The relations of voltages in the plate and grid circuits, together with the usual current flow of both plate and grid currents is shown in Fig. 2. In general there is a resonant circuit in both the grid and plate circuits. In fact any oscillator circuit can be shown to be identical with the simple oscillator described in paragraphs following this discussion. It also can be shown in all the possible variations in oscillator circuits the voltage and current relations shown in Fig. 2 are identical.

The following symbols will be employed: E_b - d-c plate supply voltage; E_p - r.m.s. value of a-c voltage developed across the plate output circuit; E_g - r.m.s. value of a-c voltage developed across the grid input circuit; E_c - d-c grid voltage; e_b - instantaneous voltage between plate and cathode; e_c - instantaneous voltage between grid and cathode; e_p - instantaneous a-c voltage across the plate output circuit; e_g - instantaneous voltage across the grid input circuit; I_b - d-c plate current average value; I_c - d-c grid current average value; i_b - plate current instantaneous value; i_c - grid current instantaneous value; I_{pm} - maximum value of a-c plate current at the fundamental frequency; I_{gm} - maximum value of a-c grid current at the fundamental frequency.

The various values of voltage and current are shown as functions of time. Note that the values above the 0 line are positive while values below this line are negative with respect to the cathode. The values of the various voltages and currents are not drawn to scale but are so chosen to emphasize the values of each. The values may be positive or negative depending upon the time but the grid and plate currents can never be negative since they can flow only when the particular electrode is positive with respect to the cathode, (excluding effects of secondary emission). The curves are drawn to represent optimum Class C operation of either an amplifier or oscillator. Other conditions can exist but experimental evidence shows that operation as depicted is best.

At all times the d-c voltage values are shown as the straight lines E_b and E_c. These are the steady plate and grid bias voltages. Superimposed upon the steady bias E_c is the varying grid excitation voltage which is shown as a sine wave. This is not an unreasonable assumption since this voltage is developed across a resonant circuit wherein the energy storage is many times the dissipation per cycle. The same reasoning holds for the plate circuit. Since the grid a-c voltage is a sine voltage wave it may be represented as a function of time: $e_g = E_{gm} \sin \omega t$. The a-c grid voltage is taken as increasing positively with respect to the fixed bias E_c and is chosen equal to 0 when $t = 0$. The effective voltage on the grid is equal to the fixed bias E_c at this instant of time. As the excitation swings positive with respect to the grid bias, it reaches a value at "a" where it, in conjunction with the instantaneous voltage on the plate, overcomes the effect of the fixed negative bias E_c and plate current begins to flow at this instant. The plate current increases as the effective voltage on the grid increases and reaches its

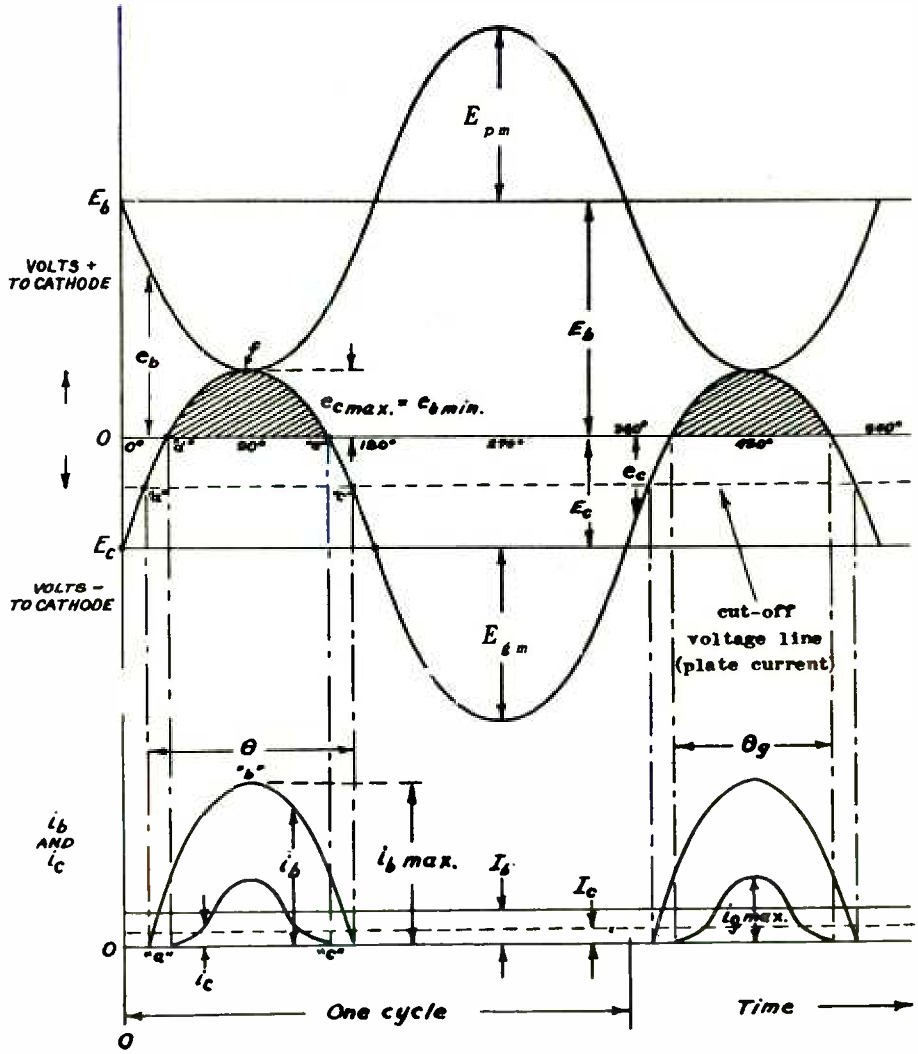

Fig. 2.—Current-voltage relations in a vacuum-tube oscillator circuit.

maximum at "b" when the effective voltage on the grid is maximum at "f", as shown. It then decreases and again becomes zero at "c". The angle θ is seen to be less than 180° and is known as the angle of plate current flow. For Class C operation, it will normally lie between 120° and 160°.

The plate current is seen to flow in pulses and these pulses can be shown by a Fourier analysis of such a pulse to consist of a d-c component, a fundamental a-c component and an infinite number of harmonic components. The d-c component is the average value of the pulse and for any given pulse may be readily determined by a d-c ammeter. The d-c plate current of the Class C amplifier or oscillator is always less than the peak value of the pulse. The notion of the average value has already been explained in earlier assignments but is shown in Fig. 3 for emphasis. The area of

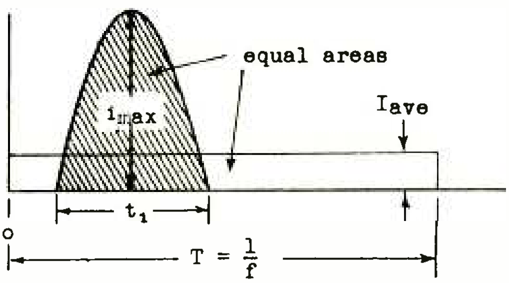

Fig. 3.—Representation of average or d-c value of a pulse.

the rectangle is equal to the area under the curve showing the current pulse. In both cases the *quantity* of electricity flowing is the same. Therefore the average current flowing continuously for the time of 1 cycle represents the same amount as that flowing during a shorter interval but with a value continuously varying.

Such a diagram as Fig. 3 represents a method of graphical integration, in this case to determine the average value.

As before mentioned, the current pulse may be thought of as a steady d-c value and an infinite series of a-c components. For example, a complex current pulse flowing as shown in Fig. 3 could be experssed as

$$i = I_0 + I_1 \sin \omega t + I_2 \sin 2\omega t + I_3 \sin 3\omega t + \ldots$$

where

i = value of the current pulse for any time t.

I_0 = the average value of the pulse or d-c component.

I_1 = the maximum value of the fundamental a-c component.

I_2 = the maximum value of the second harmonic a-c component.

I_3 = the maximum value of the third harmonic component, etc.

As an example, a typical current pulse might be

$$i = .175 + .245 \sin \omega t + .123 \sin 2\omega t + .057 \sin 3\omega t + \ldots$$

The current for such a pulse would have an average value of .175 ampere, the fundamental a-c current would have a maximum value of .245 amperes, the second harmonic a-c component would have a maximum value of .123 amperes, and so on.

The product of the average plate voltage E_b and the average plate current I_b gives the power input to the Class C amplifier, as usual. Likewise, if the a-c fundamental components of plate voltage and plate current could be found, the power output of the tube could be predetermined, for a given load impedance. Similarly, the output at the harmonics could be foretold. This is possible by a comprehensive analysis.

As the plate current rises and flows through the plate output load circuit, it supplies energy to the circuit to make up for that dissipated smoothly over the oscillatory cycle. The current flowing through this load impedance developes a voltage drop across it. This voltage drop at any instant is equal to $e_p = E_p \sin \omega t$. The total voltage available is E_b. Hence the instantaneous voltage appearing between plate and cathode must be $e_b = E_b - e_p$. Note this on the curves of Fig. 2. Also note that the minimum voltage on the plate, with respect to the cathode occurs at the time when the plate current and grid voltage are maximum, but the plate voltage between plate and cathode is minimum.

Note also that the grid current flows over a part of the excitation cycle, that part where the grid is positive with respect to the cathode, The form of the grid current pulse is shown, and the average value is also shown. The maximum value of the grid voltage is seen to be equal to the minimum value of the plate voltage. The excitation voltage. the positive grid voltage $e_{c\ max}$, and the total a-c grid swing are therefore related by $E_g = E_c + e_{c\ max}$, or $e_{c\ max} = E_g - E_c$, which for the operation shown is also equal to $e_{b\ min}$. The importance of these values will be shown.

The instantaneous relations between the grid and plate circuit are of considerable importance to a proper understanding of the operation of the Class C amplifier or oscillator and should be thoroughly understood.

