THE VACUUM TUBE AS AN A.C. GENERATOR IN RADIO-TELEVISION CIRCUITS

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STUDY SCHEDULE No. 21

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☐ 1. Practical Importance; Coil and Condenser as Oscillator; How a Vacuum Tube Oscillator Circuit Works . . . Pages 1-8

This first section is extremely important, because it gives you the basic principles upon which practically all radio oscillator circuits depend. If you understand these principles, you will not have to bother remembering the details of the many variations in oscillator circuits which are encountered in radio. Answer Lesson Questions 1, 2, 3, 4 and 5.

☐ 2. Effects of Circuit Changes; Type of Self-Excited Oscillators . . . . Pages 8-14

Here, in one brief section, are a lot of answers to that common question, "What would happen if I did this or that?" You get a lot of interesting answers, then consider briefly some of the common types of oscillators encountered in radio receivers and transmitters. Answer Lesson Question 6, 7, 8 and 9.

☐ 3. Applying Oscillator Loads; Oscillator Power Supply Connections; Frequency Stability; Crystal Oscillators . . . . Pages 14-21

If you study this section with the idea that someday you will actually be working with oscillator circuits and dealing with the various problems taken up, you will find this section intensely interesting. Try to locate the important idea in each paragraph, as an aid to understanding important facts. Answer Lesson Question 10.

☐ 4. Ultra High Frequency Oscillators; Dynatron Oscillators; Relaxation Oscillators; Audio and Beat Frequency Oscillators; A Serviceman's Modulated Test Oscillator . . . . Pages 21-29

Now we come to special types of oscillator circuits which, though interesting, need not be fully mastered at this time. If you get the general idea of how each of these circuits works, so that you can recognize the circuit when you encounter it, you can always return to this section later when you actually are working on these types of oscillators. Nevertheless, this section as well as every other section in this lesson will require careful study, because the subject of oscillators is so important to a radio man.

☐ 5. Mail your Answers for this Lesson to N.R.I. for Grading.

☐ 6. Start Studying the Next Lesson.

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The Vacuum Tube as an A. C. Generator in Radio-Television Circuits

PRACTICAL IMPORTANCE OF TUBE OSCILLATORS

RADIO, as a means of transmitting intelligence through space, depends upon the *production of high frequency A.C. currents,* and television requires the *production of ultra high frequency currents.* The operation, efficiency and stability of the super-heterodyne type of receiver depends upon the oscillator, *a generator of A.C. currents.* Some of the most successful electronic control systems are possible only because of the tube oscillator. Maintenance, testing and servicing of radio equipment can be satisfactorily carried out only with special oscillators called signal generators. Thus the very existence of sound and television broadcasting depends upon tube oscillators.

THE COIL AND CONDENSER AS AN OSCILLATOR

Long before radio was even considered as a public servant, scientists knew that an A.C. current would flow through a coil when it was connected to a charged condenser. The frequency of this current, as you already

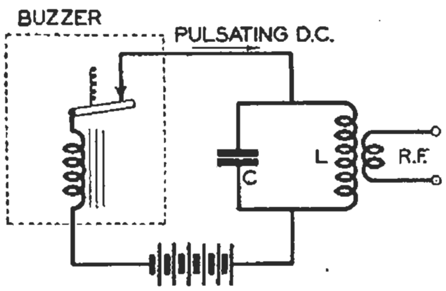

FIG. 1A. An early oscillator circuit; each closing of the buzzer contact recharges or primes condenser *C* in the coil-condenser circuit, and oscillations continue in the *L-C* tank circuit when the buzzer contact opens.

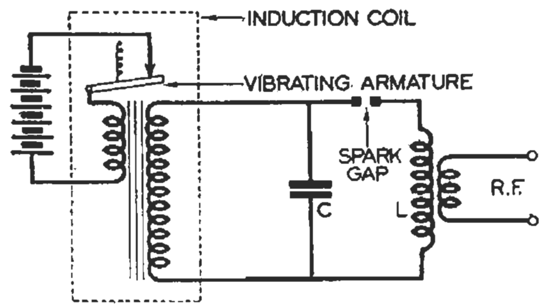

FIG. 1B. Early spark transmitter circuit. The induction coil charges condenser *C* with a high potential, the condenser voltage causes a spark to jump across the gap, and an oscillatory current flows through coil *L* and the spark gap as long as the condenser voltage is high enough to maintain the spark. Each closing of the induction coil contact recharges the condenser for another cycle of operation.

know, essentially depends upon the inductance and capacitance values. The duration of the current is fixed by the resistance in the circuit; as the energy travels back and forth between coil and condenser the losses in these two parts reduce the energy a little on each "trip," until finally the oscillations cease. Clearly it is necessary to have some means of "priming" the circuit, or feeding it with at least enough energy to overcome resistance losses; the first scheme utilized a buzzer which connected the oscillatory circuit intermittently to a battery, as in Fig. *1A,* so it would recharge the condenser regularly.

Spark Transmitter. In order to get greater power output, radio pioneers developed the high voltage oscillatory circuit of Fig. *1B;* a step-up transformer having a vibrator in series with its primary (the combination being called an *induction coil*) primes the oscillating coil-condenser circuit hundreds of times each second. *The frequency* of R.F. oscillation is determined essentially by the values of L and C.* Of course there were many later improvements on this early spark transmitter circuit, but these are now "ancient radio history," mentioned simply to show that the coil and condenser were *first* and *still are* the important frequency controlling units.