TUNED-GRID TUNED-PLATE OSCILLATOR.—Probably the most simple type of oscillating circuit is the tuned-grid tuned-plate circuit connected between the grid and filament and another tuned circuit, adjusted to *approximately* the same frequency connected between the plate and filament. This is shown in Fig. 4.

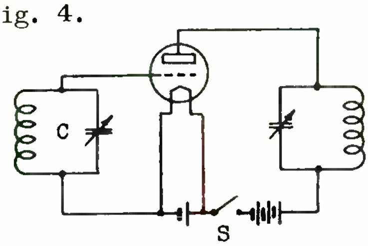

Fig. 4.—**Tuned-plate tuned-grid oscillator.**

As switch S is closed there will be a rush of electrons from the filament to the plate. As the grid is connected between the filament and the plate, and in the electron stream, there will be a difference of potential established between the grid and the filament. This will cause the plate current to be somewhat different than if the grid were not present. Due to this sudden rush of electrons through the inductance of the plate circuit, a voltage will be built up across the inductance which will cause the capacitor in that circuit to charge.

When the capacitor is fully charged it will discharge through the inductance, producing in the tuned plate circuit an alternating current.

The plate circuit may be considered as an alternator and the tube, by virtue of the capacity between the grid and plate, a capacitor, with an equivalent circuit as shown in Fig. 5 under this condition some of the power supplied by the alternator will be transferred through the capacity to the tuned circuit; if the tuned circuit has a low resistance and is tuned to very nearly the frequency of the alternator, the circulating current in the circuit can be large.

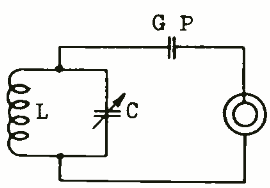

Fig. 5.—Equivalent simplified oscillator circuit.

If the circulating current is large there will be a large IX_c drop across capacitor C. Since in the actual circuit the grid is connected to one side of C and the filament to the other (see Fig. 4) the alternating voltage will be impressed between the grid and filament. This will form the excitation voltage and will cause corresponding variations in plate current which will transfer more power into the plate circuit.

It will be seen that for a given amount of power transferred back to the grid circuit the circulating current is limited by the resistance; also, that the circulating current, for a given value of C and a given frequency, determines the amplitude of the voltage impressed between the grid and filament.

If a given grid voltage variation produces a certain amount of a-c power in the plate circuit, and of this power enough is not transferred to the grid circuit to produce a grid voltage variation *at least as great as the preceding variation*, then the variations will die out and the tube will not oscillate. Everything else being equal, the condition of self-oscillation can be facilitated by decreasing the resistance in the grid circuit, and prevented by placing a sufficiently large value of resistance in the grid circuit.

Oscillations can also be prevented by making the impedance of the plate load circuit very low so that the power transferred into that circuit is small. Then the voltage built up across the load circuit will be low and very little power will be transferred back to the grid circuit. Low plate circuit impedance may be caused by too few plate turns, or by excessive circuit resistance.

The feed-back through the tube depends largely upon the plate to grid capacity of the tube. If the capacity is large the feed-back will be adequate and the circuit will oscillate readily. Conversely, if the tube capacity is very small it will be difficult to make the tuned-grid tuned-plate circuit oscillate.

This circuit, while seldom used as a power oscillator, occurs in almost all tuned radio frequency amplifiers. The tuned grid circuit of one tube is coupled through the capacity of the tube and the plate turns, to the tuned grid circuit of the next tube. This produces the effect of a tuned plate-tuned grid oscillator coupled through the capacity of the tube. When the two circuits are tuned to resonance, if they are well designed low loss circuits, oscillations will almost invariably result. In a radio frequency amplifier, means must be taken to prevent such oscillations. The methods consist of neutralizing the effects of the tube capacity by feeding energy back in the reverse direction (this method is to be discussed in detail later); or the use of a tube in which the plate to grid capacity is negligible, (screen grid tube).

A modification of the tuned-grid tuned-plate oscillator circuit is shown in Fig. 6. In this arrangement the plate circuit is a variable

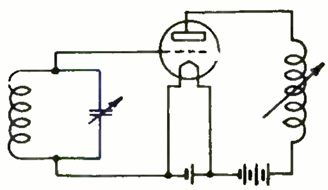

Fig. 6. Modification of armstrong circuit.

inductance. As shown by Dr. J.M. Miller some years ago, if the excitation voltage of a self-oscillating circuit is applied between the grid and filament of the tube, in order to have sustained oscillations *the plate circuit must be inductive.* For that reason in the tuned-grid tuned-plate oscillator, Fig. 4, the plate circuit is tuned to a frequency *slightly higher* than that of the grid circuit. The plate circuit then acts as an effective inductance. The plate circuit in Fig. 6 is an inductance. When the inductive reactance is made sufficiently large, enough power will be transferred back to the grid circuit to maintain oscillations. As the frequency is lowered the inductance must be increased in order to keep the reactance high enough to maintain oscillations. If the circuit in Fig. 6 is to be used as an oscillating detector, insert a grid leak and capacitor, and connect a pair of telephone receivers or an audio frequency transformer between the variometer and the plate battery.

INDUCTIVE FEED-BACK. In the circuits so far described, feed-back has been obtained solely by the capacity between the plate and grid of the tube itself. If, instead of depending on the tube capacity for coupling, the plate circuit is inductively coupled to the grid circuit, a somewhat better oscillation control will be obtained. In its most simple form this is done by

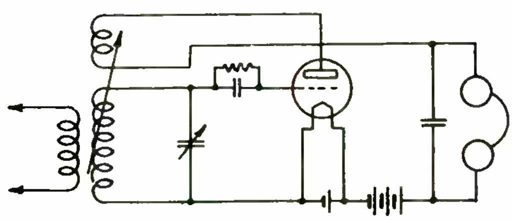

Fig. 7.—Use of tickler coil to furnish inductive regenerative feedback.

means of the so-called "Tickler". The "Tickler" consists of a number of turns of the plate circuit brought into inductive relation with the grid circuit. The amount of feed-back may be controlled by providing an arrangement whereby the plate coil can be rotated so that the plane of its windings is either parallel to or at right angles to the grid winding, or at any other angle between 0 and 90°. This is shown in Fig. 7. Additional methods of controlling the amount of feedback will be discussed later.

This circuit slightly revised to include padding capacitors and fixed plate circuit coupling, and with the telephone receivers of course eliminated, is used extensively as an oscillator in superheterodyne receivers. Both grid and plate coils are wound on the same form with the coupling sufficiently tight for strong oscillations. The triode oscillator tube in such case often consists of the cathode and the first two grids of a pentagrid converter tube such as the 6A7.

have a trimmer. C_4 is the grid blocking capacitor and R is the grid leak. L_2 is the plate feed-back coil. The cathode and the first two grids form the oscillator triode section of the tube.

In the same tube is a biased screen grid first detector, the elements of which are clearly shown above the two oscillator grids. The cathode is common for the two tube sections. The first detector tuned circuit elements are shown at the left as L_3C_5. it should be observed that C_1 and C_5 are tuned from a single control, the two being sections of a gang capacitor. C_3 is a simple by-pass capacitor around the dropping resistor and power supply. R_1 supplies bias for the first detector but *not* for the oscillator which derives its bias from the grid leak R connected *above* R_1. There are no complications to such a cir-

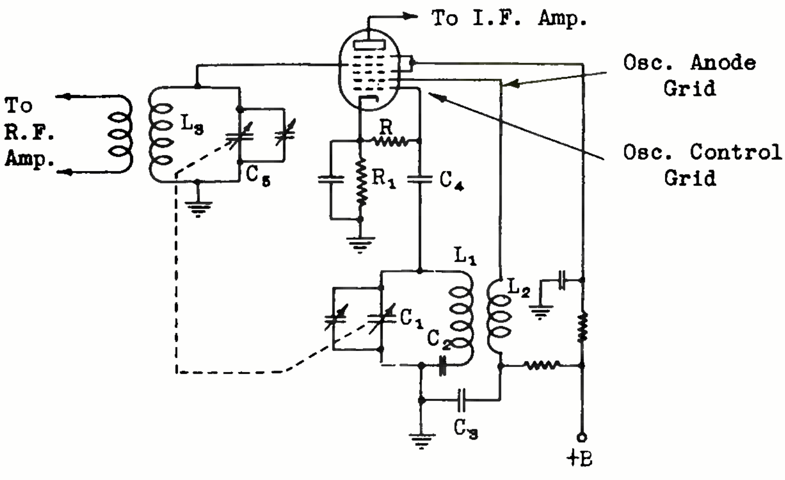

Fig. 8.—Oscillator circuit used in superheterodyne receivers.

An example of this is shown in Fig. 8. The oscillator elements are shown in the lower right. The oscillator tuned grid circuit is composed of L_1, tuning capacitor C_1 with its trimmer, and padding capacitor C_2, which will also ordinarily

cuit except the arrangement of the tuning and padding capacitors to make the oscillator and signal circuit tuning track.

HARTLEY OSCILLATOR. Carried further, the simple inductive feedback circuit can be converted into the fundamental Hartley circuit as shown in Fig. 9. In this circuit the turns between the plate end of the coil and the center or filament tap represent the feed-back turns; instead of being inductively coupled to the tuned grid circuit the coupling is conductive. If a tube is to operate properly as an oscillator the plate and grid voltages must be 180 degrees out of

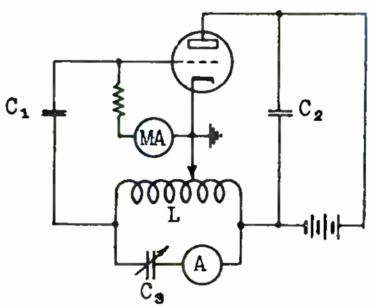

Fig. 9. Schematic diagram of Hartley oscillator.

phase. Since the plate and grid in this case are connected to opposite ends of the same coil with the filament connected in between, the correct phase relation must exist. The grid excitation voltage is the voltage drop across the inductance between the grid and filament taps, and is equal to IX_L.