Damped Waves. Each time the condenser in an oscillating circuit is charged, the applied energy immediately starts to oscillate between condenser and coil; the resistance of the oscillatory circuit (essentially the resistance of the coil or of coil and spark gap together) causes the amplitudes of successive cycles to be reduced or damped, as in Fig. *2A*. Repeated priming of the oscillatory circuit (at points *1*, *2* and *3*) give a series of such oscillation groups. Although this form of oscillation serves very well for code transmission, it has the very severe drawback that it creates excessive interference with adjacent-channel stations, often "riding in" with signals of other stations. Reducing the resistance of the oscillatory circuit improves matters by giving the wave form illustrated in Fig. *2B*, but still the damped oscillations are unsuited for the transmission of speech and music. The reason for this is simple; the damped wave form is in itself modulated at a frequency which depends upon the number of oscillatory groups per second, and this modulation note would interfere with the program being transmitted.

A continuous, constant-amplitude wave form like that shown in Fig. *2C*, free of modulation, is required as a carrier when transmitting voice, music or picture signals. This wave can be produced by a vacuum tube oscillator, a simplified circuit of which appears in Fig. *3*.

Vacuum Tube Oscillators. In a vacuum tube oscillator the power loss due to the resistance in the L-C oscillatory circuit is *constantly* being compensated for by power which is supplied by the tube acting as an amplifier, whereas in the spark gap transmitter the losses were compensated for *intermittently*.

Let us see how a vacuum tube oscillator operates. Only electrical changes in the circuit, such as connecting the tube to its power supply, will start this vacuum tube oscillator; once oscillation starts, there is produced across the condenser (or coil) terminals an A.C. voltage whose frequency is determined by the values of L and C. The vacuum tube, acting as an amplifier, will respond to this varying grid voltage and cause the plate current to vary at the same frequency. Coil L_T, carrying this A.C. plate current, will induce into coil L by mutual induction a voltage e. Coil L, condenser C and resistor R (an apparent resistance, representing the combined resistances of L, C, the grid-cathode path in the tube, and the resistance effects of a load, if used) act as a series resonant circuit. The reactance effects of L and C cancel each other, and the voltage e acting on R determines the amplitude of the oscillatory A.C. current. As in any simple generator-load

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*The frequency of an oscillatory L and C circuit can be determined from the following formula: $f = 159{,}000 \div \sqrt{LC}$ where f = frequency of oscillation in cycles per second, L = coil inductance in microhenrys, and C = condenser capacity in microfarads.

circuit, the current assumes a value which will make the A.C. voltage drop in R equal to the induced A.C. voltage e.

Because of resonance, the voltage across either L or C is greater than the induced voltage; this resonance-amplified voltage, applied to the grid of the tube, drives the plate current through large swings, and the increased current through the tickler coil increases the induced voltage e. The plate current swing and consequently the induced voltage e continues to increase up to the limit of the amplifying ability of the tube; the tube thus introduces into the oscillatory circuit, through tickler coil L_T, enough power to overcome power losses in R and make the oscillatory current assume the constant amplitude shown in Fig. *2C*.

There are many ways of operating the oscillator tube, connecting the oscillatory circuit and producing the feed-back voltage in order to secure improved performance; these will now be studied. Remember, however, that it is essentially the values of coil L and condenser C in the oscillatory circuit which govern the frequency of a self-excited vacuum tube oscillator; these values can be adjusted to give frequencies ranging from one cycle to hundreds of kilocycles per second.

HOW A VACUUM TUBE OSCILLATOR CIRCUIT WORKS

Most tube oscillators work alike, even though the method of feed-back, the position of the oscillatory circuit containing C and L (also called the

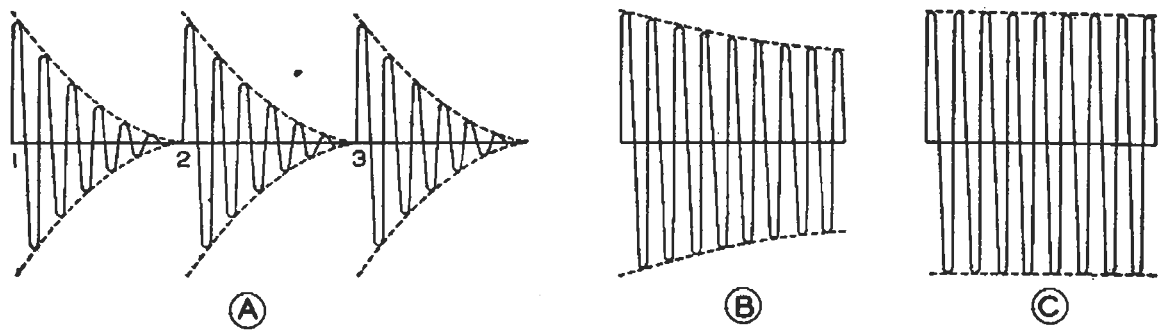

FIG. 2. Priming or recharging of an oscillator circuit gives the series or "trains" of damped oscillations shown at *A* and *B*, but present-day radio transmission calls for the constant amplitude oscillation shown at *C*, which can be obtained from a vacuum tube oscillator. For simplicity, only a few cycles of the oscillatory wave are shown here; actually there may be thousands of cycles of oscillations in each damped wave group, such as between points *1* and *2* in *A*.

tank circuit), the method of supplying the D.C. power, or the positions of the circuit components may vary. A typical oscillator circuit is shown in Fig. *4*; here, as in most oscillators, the plate feeds a part of its energy back to the grid to make the tube supply an A.C. plate current. All oscillators in which the grid takes a small part of the plate circuit power are said to be self-excited.

Power Input. Neglecting tube filament power, the total power fed to the oscillator is the D.C. plate voltage V multiplied by the D.C. plate current I. This input power is used in several ways: *1,* It overcomes resistance losses in the L-C tank circuit. If coil L is coupled to a load, the effective value of R is increased and the power consumed by the tank circuit also includes useful output power or useful work. *2,* The grid in an oscillator circuit is driven positive at times, causing grid current to flow, and the grid consequently draws power from the plate circuit; *3*, a part of the input plate power is used to overcome the A.C. plate resistance, thus heating the tube elements. In spite of all these power losses, from 50% to 85% of the input power can be converted into useful A.C. power in a good oscillator.

An oscillator circuit is unique in that changing any one thing in the circuit changes current and voltage conditions in the entire circuit; the reason for this is that the grid and plate circuits are linked together. A study of Fig. *4* will reveal a few outstanding facts which apply in general to all self-excited oscillators. The A.C. voltage across C or L can never have a peak voltage greater than the applied voltage V; in fact, the peak value of v_T will always be less than V because the charging voltage of C is equal to the applied voltage *minus* the tube voltage drop. Furthermore, as the A.C. plate current *increases* to furnish more power to the tank circuit, the A.C. voltage across C or L becomes less.

A.C. voltage v_T causes an A.C. current i_T to circulate in the tank circuit, and this current induces an A.C. voltage in the grid circuit. The amount of voltage induced in the grid circuit will, of course, depend upon the mutual inductance between coils L_G and L, upon the A.C. tank current i_T, and upon the frequency of oscillation. The mutual conductance of the oscillator tube must be such that the grid driving voltage causes enough A.C. plate current to flow to maintain oscillation; in other words, the mutual conductance (g_m) of the tube is of as much importance as the A.C. grid voltage. Oscillator action is a sort of "around the circle" affair; the grid must draw enough power from the tank circuit to swing the plate current enough to produce enough A.C. power in the tank circuit to supply the load with power and feed sufficient power back to the grid to maintain oscillation. The amount of output power can be controlled by changing the mutual conductance of the tube or by changing the mutual inductance between the plate and grid circuits.

Starting an Oscillator. Getting oscillations to start in a feed-back circuit like that in Fig. *4* is often explained as follows: When the tube is first connected to the power supply, the plate current starts to rise as soon as the cathode begins to emit electrons. A rising plate current flowing through coil L (see Fig. *4*) induces a voltage in coil L_G. This grid voltage, acting through the mutual conductance of the tube, causes the plate current to vary; *if the voltage to the grid is so phased that the original plate current change is aided,* the plate current will build up to the full capacity of the tube, as determined by the operating voltages. This primes the tank circuit with energy and it starts to oscillate, feeding A.C. voltage to the grid and causing the plate current to increase and decrease alternately; this is the desired condition for a tube oscillator. Tank current and grid voltage continue to increase until a balance is reached, this occurring when the A.C. current in the tank circuit produces (through coupling to the grid) sufficient A.C. grid voltage for the tube amplifier to supply the tank power required by the tank circuit load and to overcome the grid and plate circuit power losses. All power is obtained from the plate supply source.

Automatic C Bias. Now let us concentrate our attention on grid resistor R_C and grid condenser C_C in Fig. *4*. As you will shortly see, condenser

C_C has a double purpose. The A.C. grid voltage e_G acts directly upon the grid-cathode of the tube because C_C has a low reactance. Thus the tube is fed with an A.C. signal which makes the grid alternately positive and negative with respect to the cathode. When the grid is positively charged, it will draw electrons from the cathode, these electrons flowing through resistor R_C on their way back to the cathode since they cannot pass through condenser C_C; a D.C. voltage therefore appears across resistor R_C.

From the basic fact that electrons flow through a load from the negative to the positive terminal, point *1* of resistor R_C is negative with respect to point *2*. If condenser C_C were absent, the current flow through R_C would be of a pulsating nature since the grid is positive for only short periods of time; this condenser, however, is charged by the voltage drop across the resistor so that when the electron flow through R_C starts to decrease, condenser C_C begins feeding electrons into R_C. The result is a steady flow of electrons through R_C, and the voltage drop across it becomes constant. Thus, in addition to the A.C. voltage supplied by L_G, a steady D.C. bias voltage is automatically supplied to the grid by grid condenser C_C and grid resistor R_C; this voltage is called the *automatic C bias*. This makes the operating plate current set itself at a lower value.

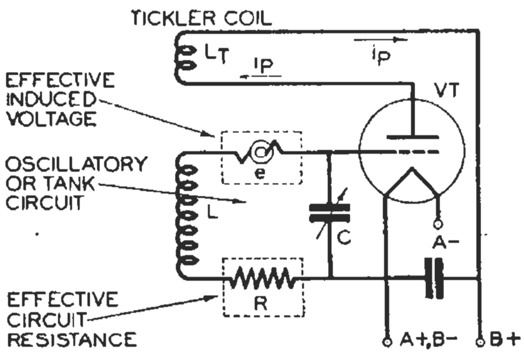

FIG. 3. Simple feed-back type vacuum tube oscillator circuit. *R* is not an actual resistor; it simply represents the resistance of coil *L* and all other resistances, apparent or otherwise, which may cause losses in the oscillatory circuit. Likewise *e* represents the voltage induced in coil *L* by the tickler coil.