C_1 is the grid blocking capacitor and C_2 is a by-pass capacitor across the plate d-c supply to by-pass the radio frequency around the battery. Tuning is done by varying C_3 and by varying the inductance L.

This is a very popular circuit for use in drivers or low power oscillators for making radio frequency measurements. In such oscillators the inductance is usually made up in form of interchangeable coils. This circuit when properly designed will oscillate freely over the full range of C_3. When used for frequency measurements or any measurement where an accurate indication of resonance between the driver and some other radio frequency circuit is desired, the resonance indicating meter is usually a low reading d-c milliammeter (with a tube such as the Type 210, the milliammeter may have a scale of 0 - 2 mils with a plate supply voltage up to 150 volts) placed in the grid d-c circuit between grid and filament. Since the amount of grid current depends upon the amplitude of the grid excitation voltage, if the excitation voltage is decreased the grid current will also drop.

The excitation voltage in this circuit is equal to IX_L. Then if I_t (in the radio frequency tank circuit) is decreased, the grid current will decrease also. If an L-C circuit is coupled to the oscillator circuit and the two are brought into resonance, the current in the oscillator tank circuit will decrease and current will flow in the second circuit due to the transfer of power by mutual induction. The grid current will vary appreciably with a slight variation of the excitation voltage, therefore, the drop in grid current when a second circuit is brought into resonance with the driver, is a very sensitive resonance indicator and permits the use of weak coupling between the driver and the circuit to be measured. When the coupling is weak, the mutual inductive effects on both circuits will be slight and the accuracy of the measurement will be increased.

This type of circuit is quite commonly used as the oscillator circuit in superhetrodyne receivers.

It is a good circuit to use at intermediate frequencies as the master oscillator in Master Oscillator--Power Amplifier transmitter circuits, but other circuits are somewhat more suitable for that purpose. The fundamental Hartley circuit is particularly useful as a driver in making radio frequency measurements because it will oscillate at only one frequency, the frequency depending upon the total inductance and the total capacity. The latter consists of the sum of the capacities, C_3, distributed capacity of the coil and the grid to plate capacity of the tube and connecting leads. All these capacities are in parallel across the common inductance and *together* control the frequency. In practice, however, all are fixed except C_3.

A circuit in which the above condition does not exist is a modification of the Hartley circuit, the tuned plate Hartley circuit, as shown in Fig. 10. In this circuit

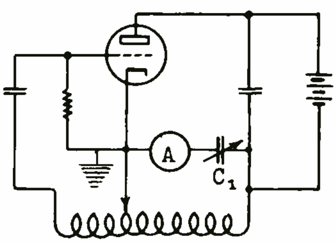

Fig. 10. Tuned-plate modification of Hartley circuit.

the variable capacitor C_1, which forms a part of the tuned circuit, is across only a portion of the coil.

The very serious disadvantage of this circuit is the fact that when C_1 is set at a low value of capacity the circuit may break into oscillations at a frequency controlled by *all* of the inductance with the distributed capacity of the coil in parallel with the grid to plate capacity across the coil.

When two tuned circuits are closely coupled together in such a manner that either may possibly control the frequency of oscillation of a common tube, there will be a tendency for the frequency of oscillation to jump from that of one circuit to that of the other. This will occur to any great extent only when the two circuits are tuned to very nearly the same frequency. Since the total inductance is greater than the inductance included within the normal tuned circuit, it will, to some extent, make up for the comparatively small capacity across it, and when the value of C_1 is made quite small, the L-C values of the two circuits may be very nearly the same and either may control the frequency.

The tuned grid Hartley circuit of Fig. 11 may develop the same

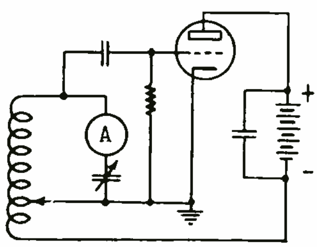

Fig. 11.—**Tuned-grid modification of Hartley circuit.**

trouble as the tuned plate circuit. However, since the grid is the controlling member of the tube, and since the power is developed directly in the grid circuit, the changes of frequency jumping are more remote. This circuit is not quite as strong an oscillator as those previously discussed, but it can be designed to hold a quite constant frequency.

THE COLPITTS OSCILLATOR. This circuit is probably the best of all the oscillator circuits for transmitter purposes. It may be used either as the master oscillator in Master-Oscillator-Power Amplifier circuits, or as a power oscillator feeding directly into an antenna.

Fig. 12 shows the fundamental Colpitts circuit. C_1 is called the grid coupling or "Feed-back" capacity; C_2 is the plate coupling capacity. The frequency is controlled in the capacity coupling between plate and grid.

Tuning of the Colpitts circuit is usually done entirely by variations of L. In many circuits where it is used as a master oscillator, L consists simply of a variometer across C_1 and C_2 the capacities of which are fixed. The entire frequency band of the transmitter is covered by the variation of the variometer inductance. This method would not be desireable if the circuit were designed to operate as a power circuit because there is no means of controlling either the excitation voltage or the plate impedance. There are both very important factors if efficient operation and large power output are desired, but of minor importance as compared with stable frequency and ease of tuning in a master oscillator.

A better design for a power circuit is shown in Fig. 13. Since the

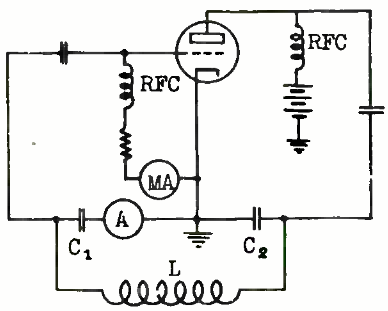

Fig. 12. Schematic diagram of fundamental Colpitts circuit.

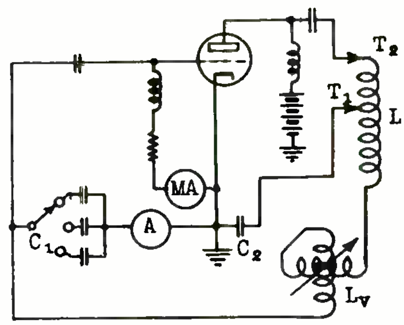

Fig. 13. Improved circuit for power oscillator.

part of the radio frequency circuit between the grid and filament consists simply of C_1, the grid excitation voltage must equal the IX_c

drop across C_1. As X_c is a function of frequency, if the same excitation voltage is desired over the entire frequency band, the capacity of C_1 must be changed when the frequency is changed.

The plate output impedance is varied by means of tap T_2. This adjustment permits matching the output impedance with R_p under which condition the maximum power will be delivered by the tube. The tuning of the circuit is done by means of tap T_1 and variometer L_v.

The most critical adjustment in this circuit is the capacity of C_1 which controls the grid excitation voltage. If this voltage is too high, too much power will be expended in the grid circuit; if the excitation is insufficient, the efficiency is low and the desired output will not be obtained. The minimum grid excitation voltage of a power oscillator should be considerably greater than E_b/μ where E_b is the plate voltage and μ is the amplification factor of the tube. When biased to almost cut-off this will allow plate current to flow approximately one-half the time.

The excitation voltage IX_c is a function of the capacity, the frequency, and the current in the circuit.

Consider a practical example, to compute the capacity of C_1. Assume a tube with an amplification factor of 10, capable of supplying 1,000 watts into a 6 ohm circuit with d-c plate potential of 2,500 volts. The oscillator is to operate at 500 kc/s.

The required minimum grid excitation voltage is $E_b/\mu = \frac{2500}{10} = 250$ volts.

Since the circuit is to have an effective resistance of 6 ohms and the tube output will be 1,000 watts, the radio frequency current in the circuit can be determined.

$$I^2 = P/R \text{ and } I = \sqrt{P/R}$$

$$I = \sqrt{\frac{1000}{6}} = 13 \text{ amperes}$$

(Approximately)

The excitation voltage must equal IX_c; then $X_c = E/I = 250/13 = 19$ ohms of capacity reactance.

$$X_c = 1/2\pi FC \text{ and } C = 1/2\pi FX_c$$

$$F = 500{,}000 \text{ cycles.} \quad X_c = 19 \text{ ohms.}$$

$$\text{Therefore } C = \frac{10^{-3}}{628 \times 19 \times 5}$$

$$= .0167\ \mu F$$

Under the conditions specified the grid coupling capacity C_1 must be .0167 µF to obtain the minimum required excitation at 500 kc/s. Since to obtain fairly high operating efficiency the bias is usually greater than that required for I_p cut-off, in practice C_1 should be made somewhat smaller to allow greater excitation. If it is desired to decrease the frequency to 250 kc/s, the other conditions remaining the same, the capacity of C_1 should be doubled in order to keep the excitation voltage, IX_c, constant.

Thus, in adjusting the Colpitts circuit the capacity of the grid coupling capacitor should be *increased when the frequency is decreased and vice versa.* In other words, the correct grid coupling capacity for maximum output varies inversely as the frequency. (This, of course, assumes that the radio frequency current in the circuit is essentially the same over the entire frequency range of the transmitter, which, of course, is not necessarily true, because the load and r-f circuit resistances will usually vary to some extent with frequence.)

Consideration of this problem will show that the required value of grid feed-back capacity is a function of the circuit resistance. The excitation voltage, IX_c, depends directly upon the value of the circulating current. The current depends upon the effective resistance of the circuit. Assuming a given power output, $I = \sqrt{P/R}$. I varies inversely as the square-root of the circuit resistance. If the circuit resistance is doubled, the current will be decreased by $1/\sqrt{2}$, 1/1.41 or .707. If the current is decreased by an increase of resistance, the capacity of C_1 must also be decreased in order to obtain a proportionate increase in X_c so that IX_c remains unchanged. An example of this is where an oscillator is adjusted while unloaded and an antenna is then coupled to it and resonated, this, of course, increasing the effective resistance of the oscillator circuit.