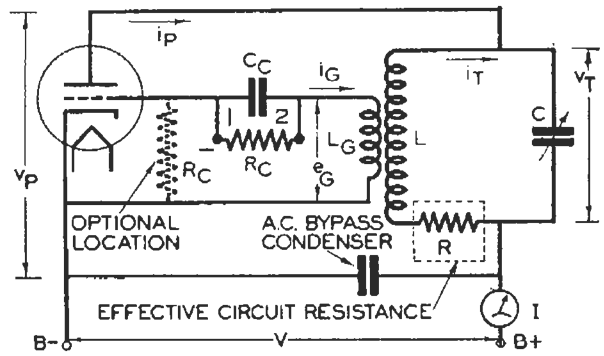

FIG. 4. An understanding of this basic self-excited oscillator circuit will simplify your study of other oscillators. *L* and *C* form the oscillatory tank circuit. *L* induces into L_G the required feed-back voltage; C_C and R_C provide automatic C bias for the tube.

You may consider the A.C. voltage and the automatic C bias voltage as acting independently on the tube, or you may consider both effects at the same time, as you prefer. The presence of the C bias lessens the effect of the A.C. grid voltage on the tube, actually reducing the time and the amount by which the grid is driven positive; the C bias cannot, however, completely prevent the grid from being positive, for if it could, there would be no grid current to produce the automatic C bias.

The automatic C bias can never be greater in value than the peak A.C. grid voltage. The average value of grid current multiplied by the ohmic resistance of R_C determines the C bias in the circuit. It should be pointed out that the grid bias resistor may be connected from grid to cathode (instead of across the condenser) without changing the automatic C bias.

Operating Efficiency. It is true that the circuit in Fig. *4* will oscillate without any form of C bias, but in this case the D.C. plate current will be so high that losses will be excessive, giving very poor tube efficiency at normal plate voltage, and the resulting heat may melt the tube elements. The use of an automatic C bias keeps D.C. plate current at a minimum and limits the effects of the A.C. grid voltage, allowing the tube to work more efficiently. The value of R_C and the feed-back voltage are so selected that the average C bias at least equals the value for plate current cut-off (this C bias approximately equals the plate voltage divided by μ, the amplification factor of the tube). This means that plate current flows for one-half of each cycle, and grid current flows during a much smaller part of the cycle.* The coil and condenser tank circuit stores up energy, and because of its oscillatory nature continues to oscillate during those parts of the cycle when there is no plate current; the resulting tube efficiency is at least 50%. By making the C bias even greater than cut-off value, the time of plate and grid current flow is reduced and greater efficiencies, which may be as high as 85%, are obtained. Although increasing the C bias does increase efficiency, it naturally reduces the power output; a compromise must therefore be made between maximum efficiency and maximum power, to suit a particular need.

A fixed C bias voltage (secured from a tap on the voltage divider of the D.C. power supply) could be introduced in place of R_C and C_C, but if it is made greater than the plate current cut-off value, the oscillator will not be self-starting (the original rise in plate current will not occur). Automatic C bias is a very practical solution, for the C bias generally sets itself automatically for best operation.

Blocking. The ohmic value of the grid resistor in a self-excited vacuum tube oscillator (such as R_C in Fig. *4*) is not critical, but if it is made too large, its D.C. voltage will build up to such a high value that the oscillator will *block* (stop oscillating momentarily) at regular intervals. Values of R_C above about one megohm cause the oscillator to block, producing a tone modulation whose frequency depends upon the time constant of the resistor-condenser combination; the value of R_C in megohms multiplied by the capacity of C_C in microfarads gives the approximate time of one blocking and starting cycle. When the value of R_C is low (5,000 to 250,000 ohms), the bias is never driven so far negative that intermittent oscillation is obtained. The grid condenser C_C can be any size sufficiently large to make its A.C. reactance in the grid circuit negligible.

In a properly adjusted oscillator, the C bias is zero at the instant of starting the oscillator, and a definite value of plate current flows. This plate current *decreases* quickly to the operating value I_P as automatic C bias comes into action, for the operating bias is now more negative. This means that if the oscillator is stopped by shorting one of the coils (or by an internal short in tank condenser C), the plate current will *increase;* in some low power oscillators this is actually done to determine if the circuit is operating, but in high power oscillators the high plate current resulting from such a procedure might damage the tube.

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*These pulsating grid and plate currents produce many harmonics, but the tank circuit accepts only the fundamental. Coil L suppresses and condenser C by-passes the harmonics; by using a large value for C and a small value for L, the ability of the tank circuit to reject harmonics will be improved even more.

To adjust an oscillator to best operating conditions once the load to the oscillator is fixed, it is customary to adjust the different circuit parts to the values which give minimum D.C. plate current at the desired frequency. When an oscillator is to be tuned over a wide range of frequencies by varying the tank circuit capacity, as is the usual procedure, an optimum (best) circuit adjustment for one frequency may be unsatisfactory at some other frequency. For example, if the circuit is adjusted for best operation at a high frequency in its range, the resetting of the tank circuit to a low frequency may result in too low output or no oscillation due to too low a feed-back voltage. When a wide range of frequencies is to be covered, it is best to make optimum adjustments at a mid-frequency; this should provide ample feed-back excitation at the lowest frequencies.

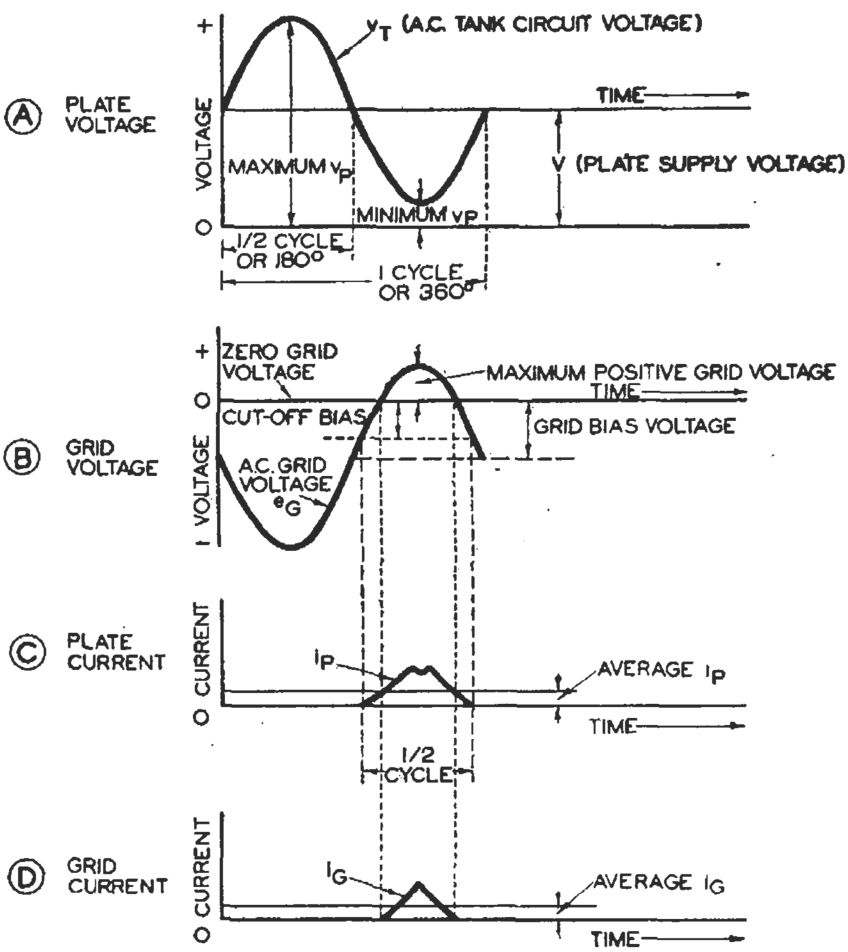

FIG. 5. These plate and grid currents and voltages represent operating conditions in the oscillator circuit of Fig. 4. Remember that graphs like these are always read from left to right. When comparing two voltages, that one which reaches a positive peak *closest* to the vertical reference line is said to *lead* the other; thus, v_T in *A* leads e_G in *B*.

Current and Voltage Relations. The curves in Fig. 5 present a picture of the grid and plate voltages and currents in the oscillator circuit of Fig. 4 during operating conditions; these curves are characteristic of all types of oscillators. Notice that although the applied plate voltage *V* in Fig. 4 is a D.C. voltage, the voltage v_T across the tank circuit (the plate-to-cathode A.C. voltage component) has essentially the sine wave form shown in Fig. 5A. Although the A.C. plate voltage swings above and below the D.C. plate supply voltage value, it never is driven to zero because of the A.C. plate resistance.

In Fig. *5B* is shown the A.C. grid voltage curve; you will notice that the A.C. grid voltage reaches its maximum positive value half a cycle (180 degrees) after the A.C. plate voltage reaches its maximum, or in other words, the A.C. grid voltage lags 180 degrees behind the A.C. plate voltage; coils L_G and L in Fig. *4* are so connected that this phase relation is produced. In this way the grid can be driven positive during the time when the plate-to-cathode voltage is low; current thus flows in the plate circuit when the grid swings positive, and the tank circuit absorbs or stores up energy. This energy is released because of the oscillatory action (also called the flywheel effect) of the tank circuit when plate current drops to zero, completing the A.C. cycle and producing the sinusoidal voltage wave shown in Fig. *5A*.

Looking at Fig. *5C*, note that plate current i_P begins to flow when the instantaneous A.C. grid voltage becomes more positive than the cut-off value of C bias. Grid current (Fig. *5D*) flows only when the A.C. grid voltage overcomes the effective C bias, and makes the grid positive with respect to its cathode. Thus plate current flows for a longer part of a cycle than grid current. Since the flow of grid current robs the plate circuit of current, a dip appears in the peak of the plate current curve; a dip will also appear in the grid current curve if a large amount of secondary emission takes place at the grid of the tube. The average value of plate current controls the amount of power taken from the supply; in the grid circuit the current through the grid resistor is averaged out by the smoothing condenser. By studying curves *A, B* and *C* together, you can see that the minimum plate voltage value is very important in controlling plate current; the larger this minimum voltage, the larger the plate current.