The correct adjustment of C_1 is usually determined by observing the reading of the grid current milliammeter in series with the grid leak. The grid current is a function of the excitation voltage, varying as the value of the excitation voltage. An increase of frequency, if C_1 were not changed, would decrease X_c, and the grid current would decrease. If the frequency is held constant, an increase in the capacity of C_1 will decrease X_c, thus decreasing IX_c, and the grid current will decrease. From this it will be seen that the excitation voltage tends to increase with a decrease of frequency, and this increase must be counteracted by an *increase of capacity.*

The capacity of C_2, the plate coupling capacity, is not critical and is usually fixed for the entire frequency range of the transmitter.

The Colpitts circuit holds its frequency exceptionally well and for that reason is well adapted for use as a master oscillator. At the intermediate frequencies it is little affected by slight changes in the tube capacity because the entire capacity of the circuit is in parallel with the capacities of the tube and the percentage change is small.

There is no tendency for the Colpitts circuit to jump into oscillation at a frequency close to, but different from that of the desired frequency, although, in common with *all* circuits having L and C, it *may* develop undesired very high frequency parasitic oscillations. The parasitics, however, may usually be prevented by fairly simple means so that this is no particular disadvantage.

In any oscillator in which it is desired to develop the maximum power output the plate tap is a very important adjustment, as the position of the plate tap not only largely determines the power output but, also, the *stability of oscillation.* The output of a power oscillator is normally used to excite an antenna or a following stage of amplification. As the coupling to the oscillator circuit is increased to increase the power transfer, the effective circuit resistance is increased. If the plate output turns are too few the output of the tube will not be maximum and, while the circuit may oscillate freely when unloaded, when the load is applied it will tend to become unstable and oscillations may suddenly stop.

In an oscillator the grid bias is practically always obtained by means of a grid leak. Thus, when oscillations "break" the plate current rises suddenly and the tube may be damaged. An oscillator will always be more stable when operating with too many plate turns (high Z_L) than with too few plate turns and low Z_L. This point should be taken into consideration when the final adjustment is made and the plate tap should *not* be placed on the critical point of maximum output when the circuit is unloaded. Just as in the case of an r-f amplifier, the plate load impedance of the tube is a function of $Z_L = L/CR$, and when the circuit is loaded the effective R is increased, this decreasing Z_L, the load impedance. If $Z_L = R_p$ before loading, it will be less than R_p after the load is coupled and the circuit will be an inefficient oscillator. If $Z_L > R_p$ before coupling the load, the increase of R will tend to bring Z_L nearer the value of R_p and the power output will be increased.

In a properly adjusted power oscillator, the tube operates very efficiently when delivering large power output. The bias is obtained from the drop across a grid leak. As the excitation voltage is increased with a corresponding increase in power output, the grid bias is also increased. Thus, at an optimum adjustment, a power oscillator is biased beyond cur-off and operates in a manner similar to a Class C amplifier, with operating efficiency which will usually be in the order of 60 per cent. Under such conditions, since the amplification factor of the tube is decreased as the cut-off point approached, and is zero beyond cur-off, the excitation voltage required for maximum power output will exceed E_b/μ. Optimum adjustment is obtained by varying the excitation voltage and the load impedance.

THE ELECTRON COUPLED OSCILLATOR.—The electron coupled oscillator, originally developed by J. B. Dow, is the result of experimental work to develope power oscillator which could be made to deliver an appreciable amount of power into a coupled load circuit with the frequency of oscillation independent of variations of load impedance and coupling. Consider the case of a conventional Hartley or Colpitts oscillator used to supply excitation for a stage of radio frequency amplification. The grid of the amplifier is either inductively or capacitively coupled to the oscillator. As the amplifier plate tank circuit is tuned through resonance, the load on the tube is changed, a change in the effective capacity is reflected back into the oscillator circuit, and the oscillator frequency is varied. It has been found that all conventional oscillator circuits are subject to considerable frequency variation with variation in load constants so long as the coupling between the load and the oscillator circuit is sufficient for good transfer of power.

Conventional oscillator circuits, unless some means are taken to stabilize the frequency, are also subject to serious frequency variation with variation in plate potential. Of course, in many cases, a temperature controlled quartz crystals can be used to maintain a constant frequency. However, where it is desired that a transmitter be continuously variable over a given frequency range, or where an oscillator is to be used to supply a test voltage over a given continuous frequency range, crystal control is not practical.

The electron coupled oscillator as shown in Fig. 14 (temporarily disregard dotted lines) demonstrates *a remarkable freedom from reaction between the tuned circuit and the load.* Using a conventional screen grid tube such as the Type 865, the

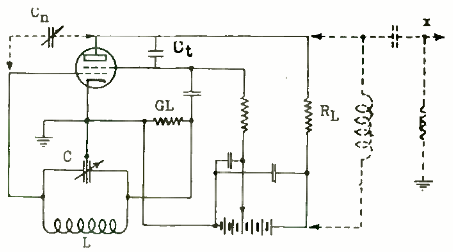

Fig. 14.—**Schematic diagram of the electron-coupled oscillator.**

control grid, filament, and screen grid, in conjunction with the tuned circuit L-C, form a simple Colpitts circuit, C being a split-stator type of capacitor half of which is between grid and cathode and half between screen grid and cathode.

The load circuit R_L is not coupled directly to the tuned circuit. As the frequency determining circuit oscillates, the amplitude of the electron stream between filament and plate is modulated at the oscillator frequency. The variations in plate current through the load impedance transfer power to the load circuit.

The weakness of the circuit, as shown only by the heavy lines, is the capacity between the plate and the screen grid. This capacity allows a certain amount of undesirable reaction between the load circuit and the frequency determining circuit as load variations occur. This capacity effect can be effectively neutralized in most types of screen grid tubes by the use of a variable capacity C_n (shown by dotted lines) connected between the plate and the control grid. If C_n = neutralizing capacity, C_t = interelement capacity between plate and screen grid, C_g = capacity of the grid section of C, and C_p = capacity of the plate section of C, the following relation will be approximately correct; $C_n : C_t :: C_g : C_p$. Since this forms a simple capacity bridge circuit, the adjustment is independent of frequency. The adjustment of C_n is simple. The plate voltage is removed, a radio frequency milliammeter is connected in series with R_L, and C_n is adjusted for zero current in the load circuit.

In practice, where the oscillator is used to excite an r-f power amplifier, the simple resistor R_L is replaced with a circuit as shown by dotted lines. The voltage established across the load reactance is used to drive the following amplifier tube.

When the oscillator is to be used for receiver testing, calibration of frequency meters, etc., point x on the load circuit connects to a terminal on the panel from which a lead is taken to the circuit measurement. The power output may be connected to any desired type of load with little effect on the oscillator frequency.

In the development of the electron coupled oscillator it was found that given d-c voltage variations on the plate and screen produced almost exactly opposite frequency variations. Thus, by properly proportioning the plate and screen voltages, the frequency can be made almost independent of anode voltage variations.

Frequency variation with temperature change is to be expected in any oscillator, including a crystal controlled circuit. (The practical exception to this is the zero temperature coefficient quartz crystal in which the frequency change per degree of temperature variation is extremely small). Thus, if the frequency is to be independent of temperature variation, the frequency controlling circuit, L and C, and the neutralizing capacitor C_n must be placed in a compartment the temperature of which is thermostatically controlled. Frequency variation with changes of ambient temperature, if the circuit is not under temperature control, are due to expansion and contraction of the L and C elements with temperature variation, as well as to distortion of the L and C elements due to mechanical strain when the panel and base assembly expand and contract with temperature variations. Dow found that without temperature control of the frequency determining part of the circuit, a frequency variation in the order of .005 per cent per degree Centigrade change in temperature could be expected. At 5,000 kc/s, this amounts to 250 cycles per degree of temperature variation and is serious. Thus, if full advantage is to be taken of the other frequency stabilizing features of the circuit, the temperature of the frequency determining elements must be maintained within .2 degree Centigrade. With temperature control of the circuit, but not of the tube itself, a frequency drift of .001 percent per degree Centigrade of ambient temperature change may be expected.

TANK CIRCUIT DESIGN AND LOAD COUPLING.—The selection of tank circuit constants will depend largely upon the purpose for which the oscillator is to be used. If, as in the case in most modern transmitters, the oscillator is used simply to supply excitation to a series of power amplifiers, a circuit as shown in Fig. 15 may be used. The Colpitts oscillator is coupled by means of C to the grid of the screen grid buffer tube. The buffer amplifier operates with a negative bias such that the excitation never drives the grid positive. The use of the

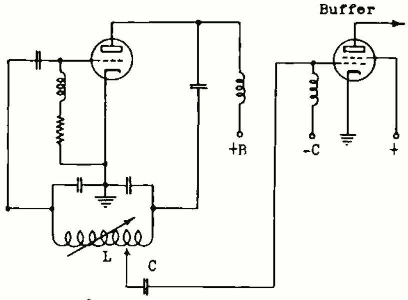

Fig. 15.—The typical tank circuit used when oscillator is used to excite a number of power amplifiers.

screen grid tube minimizes reaction between the buffer plate circuit and the oscillator circuit. Thus, the only load on the oscillator is the small r-f current flowing through the grid-filament capacity of the buffer tube. In other words, the oscillator operates practically unloaded, and almost all the circuit resistance is the resistance in coil L. Therefore, the principal problem of design is to obtain a ratio of tank circuit L and C that will tune over the desired frequency range with stable oscillations. In several commercial transmitters employing a quite similar circuit the oscillator grid and plate tank capacities are fixed and L consists of a simple variometer, the tuning of which will cover the desired frequency range. Where a wider frequency range is required, L may consist of two or three variometers, any one of which may be connected by a hand-change switch across the circuit capacity.