An Important Oscillator Requirement. Any self-excited oscillator *must have* the same phase relationship between grid and plate A.C. voltages that exist in an ordinary amplifier—the *A.C. grid voltage* must be 180 degrees out of phase with the *A.C. plate voltage.* For example, in an amplifier having a resistance load, a positive swing in grid voltage makes the plate current increase, increasing the IR drop in the load and therefore decreasing the plate-to-cathode voltage; the tank circuit of an oscillator is in effect a resistance load at resonance, and the same relation must therefore exist—grid voltage *increase* causes plate voltage *decrease.*

EFFECTS OF CIRCUIT CHANGES

Changes in the adjustments of various parts of an oscillator circuit will naturally affect the oscillatory condition; the following discussion of these changes will in general apply to all self-excited oscillators.

Static and Oscillating Plate Current. If the coupling between plate and grid in an oscillator is reduced or the grid excitation supply is shorted, the circuit will not oscillate, and the plate current will assume a *static* value which is governed essentially by the plate supply voltage and the D.C. plate resistance (the grid bias being zero for a self-excited circuit which is not oscillating). If the circuit was originally adjusted for optimum efficiency as an oscillator, an unusually high plate current will flow; in high power oscillators the tube will overheat and plate and filament will be destroyed by heat. In the case of low power oscillators such as those found in testing equipment and in superheterodyne receivers, the excessive plate current may weaken the cathode emission qualities of the tube. When the fault is remedied and oscillation starts again, the D.C. plate current will immediately drop. In the case of high powered oscillators, the plate current should immediately assume its normal value (much lower than the estimated static value); if plate current is above normal the circuit should be disconnected from the supply at once.

Effect of Plate-to-Grid Coupling. There can, of course, be no oscillation when plate-to-grid coupling is very loose; as coupling is gradually increased, oscillation will start at a definite point and the D.C. plate current will drop from the static value to the operating value. Further increases in coupling simply increase the grid excitation (increase the grid voltage swing), thus increasing the rectified grid current value and shifting the operating grid voltage more negative, but D.C. plate current remains practically constant for all values of coupling which maintain oscillation. When coupling is increased beyond a certain critical point, the time duration of the plate current pulses becomes such a small fraction of a cycle that the tank circuit can no longer supply sufficient energy to build up the voltage wave for the rest of the cycle, and oscillation stops; plate current then rises to the static value. Any change in coupling also changes the inductance and resistance of the tank circuit, thereby changing the frequency of oscillation slightly.

Effect of Loading the Tank Circuit. The tube circuit of an oscillator must supply a certain amount of power to the tank circuit in order to maintain oscillation; this power comes from the D.C. supply, for there is no other source of power in a self-excited oscillator. If a load is coupled (usually inductively) to the tank circuit, the tube must also supply the extra power demanded by the load, and this extra power must likewise come from the D.C. supply. This means that the D.C. plate current *increases* in value when a load is applied to the tank circuit of a self-excited oscillator (since power is equal to voltage multiplied by current, and the D.C. supply voltage is here essentially constant).

The A.C. plate current must increase either in amplitude or in the duration of a pulse in order to produce the increase in average or D.C. plate current; actually both factors increase, for the reduced tank current lowers the grid excitation, making the C bias more positive and allowing a current pulse of greater amplitude to flow for a slightly greater fraction of a cycle.

Effect of Plate Supply Voltage. Increasing the D.C. plate supply voltage of a self-excited vacuum tube oscillator increases the A.C. tank voltage, thereby raising the tank current and *increasing the power output.* The higher tank current also serves to increase the grid excitation, the rectified grid current, the automatic C bias and to a slight extent the D.C. plate current. If a self-excited oscillator will not start by itself, increasing the plate supply voltage will generally cure the trouble.

Effect of Increasing C Bias Resistor. Increasing the ohmic value of the C bias resistor makes the grid bias voltage more negative, with the result that grid and plate currents flow for smaller fractions of the cycle. Other effects are a lowering of the D.C. plate current, a decrease in the amount of energy supplied to the tank circuit and an increase in oscillator efficiency. These changes are not very great, for the increased efficiency tends to feed more grid A.C. voltage to the oscillator input, offsetting the increased bias. If the resistor value is increased too much, repeated blocking will take place, and stability (the tendency to remain in oscillation) will be reduced.

General Circuit Effects. It is desirable to have a high inductance-to-resistance ratio (high Q factor*) in the tank circuit of an oscillator in order to improve the flywheel action of the circuit and reduce the generation of harmonics in the tank circuit. On the other hand, a high Q factor gives a high tank current, increasing circuit losses unnecessarily. Circuits which are heavily loaded have a low Q factor and are very unstable, hence a compromise involving a mid-value of Q factor is usually required.

Changing the capacity in the oscillatory circuit naturally changes the frequency of oscillation; as the condenser capacity is reduced, the frequency goes up. The feed-back voltage or grid excitation depends upon the coupling (usually fixed), upon the tank current and upon frequency, hence tuning an oscillator to a higher frequency increases the feed-back voltage. Although the losses in the tank circuit increase with frequency, causing the tank current to reduce, this is more than overcome by increased feed-back. Increased feed-back makes the oscillator generate more power, but this effect is somewhat reduced by the resulting increased grid current and increased C bias voltage. By limiting feed-back, it is possible to secure an oscillator which can be tuned over a wide range of frequencies.

On the other hand, an oscillator set for optimum conditions at a high frequency may stop oscillating at the lower frequencies because of insufficient feed-back. In superheterodynes an oscillator may fail at lower frequencies because of poor tube emission, low plate voltage, or too high a C bias resistor value. Remedies include trying a new tube at normal voltage or adjusting the plate voltage and C bias resistor values to give oscillation at the lowest frequency desired with a given tank circuit coil and condenser.