Where the oscillator must supply considerable power to a load, such as when the oscillator is coupled directly to an antenna, more care must be taken in tank circuit design. An example of such a circuit is shown in Fig. 16. In this case the resistance of the antenna, which, by proper coupling between L and L_2, is reflected into the tank circuit, forms the load into which the oscillator works. Where the transmitter in question has a fairly large power output the coils will be constructed of copper tubing so that the actual coil resistance will be small compared with the reflected load resistance. Thus, in the case of an antenna having a resistance of 20 ohms, by proper coupling this resistance becomes essentially the oscillator tank circuit resistance.

For stable oscillations the circuit Q, that is, the ratio of X_L/R in the oscillator tank circuit, should be not less than 12. In a low Q circuit the output will contain an excessive amount of harmonic components and will be unstable. This was shown in an earlier assignment. If the Q is much higher, the tank circuit losses will be unnecessarily large because of the large circulating current, although, the operation of the oscillator will be excellent. As an example, assume the circuit shown in Fig. 16, operating at a frequency of 600 kc/s, and furnishing a power output into a 20-ohm antenna of 5 kw. The tank inductance is designed to have a loaded Q (Q with the antenna load connected) of 10 = X_L/R, and the unloaded Q (with the antenna disconnected or detuned) of 100. Assume further that the inductance of the tank coil is L_T = 74 μhenries.

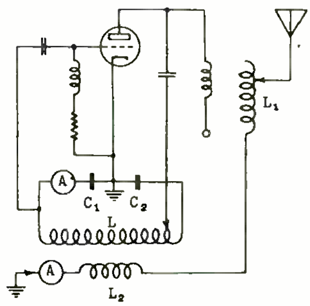

Fig. 16.—Typical tank circuit used when oscillator feeds load directly.

The reactance of the tank coil is

$$X_{LT} = 2\pi\, 600 \times 10^3 \times 74 \times 10^{-6}$$

$$= 280 \text{ ohms.}$$

Then, since $Q = X_L/R$, $R = X_L/Q$, or the resistance of the tank coil is (using the unloaded Q)

$$R_c = 280/100 = 2.8 \text{ ohms.}$$

The loaded Q, which includes the reflected resistance of the 20-ohm antenna, is

$$R_{ca} = 280/10 = 28 \text{ ohms.}$$

This means that in addition to the 2.8 ohms of the tank coil, there is inserted or reflected in SERIES with the tank coil additional resistance, owing to the antenna, that raises the resistance to 28 ohms. This is illustrated in Fig. 16A. The resistance coupled in by the antenna is clearly 28 - 2.8 = 25.2 ohms.

It is this resistance that represents the load absorbing 5 kw from the tank circuit and associated oscillating tube, and passing it on to the antenna. From this the tank

coil current can be computed.
Thus,

$$I_{LT} = \sqrt{5000/25.2} = 14.11 \text{ amperes.}$$

This same current flows through the 2.8 ohms resistance of the tank coil, and produces the ohmic losses in the coil. This amounts to

$$I_{LT}^2 R_c = (14.11)^2 (2.8) = 560 \text{ watts.}$$

Hence there is developed a total of 5000 + 560 = 5560 watts in the tank circuit, of which 5000 watts pass on to the antenna circuit.

The total tank capacity is C_T, and represents C_1 and C_2 in series. Its value is found from the resonance formula and the known values of L_T and f:

$$C = \frac{1}{(2\pi f)^2 L_T}$$

$$= \frac{1}{(2\pi\ 600 \times 10^3)^2\ 74 \times 10^{-6}}$$

$$= 953 \times 10^{-12} \text{ farad} = 953\ \mu\mu f.$$

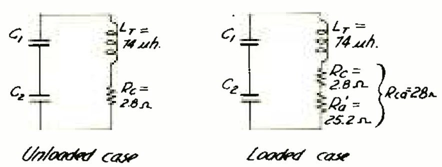

Fig. 16A.—Showing how the resistance in series with the tank coil increases when the antenna circuit is coupled to it and loads it down.

The calculation for C_1, as determined by the required excitation, has already been discussed. Then C_2 can be found from the formula:

$$C_2 = \frac{1}{1/C - 1/C_1}$$

However, it must be remembered that the capacity values are only approximate, since the interelectrode tube capacities actually have to be taken into account, too.

If the antenna is detuned from the tank circuit, two things happen. In the first place, it now reflects into the tank circuit a reactance as well as a resistance. The reactance tends to change the resonant frequency of the tank circuit, but the effect is usually small if the coupling is normal, and the oscillator readily adjusts itself to this new resonant frequency.

The second effect is that the antenna draws very little current, and therefore reflects a higher resistance than before (25.8 ohms) into the tank circuit. This higher resistance, however, is less than the reactance mentioned previously which it reflects into the tank circuit; the total impedance it reflects into the tank circuit is still small compared to X_{LT} of the tank coil for normal values of coupling.

The result is that the tank coil current I_{LT} decreases somewhat because of the higher impedance in that branch of the circuit, but more important is the fact that I_{LT} now

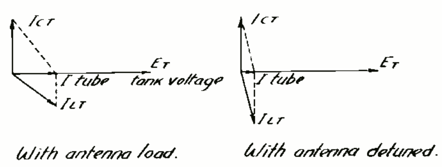

Fig. 16B.—When the antenna is detuned, the tank coil current I_{LT} decreases slightly and becomes more nearly 90° out of phase with E_T. As a result, the tube or line current I_{tube} decreases.

lags the voltage across the tank circuit by more nearly 90°. This in turn means that the tube or line current is LESS, as is clearly shown in Fig. 16B. As a result the tube "sees" a higher impedance "looking" into the tank circuit; i.e., it is as if the antenna circuit were removed.

EXCITATION AND BIAS VOLTAGES.— It will be observed that specific values of excitation and bias voltages have not been given. Unlike the various types of amplifiers where in almost all cases definite bias and closely controlled excitation voltages are absolutely essential for true reproduction of an input voltage, the bias and excitation of an oscillator are seldom critical. The bias is obtained by grid leak action for two principal reasons: first, it makes the oscillator self-starting because of the strong surge of plate current when plate voltage is applied before the bias is established; second, the grid leak bias will automatically increase to take care of increased excitation as the output is increased.

The bias will be determined by two principal factors, the resistance of the grid leak and the amplitude of the excitation voltage. Since it is due to the flow of grid current through the grid leak, it is apparent that the negative bias will be something less than the peak amplitude of the excitation voltage. Thus, with a fixed grid leak resistance, as the excitation is increased the grid will be driven more positive on the peaks, more grid current will flow, this will increase the bias and tend to reduce the positive grid swings until a point of equilibrium is reached.

If the excitation voltage is equal to E_b/μ and the proper grid leak is used, the bias will be slightly less than that required for plate current cut-off, plate current will flow slightly more than one-half the time, and the operating efficiency will be something less than 50 per cent. As the excitation voltage is then increased, the increased grid current will cause an increase in the bias, the duration of plate current flow per cycle will be decreased, and the operating efficiency will be increased. Very high efficiency is obtained when the plate current is in the form of a very short pulse at the peak of each excitation cycle. For such operating condition a large grid leak resistance and large excitation voltage are required and the efficiency may approach 90 per cent. However, that is not a very practical operating condition, due to the difficulty of obtaining sufficient power input with the very short duration of plate current per cycle.

With a negative grid bias of something more than E_b/μ and excitation of course somewhat greater than the bias voltage, it is very practical to obtain an operating efficiency in the order of 60 per cent, together with good output.

The required grid leak resistance is not at all critical. If it is too low, the operating efficiency, for given excitation, will be low. If it is too high, the tube will periodically block. The optimum value is ordinarily determined by trial. In the case of a Type 807 tube, optimum output and efficiency will be obtained with a grid leak resistance in the order of 13,000 ohms. In the case of 10 kw water-cooled tube, the resistance may be in the order of 600 to 700 ohms. For small receiver type tubes the grid leak resistance may be in the order of 20,000 or 50,000 ohms, or occasionally as large as .1 megohm.

A second method of power oscillator calculations will now be discussed utilizing the information obtainable in the Transmitting Tube Manuals. While a knowledge of forecasting the tube performance is desirable, it is beyond the scope of this assignment.

The statement that the ratio of VA/W should be 12 has been made. The reason for this choice will be shown. The ratio of energy stored to energy dissipated per cycle is very important since the stability of the oscillator and the preservation of a desirable a-c wave shape at the oscillator frequency across the tank are functions of this choice.

Consider the relations shown in Fig. 1. At the instant t = 0, all the energy is stored in the capacitor. The instantaneous energy storage equation for a capacitor is

$$\text{Energy stored} = \frac{CE^2}{2}$$

The voltage across the capacitor in the diagram is the peak value occurring during the oscillation cycle. For the case considered, the maximum voltage for the equation above will be $\sqrt{2}E$. Substituting this value gives.

$$\text{Energy stored} = \frac{C(\sqrt{2}E)^2}{2}$$

$$= \frac{2CE^2}{2} = CE^2$$

The energy dissipated per cycle will be W/f since W is the energy dissipated per second so the energy dissipated per cycle is as shown. One can then write

$$\frac{\text{Energy stored}}{\text{Energy dissipated per cycle}}$$

$$\frac{CE^2}{W/f} = \frac{fCE^2}{W}$$

Multiply both numerator and denominator by 2π and get

$$\frac{2\pi fCE^2}{2\pi W}$$

Now the current in the capacitive branch is always $I = E/X_c = 2\pi fCE$. The numerator of the expression above may be written as $2\pi fCEE$ since E occurs squared. Substitute for $2\pi fCE$, its equal I and obtain

$$\frac{\text{Energy stored}}{\text{Energy dissipated per cycle}}$$

$$= \frac{\text{volt-amperes}}{2\pi \text{ watts}} = \frac{VA}{2\pi W}$$

To determine what this ratio should equal requires some experience with oscillators. Experience shows that the ratio should be 2 if the oscillator is to have good stability and not too large inherent tank circuit losses. This gives

$$\frac{VA}{2\pi W} = 2 \text{ or } \frac{VA}{W} = 4\pi = 12.56,$$

hence the approximate choice of 12. If one chooses a ratio in excess of 12, he gains stability but the tank current rises and produces an inherently large I^2R tank loss. If he chooses a value less than 12, he loses stability but perhaps reduces the inherent tank loss. For the oscillator, frequency stability is desirable, so a choice less than 12 is not good practice. For high stability, a VA/W ratio of 50 may be required.

However, choices in excess of 20 are seldom made and for power oscillators, from 12 to 15 is considered good practice. For a Class C amplifier, the choice can be made less than 12 since the frequency stability is not determined by the amplifier itself but the preservation of sinusoidal wave shape at the desired operating frequency makes a choice of from 8 to 12 desirable, thereby obtaining good harmonic reduction.

Having seen the reason for the choice of VA/W and having made such an arbitrary choice, the design proceeds in straightforward manner. Reference to any Transmitting Tube Manual will show a listing of Typical Operating Conditions for most tubes for various classes of service. Since a power oscillator is to operate Class C, the necessary information is gained from those operating conditions.

It is desired to use a 203-A tube as a power oscillator with a plate supply voltage of 1,000 volts on a frequency of 500 kc/s. A Colpitts oscillator circuit has been chosen. The basic circuit is shown in Fig. 12. Reference to the curves of Fig. 2 will show that the a-c grid excitation voltage is to be obtained from the drop across C_1 while the a-c plate voltage will be developed across C_2. Optimum oscillator performance is desired, hence the curves of Fig. 2 give a clue to the values of these voltages, together with the information under Typical Operation Conditions. For 1,000 volts plate supply,

d-c plate voltage	1,000 volts
d-c grid voltage	-100 volts
peak r-f grid voltage	255 volts
d-c plate current	150 milliamperes
d-c grid current (approx)	25 milliamperes
grid driving power (approx)	6 watts
power output (approx)	100 watts

The first item is the supply voltage E_b. The second item is the bias E_c. The third item is the peak value of the a-c grid voltage E_g. The fourth item is the average plate current I_b. The fifth item is the average grid current I_c. The others require no comment as far as symbols are concerned.

The value of the maximum positive excursion of the grid can be determined from the expression $e_{c\,max} = E_g - E_c$. Substituting the values from the data gives $e_{c\,max} = 225 - 100 = 125$ volts. Since this last value is also the value of $e_{b\,min}$, the value of the a-c plate voltage E_p is readily determined from $e_{b\,min} = E_b - E_p$ or $E_p = E_b - e_{b\,min}$. Again by substitution, $E_p = 1{,}000 - 125 = 875$ volts. The grid excitation voltage is 225 volts as stated and will be developed across C_1. The a-c plate voltage E_p is 875 volts and is developed across C_2. The tank current will flow through each of these capacitors and will develop these voltages. The ratio of these voltages will thus be the same as the ratio of the reactances of the capacitors and their capacities will be in inverse ratio. The reactance ratio is the $X_{c1}/X_{c2} = E_g/E_p$ or $225/875 = 1$ to 3.9 (very nearly).

The next step is the choice of VA/W which will be taken as 12. The power output is 100 watts so the VA value is $100 \times 12 = 1{,}200$ (since VA/W = 12 and VA = 12 W). The excitation and a-c voltage across the capacitor C_2 must now be converted to rms values since power is the rms product of voltage and current.

E_g(rms) = $225/\sqrt{2}$ = 159 volts and E_p(rms) = $875/\sqrt{2}$ = 620 volts. The rms tank current is then VA/V 1200/779 = 1.54 amperes. The reactance of C_2 = 620/1.54 or 403 ohms while the reactance of C_1 = 159/1.54 = 103 ohms. It will be observed that the reactance ratio, 103/403 is also 1/3.9. At 500/kc/s, C_1 = $1/2\pi fX_c$ = .00309 μF and C_2 = $1/2\pi fX_{c2}$ = .000791 μF.

The reactance of the inductance is equal to the sum of the capacitive reactances or 103 + 403 = 506 ohms and the inductance at 500 kc/s is L = $X_L/2\pi f$ = 161 μH. In practice, some departure from these exact values is permissible and the capacitors chosen might then be taken in "round" values. Fixed mica capacitors with a variable inductance is the usual practice.

The power input for the grid circuit must be supplied from the plate circuit so the total power output will be, for this example, 100 - 6 = 94 watts. That is, 94 watts will be available for inherent tank circuit loss and power to the load. A good tank circuit will not extract more than 5 per cent or so of power which leaves approximately 90 watts delivered to the load.

The power input to the plate circuit is $E_b \times I_b$ or 1000 × .150 = 150 watts. This gives an efficiency for the oscillator of 90/150 or 60 per cent. As a Class C power amplifier, the efficiency would be somewhat higher since the grid losses would be supplied by the driving amplifier.

The value of proper grid leak is stated in the Operating Conditions but can be determined by $Rg_L = E_c/I_c$. This has been previously shown in an earlier assignment.

It has probably been observed that the values for L and C_1 and C_2 are somewhat different than for the previous calculation. That is because the operating conditions were quite widely different. Much useful information can be gleaned from the tube manual and the student is urged to familiarize himself with the information contained in it.

SPECIAL REQUIREMENTS OF SUPERHETERODYNE OSCILLATORS. In an earlier assignment the oscillator tuned circuit was discussed with reference to padding and capacitor plate shape to allow the oscillator and r-f circuits to track. There is a common oscillator trouble encountered in superheterodyne receivers which has been extremely difficult to overcome. That trouble is "oscillator drift" and is caused by the effect of temperature change on the elements making up the oscillator tuned circuit. It has been shown in this assignment that frequency deviation is encountered even in the well designed electron coupled oscillator unless temperature control is used. Thermostatically controlled temperature compartments are bulky and expensive and are, therefore, impractical for use in broadcast receivers. Such receivers are used under all operating conditions and in all ranges of climate and temperature. In addition, as the receiver warms up in operation, the temperature within the receiver may change many degrees. Thus, oscillator drift has been a common trouble in all superheterodynes, both expensive and inexpensive.

This difficulty can be corrected by the use of "AFC—automatic frequency control." This is explained in detail in a later assignment. Briefly, it consists of a frequency discriminating circuit connected into the intermediate frequency amplifier. When the signal is properly tuned in and the oscillator is developing the proper frequency, the beat frequency is the correct intermediate frequency. When the oscillator frequency drifts, the correct intermediate frequency is no longer developed. The discriminator tube and circuit of the AFC system, then operate to change the operating condition of another tube which is connected across the oscillator tuned circuit in such a manner that a change in the operating conditions of this tube causes a corresponding change in the inductance or capacity (usually inductance) of the oscillator tuned circuit. This corrects for the oscillator drift, due to temperature variations.

Since the AFC system operates whenever the intermediate frequency is not correct, the circuit will automatically correct improper tuning of the receiver. Thus, even a broadcast signal is carelessly tuned in, (the common condition), the AFC system automatically applies the proper correction to the oscillator to produce the correct intermediate frequency.

For the design of an oscillator where frequency stability is the major item, the problems of power output and efficiency are made of secondary importance. The designer is willing to make a considerable sacrifice in both the latter and as a result the usual practice is to determine the values employed experimentally. Such oscillators seldom are of the power type and consequently require little predesign other than a general knowledge of the factors inherently affecting the stability. These have been discussed.

The use of AFC has been shown to make the design of oscillators for use in the superheterodyne somewhat less rigorous in the requisite of stability. There are many receivers lacking the AFC circuit. Recent designs have almost without exception disregarded AFC circuits. For this reason, other factors have a real significance in the oscillator design requirements for receivers.

Primarily, the oscillator must have a reasonable frequency stability and must also have a voltage output as nearly constant as possible. The circuit almost universally employed for such oscillators is the tuned grid oscillator with inductive feed-back from an untuned plate coil. This circuit has been shown earlier in this assignment.

The tuned circuit must have as high a Q as possible, and this may be quite difficult to realize in the higher frequency bands of the receiver. To get this high Q, the usual conditions are imposed in the design of the tuned circuit. It will be remembered that the Q of a coil increases with diameter and is generally higher when a small ratio of length to diameter is maintained. There is also an optimum wire diameter and this has been shown to be determined by the ratio of wire diameter to pitch. The optimum ratio has been shown to be .6 (Harris and Siemens in a paper before the Rochester Fall Meeting of the Institute of Radio Engineers, 1935). The variation of " with wire diameter is small in the vicinity of the optimum ratio, i.e., 0.6, which means that a satisfactory choice involving the nearest standard wire size can always be made. For the high frequency coils, the matter of high Q is of the greatest importance.

The plate coil is coupled to the grid coil, usually by the use of a single coil inductively related to the grid coil. Usual practice is to use a single plate coil. The coefficient of coupling k should be chosen as high as possible. This means that a large number of plate turns in the plate coil should be employed. In fact, the plate coil should be as large as possible but not so large that it will resonate with its distributed capacity to some frequency within the tuning range of the oscillator. If this happens, the plate circuit will take control of the frequency and the variations in the tuning capacitor will have negligible effect on the tuning. Harris and Siemens showed that the product of $Q \times k$ should be as large as possible, as long as the condition just cited is not encountered.

The oscillator grid current is a good criterion of the oscillator performance. The variation in this current should not be too great as one tuned the oscillator over the frequency range. The proper value or variation in value for oscillator grid current may be obtained from the tube manual on receiving tubes for most of the prevailing oscillator-mixer combinations. The value of grid leak and capacitor is of high importance. The grid leak chosen, together with the grid capacitor, should be of such a value that relaxation effects are not encountered. A grid leak in the order of 50,000 ohms is generally advisable with grid capacitors running as small as from 25 to 15 μμF.

Tubes satisfactory as oscillators have been found to be the 6C5, 6K7 and the 6F6.