TYPES OF SELF-EXCITED OSCILLATORS

As I pointed out before, the basic oscillator ideas which you have been studying apply in general to all types of self-excited oscillators. Now we will take up the common variations of the self-excited oscillator circuit.

Tuned Grid Oscillator. This is of the form shown in Fig. *6A*. The tank circuit is in the grid circuit, plate A.C. power being fed to it by inductive coupling. The circuit as shown here is for low power oscillators, such as those found in superheterodynes and in test oscillators. To prevent over-excitation and to permit greater tank current, the grid is often connected to a tap on the tank coil; in this way the tank circuit can be inductively loaded, and the grid excitation can be adjusted to a satisfactory minimum value.

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*A parallel resonant circuit acts as a large resistance, even though the circuit parts themselves have comparatively low resistances. The number of times the resistance of a parallel resonant circuit has been increased by tuning is called the *Q factor* of the circuit; this Q factor is equal to $\omega L \div R$, where ω is 6.28 times the frequency in cycles, L is the inductance of the coil in henrys and R is the resistance of the resonant circuit in ohms.

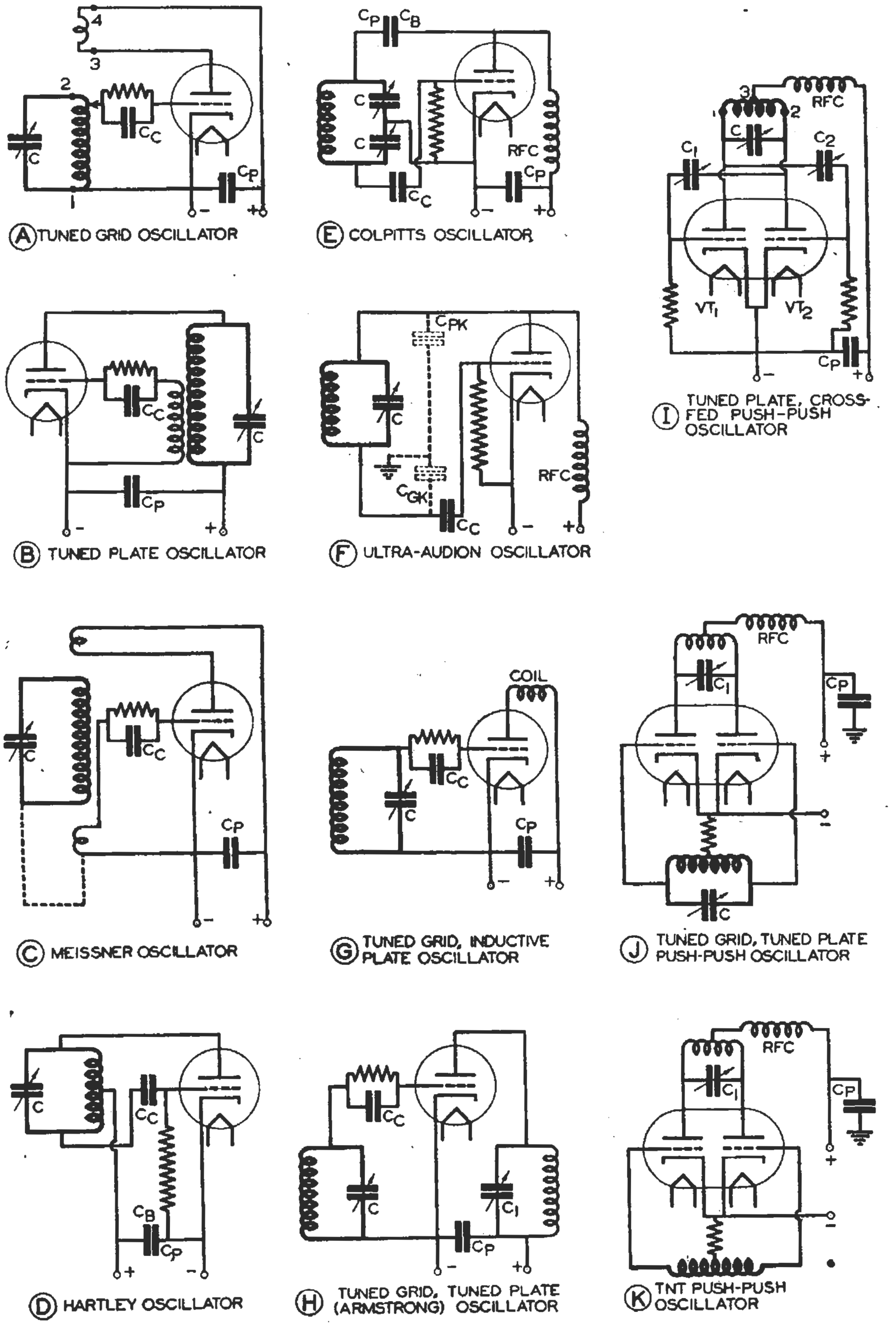

FIG. 6. Simplified schematic circuit diagrams of eleven different types of self-excited vacuum tube oscillators. Heavy lines indicate the coil and condenser tank circuit combination which controls the frequency of the oscillator. Although there are many possible variations of each of these circuits, you can identify a particular oscillator by the way in which its frequency-controlling tank circuit is connected to the grid and plate electrodes of the tube. Condensers marked *C* are frequency-controlling condensers; C_1 and C_2 are oscillation-controlling condensers; C_C is the low A.C. reactance condenser, which also smooths the rectified grid current; C_P is a low reactance A.C. by-pass condenser; C_B is a D. C. blocking condenser. When a condenser is double-marked, as C_B and C_P, it acts as a blocking condenser for D.C. and as a low reactance condenser for A.C.