The design of oscillators for the use in receivers is largely experimental in nature and only general rules are possible.

CAPACITY NEUTRALIZING (BALANCE) CIRCUITS.—The ease with which the vacuum tubes connected between tuned radio frequency circuits can be made to oscillate has been shown. In fact, except where oscillations are actually desired, one of the most serious problems in radio design is to prevent the tube and circuit from oscillating. Just as in the case of the tuned-grid tuned-plate oscillator, the radio frequency amplifier, either transmitter or receiver, employing efficient low loss tuned circuits connected to the grid and plate, is a natural oscillator by virtue of the inter-element grid-plate tube capacity, even though the actual circuits are effectively shielded so that there is no inductive or capacitive circuit coupling.

Assuming efficient circuit shielding, feed-back through the tube may be prevented in two ways: first, by the use of a screen grid tube (tetrode or pentode) in which the grid-plate capacity has been reduced to a negligible (usually) value; second, by the use of a circuit in which the effect of the grid-plate tube capacity may be neutralized by feeding back a voltage of the correct amplitude and, opposite in phase to counteract the voltage fed back through the tube itself. The first method is most commonly used today in receivers, although, it was only a few years ago that the development of the "neutradyne" circuit for broadcast receivers, for the first time made efficient radio frequency amplification practical.

Screen grid tubes are commonly used in the low power r-f amplifiers of transmitters. However, in high power transmitters, the triode still dominates and capacity neutralizing circuits must be used. The neutralizing circuits to be discussed may be, and are, used in both transmitters and receivers.

Neutralizing circuits will be discussed in the following sequence: Hazeltine, Rice, Miller, and Criss-Cross or Push-Pull circuit.

through L_2 and, by mutual induction, causes current to flow in L_3. It should be observed, however, that the currents flowing in L_1 and L_2, due to the voltage at the grid will be in opposite directions with respect to L_3. Therefore, the two currents induced in L_3 will be 180° out of phase, and if of equal amplitude will cancel, with the result that there will be no current flow in L due to the tube capacity.

Signal current in L_1 due to the

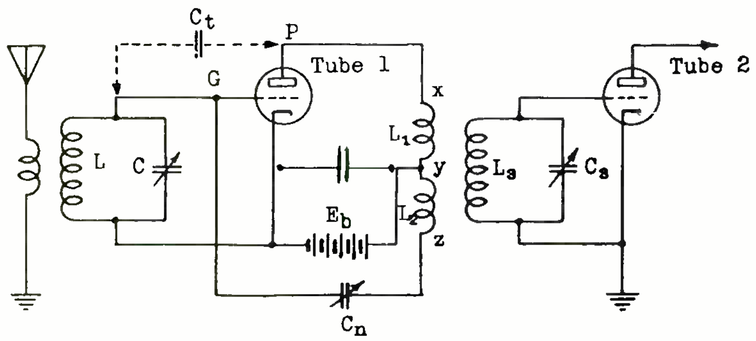

Fig. 17.—Hazeltine neutralizing circuit.

The Hazeltine circuit is shown in Fig. 17. This is the original circuit designed for the purpose of neutralizing the interelement tube capacity. The operation is simple. Assume that a voltage due to an incoming signal is impressed at the grid of Tube 1 between grid and cathode. Due to capacity C_t (grid-plate) the signal voltage is also impressed across circuit $C_tL_1E_b$ and signal current flows in L_1 which, by mutual induction, causes current to flow in L_3, due to the capacity of the tube and not to its amplifying action. The same signal voltage is impressed across circuit $C_nL_2E_b$, signal current flows

amplifying action of the tube is not neutralized by C_nL_2 and the amplified signal current flows in L_3 as desired. A similar operation prevents feed-back from L_3C_3 to L-C. When current flows in L_3 a voltage is induced across L_1 and L_2. However, the voltages xy and zy are 180° out of phase and, transferred through C_t and C_n respectively to G, cancel. With this condition there will be no energy transfer back to the tuned grid circuit of Tube 1 and consequently no tendency to oscillate. (It is assumed, of course, that the circuits are efficiently shielded from each other so that there is negligible circuit coupling.)

If L_1 and L_2 are equally coupled to L_3, then for neutralization $C_n = C_t$. However, that condition is seldom attempted. Usually L_2 has fewer turns than L_1 and C_n is larger than C_t. The larger capacity of C_n allows more current to flow through L_2 than can flow in L_1, this larger current compensating for the weaker inductive coupling between L_2 and L_3. The principal advantage of this arrangement is the fact that with C_n larger, the adjustment is less critical than when $C_n = C_t$; that is, a small capacity change in C_n will have a smaller percentage effect on the total capacity of C_n than if C_n were originally very small.

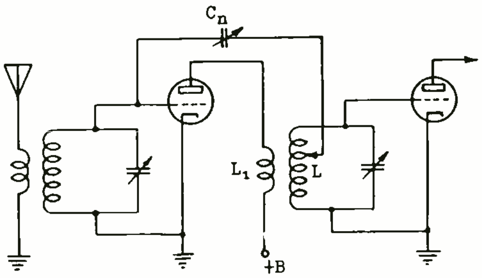

Fig. 18.—Modified Hazeltine neutralizing circuit.

Adjustment is not at all difficult. One filament prong of Tube 1 is insulated so that the filament does not light and the tube, instead of amplifying, is simply acting as a capacity. An r-f oscillator is coupled to L-C; L-C and L_3C_3 are tuned to resonance with the oscillator frequency so that there is maximum current flow in L_3C_3. C_n is then adjusted until the current in L_3C_3 is zero. If the circuit being neutralized is an r-f amplifier in a transmitter, the test oscillator is replaced by the regular transmitter oscillator adjusted to its assigned frequency and an r-f milliammeter is connected in L_3C_3 to indicate neutralization. Also, in a transmitter it is customary to remove the plate voltage when neutralizing the circuit instead of removing filament power. In the case of a receiver, a modulated r-f oscillator is used and neutralization is indicated by zero or minimum signal in a pair of phones connected into the audio output. A properly designed circuit can be very easily neutralized.

Fig. 18 shows a modification of the Hazeltine circuit often used in receivers. Instead of the use of a separate winding for coupling the neutralizing circuit inductively to the tuned circuit of the second tube, simple conductive coupling is used. The results are the same with a somewhat more simple coil design.

Fig. 19 illustrates *the Rice Balance*. This circuit is used more extensively in transmitters than is the Hazeltine circuit. The principle of operation, however, is the same, the only difference being that the neutralizing circuit is reversed. The grid circuit of Tube 2, the tube being neutralized, consists of C_1, A, and the inductance of L_1 between the taps connecting from C_1. It should be noted that the lower side of the grid tank circuit of Tube 2 (which is also the plate tank circuit of Tube 1) connects to ground.

Grid excitation tap G of Tube 2 connects into L_1 above ground. The neutralizing tap N connects to L_1 below ground. The neutralizing r-f voltage is taken from the plate of Tube 2, through C_n, to tap N. Feedback voltage through the tube grid-plate capacity is taken from the same point, through the tube to tap G.

With the two taps connected to L_1 on opposite sides of ground, two voltages induced across the tank inductance will be 180° out of phase, and if of equal amplitude will cancel, the resulting feed-back will be zero, and the circuit will not oscillate.

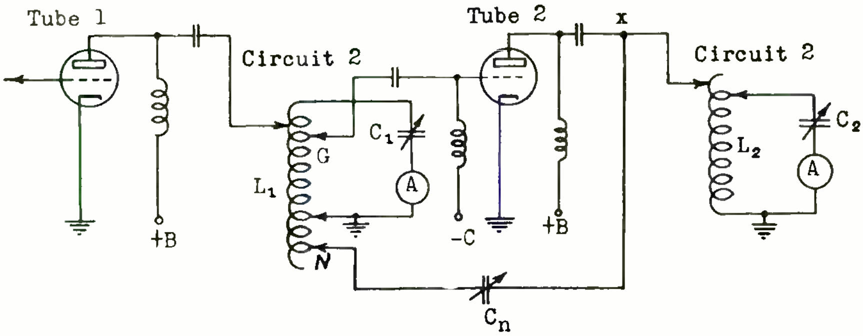

Fig. 19.—Rice balancing circuit.

In the reverse direction: the tank current in L_1C_1, due to the output of Tube 1, develops IX_L voltages at taps G and N, the two voltages being 180° out of phase. Transferred through the tube capacity and C_n to point x, the two voltages can be made to exactly cancel with the result that the energy in the plate tank circuit L_2C_2 due to tube capacity is zero. The circuit is neutralized by removing plate voltage from Tube 2, energizing the tank circuit L_1C_1 from Tube 1, and adjusting Tap N and the neutralizing capacity C_n until there is zero current in L_2C_2 when that circuit is tuned to resonance. As this condition is approached the r-f ammeter in L_2C_2 should be replaced with an r-f milliammeter in order to obtain a more exact adjustment. *Be sure to remove the milliammeter before applying plate voltage.* When plate voltage is then applied to Tube 2 the current in L_2C_2 will be due entirely to the amplifying action of the tube and not to its capacity.

It should be observed that the neutralizing capacitor is connected at point x and not directly to the plate. This is so there will be no high voltage d.c. on the neutralizing capacitor. So far as the neutralizing action is concerned, C_n may be connected to either side of the plate blocking capacitor. However, if connected to the plate side, a flash-over or short-circuit of C_n would short-circuit the d-c plate supply. In practice the connection as shown is the more desirable. When neutralizing the circuit, the more neutralizing turns between tap N and ground, the smaller the required capacity of C_n, and vice versa. As in the Hazeltine circuit, the adjustment is less critical if a comparatively large capacity is used at C_n. For most tubes, a variable capacitor having a maximum capacity of 50 μμf will be suitable for C_n. It must be remembered that the entire a-c component of plate voltage is applied across C_n so that the spacing of the plates must be such as to allow adequate safety factor of breakdown voltage.

A condition which is frequently encountered and which must be avoided in final adjustment is an adjustment of tap N and C_n such that a series resonant circuit is formed between point x and ground. This will usually be indicated by a flash-over at C_n.

The Miller Balance, as shown in Fig. 20 with its equivalent electrical circuit in Fig. 21, operates simply as a capacity bridge. The grid-plate tube capacity and the grid-cathode tube capacity form two arms of the bridge. C_1 and C_2 form the other arms.

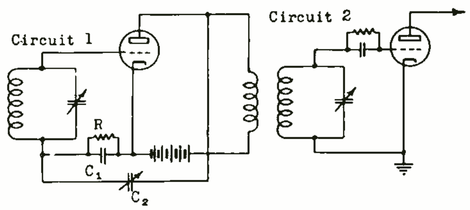

Fig. 20.—Schematic of Miller balance circuit.

Fig. 21 shows the balance in the form of a capacity bridge. C_3 represents the grid-cathode capacity of the tube; C_4 represents the grid-plate capacity of the tube. C_1 corresponds to C_1 in Fig. 20; C_2 corresponds to C_2 in Fig. 20. The alternator, Alt, corresponds to Circuit 1 in Fig. 20 and is the driving voltage of the bridge. Circuit 2 in Fig. 20 is represented by the circuit between points A and B in Fig. 21.

Fig. 21 shows plainly that the arrangement is a capacity bridge and operates on the bridge principle of divided voltages across a split circuit. Since the two capacities of the tube form two arms of the bridge, it is merely necessary to add two small capacities, C_1 and C_2, to form the other two arms. The bridge is balanced when $C_1 : C_2 : : C_3 : C_4$. With this condition there is no voltage across Circuit 2 except when the tube is amplifying. Since C_1, C_3 and C_4 are fixed, it is merely necessary to adjust C_2 until the correct ratio is obtained just as the variable arm of a Wheatstone bridge is adjusted for zero reading on the galvanometer.

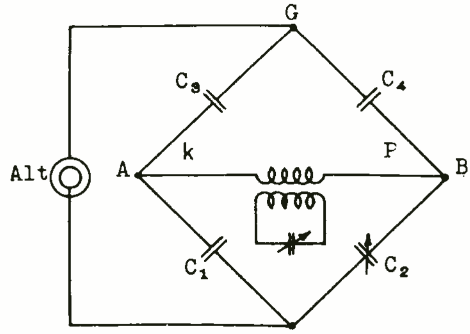

Fig. 21.—Equivalent circuit of Fig. 20.

The capacities within the tube are fixed and have a given ratio to each other. It is only necessary that this same relation exists between C_1 and C_2. *It is not necessary that the capacities of C_1 and C_2 equal the tube capacities.* Their ratio is the important factor.

This circuit is particularly well adapted for receivers, because once adjusted, it holds its adjustment for practically all frequencies. This feature is very desirable for high frequency receivers using a plug-in coil system. Capacity C_1 is fixed for all coils and a separate small variable capacity C_2 is mounted on the base of each coil and adjusted to give the best results for that particular frequency range.

In most triode receiving tubes

the Grid to Plate capacity is about three times as large as the Grid to Cathode capacity. Therefore, C_2 should usually be about three times as large as C_1. If C_1 is 20 μμF capacity then C_2 should be variable from about 40 to 80 μμF. If C_1 is larger, then C_2 should also be larger.

Resistor R, Fig. 20, is placed across C_1 to provide a d-c return from grid to filament. Without this resistor the tube would block. R is usually the grid leak type with about 500,000 ohms resistance. It is sometimes placed directly between the grid and cathode of the tube socket. Similar results are obtained in both cases, although, in the latter case the resistor is also across the tuned circuit. However, as the resistance is very high this does not cause any particular trouble. The arrangement shown in Fig. 20 is probably preferable for all-around work.

For high frequencies the capacities specified for C_1 and C_2 will give excellent results. For lower frequencies such as used in the broadcast band somewhat larger capacities should be used. For those frequencies C_1 may be about 80 μμF and C_2 variable from 150 to 250 μμF. The smaller capacities may be used but the high reactance at the lower frequencies will considerably lower the signal strength because a relatively large proportion of the signal voltage will be expended across C_1. Up to a certain point as the capacity of C_1 is increased, the signal voltage on the grid will also increase. In the broadcast band, however, the effect of an increase of C_1 beyond about 80 μμF is negligible and the space occupied by the large variable capacitor at C_2 prohibits too great an increase in C_1.

THE CRISS-CROSS BALANCE.—The neutralizing system was developed for use in push-pull radio frequency amplifier circuits, either transmitting or receiving. This is an extremely simple and effective neutralizing circuit for use with a push-pull combination of amplifier tubes. The circuit actually used is shown in Fig. 22.

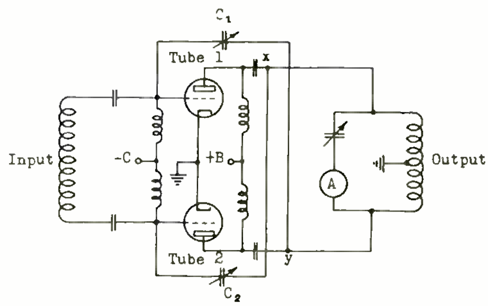

Fig. 22.—Criss-cross circuit for push-pull operation neutralizing.

C_1 and C_2 are the two neutralizing capacitors. Excitation energy is applied to both grids simultaneously and at opposite polarities. Some of the energy at the grid of Tube 1 will normally be transferred through the grid-plate capacity of Tube 1 to point X and into the output circuit. Energy of opposite polarity is available at the grid of Tube 2, and if enough of this energy is transferred by means of C_2 to point x, the energy fed through the capacity of Tube 1 can be neutralized and the power transfer into the output circuit will be zero.

Consider the condition at Tube 2: energy is available at the grid of Tube 1, which when transferred to point y by means of C_1, will effectively neutralize the grid-plate capacity transfer of energy through tube 2.

Thus when the capacity of C_1 is equal to the grid-plate capacity of Tube 2 and the capacity of C_2 is equal to the grid-plate capacity of Tube 1, no energy transfer through the capacity of either tube is possible. (That statement is correct only when the circuits are symmetrical so that the symmetrical voltage conditions are obtained at the plates and grids of the two tubes. Since symmetry is essential to the correct operation of all pushpull circuits this condition is not an unreasonable assumption). In many transmitters C_1 and C_2 operate from the same shaft. This is possible when the tube characteristics are very uniform.

The push-pull neutralizing circuit is easy to adjust and may be used in both transmitters and receivers. Two extreme examples of the universal application of this type of neutralization in push-pull circuits are: the intermediate and power amplifiers in a 50 kw broadcast transmitter; the push-pull screen grid radio frequency amplifier in a high frequency receiver which operates up to 30 megacycles. In the first case the capacity neutralized is that of two 100 kilowatt tubes; in the second case the capacity balanced out is the extremely small capacity of receiving type screen grid tubes. The neutralization is equally successful in both cases.

There are other capacity neutralizing systems in use but most are modifications of some of the above described circuits; others use some of these circuits under other names. The principles of practically all neutralizing circuits are quite similar, and if the principles are thoroughly understood no trouble should be experienced in adjusting any type of r-f amplifier to prevent oscillation.

The principal point to remember in the entire operation of neutralizing the capacity of a tube is that the capacities dealt with are often extremely small and the least variation from the condition of balance will usually result in oscillation. For that reason the greatest care should be exercised in the entire operation if satisfactory results are to be obtained.

OSCILLATOR AND NEUTRALIZING CIRCUITS

EXAMINATION

1. (A) Explain the circuit conditions necessary for vacuum-tube oscillation.

   (B) Explain what is meant by "negative resistance" as applied to an oscillator circuit.

2. (A) Explain the operation of a Hartley oscillator.

2. (B) What are the advantages and particular applications of this type of oscillator?

3. (A) Explain the operation of a Colpitts oscillator.

(B) What are the advantages and particular applications of this type of oscillator?

4. (A) Explain in detail the operation of an electron-coupled oscillator.

4. (B) How is power transferred to the load?

5. (A) Why is the frequency of electron-coupled oscillators more independent of load variations than that of most other types of oscillators?

(B) How may the effects of variation of anode potential on frequency be compensated for?

6. (A) Explain *how* you would neutraliza a push-pull amplifier stage.

6. (A) *(Continued)*

(B) What are the circuit and tube requirements for good neutralization?

7. You wish to design a Hartley oscillator to oscillate over the band 450 to 550 kc/s. This oscillator is to work into a 30-ohm load, and the Q at the low-frequency end is to be 14. Tuning is to be done by variable capacity. The tube and stray circuit capacities are estimated at 20 μμF. *What must be the capacity range of the variable condenser?*

8. You wish to design a Colpitts power oscillator to operate at 250 kc/s. The tank circuit losses are estimated at 75 watts and the useful power in the load at 1,500 watts. The effective resistance of the tank circuit when loaded is 12 ohms. E_p = 2,500 volts r.m.s., μ = 15, and the RMS excitation required 1.5 E_p/μ. *Calculate required feedback capacity.*

9. An RCA type 800-triode transmitting tube is to be used as a power oscillator in a Hartley circuit. The tuning capacitor is connected across the entire coil. The data listed for typical operation for a plate voltage of 1,250 volts will be used. A VA/W ratio of 15 has been chosen for the tank circuit. Frequency is 2,000 kc/s.

DATA FOR 800 TUBE:

E_b = 1,250 V
E_c = 175 V
E_g = 300 V
I_b = 70 ma
P_o = 65 watts

(A) Determine the inductance in the grid section of the tuning coil.

9. (A) *(Continued)*

(B) Determine inductance in plate section of tuning coil.

10. (A) Reference Problem 9. If tube and circuit capacities are estimated at 20 $\mu\mu F$, what value of tuning capacity will be required across the coil?

(B) What is the effective resistance of the tank circuit?