Tuned Plate Oscillator. You are already quite familiar with this simple but effective oscillator circuit, shown in Fig. *6B* and also in Fig. *4*. The tank tuning condenser is in the plate circuit; changing the mutual inductance between grid and plate coils changes the grid excitation. This circuit is better than that in Fig. *6A* for high frequency power generation. Often the plate is connected to a tap on the tank coil to get a better impedance match between the tank circuit and the A.C. plate resistance of the tube;* this gives greater efficiency.

Meissner Oscillator. This circuit, named after its inventor, is shown in Fig. *6C*; the fact that feed-back and grid excitation are essentially independent of each other is an outstanding feature. Though not intended for high power requirements, the circuit is easily adjusted for optimum conditions, and gives highly stable operation. The tank circuit is usually coupled loosely to the grid and plate coils, giving the tank coil and condenser practically perfect control of the oscillating frequency. The isolation of the tank circuit also permits grounding of the condenser without affecting the supply circuits or R.F. circulating currents.

Hartley Oscillator. Also named after its inventor, the Hartley is perhaps the most widely used oscillator in the radio field. The basic circuit is given in Fig. *6D*. The Hartley oscillator can always be identified by the fact that *the tank circuit is in both the grid and plate circuits, the division of voltages being made by a tap on the tank coil.* This tank coil tap, which connects through an R.F. by-pass condenser to cathode and ground, divides the relative plate and grid R.F. voltages without disturbing the frequency of oscillation. Moving the tap away from the plate reduces the grid excitation. The optimum condition, when D.C. plate current is at a minimum value, is easily obtained. Additional improvement in efficiency is often realized by connecting the plate to a movable tap on the tank coil, especially when low plate impedance tubes are used.

Colpitts Oscillator. Where highly stable oscillators are needed, this circuit (shown in Fig. *6E* and named after its originator) is widely used. A unique feature is the use of two tuning condensers to divide the R.F. voltages between plate and grid circuits; individually the condensers determine the plate and grid A.C. voltages, but together in series they determine the frequency of oscillation. Decreasing the grid to cathode capacity increases the grid excitation, but the plate to cathode capacity must then be increased to maintain the frequency of oscillation. These adjustments are usually carried out until minimum D.C. plate current is obtained. A low-capacity variable condenser is often connected in parallel with the tank coil to make the final frequency adjustment. Because the division of A.C. plate and grid voltages is independent of frequency, the inductance can be changed from one frequency band to another without affecting the adjustment for best operating conditions. In a few of the low powered Colpitts oscillators the correct distribution of plate and grid capacity is determined beforehand and the two units ganged (their rotors mounted on the same shaft) for quick variation of frequency in a given band.

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*With this connection the peak amplitude of the tank voltage will be greater than the applied D.C. plate voltage.

Ultra-Audion Oscillator. As one of the oldest of oscillator circuits, this seems to have been used long before the reason why it worked was known. The tank circuit is connected between grid and plate, the D.C. plate current being kept out of the grid by a blocking (grid) condenser, as shown in Fig. *6F*. This circuit oscillates because the plate-to-cathode and grid-to-cathode tube capacities (indicated as C_{PK} and C_{GK}) form an A.C. voltage divider which makes the circuit a variation of the Colpitts oscillator. At very high R.F. values the tank tuning condenser may be eliminated, the tube capacities serving both for voltage division and for tank tuning. The circuit may be adjusted for the optimum operating condition by varying the plate voltage and the grid resistor value. A midget type variable condenser is often connected between the grid end of the tank circuit and the cathode, to give control of the intensity of oscillation.

Tuned Grid, Inductive Plate Oscillator. This circuit, shown in Fig. *6G,* is on the whole an undesirable (parasitic) oscillator, more often eliminated from than introduced into a system; it is one of the reasons for oscillations in amplifying stages. The operation of the circuit is such that when the plate load is an inductance, the A.C. voltage which is fed back to the grid circuit through the grid-to-plate capacity of the tube is *in phase* with the A.C. grid voltage. This feed-back voltage thus *aids* the A.C. grid voltage, resulting in large sustained plate current swings and a transfer of power from the plate circuit to the grid circuit. If the plate inductance is large (high reactance), sufficient voltage will be fed back to overcome grid circuit losses and sustain oscillation. The frequency is, of course, controlled by the oscillatory circuit connected to the grid. The oscillations can be reduced by shunting the plate coil with a resistor, by introducing a resistor into the grid lead, by reducing the plate voltage, by introducing plate-to grid capacity-bucking components (so called neutralizing circuits), and by using screen grid tubes. However, the tuned grid, inductive plate oscillator does serve a highly useful purpose, when the tank circuit is replaced with a crystal oscillator.

Tuned Grid, Tuned Plate Armstrong Oscillator. The so-called Armstrong (the inventor) tuned grid, tuned plate oscillator is shown in Fig. *6H.* This circuit is essentially like that shown in Fig. *6G,* except that a parallel resonant plate circuit is used to create the inductive plate load which is necessary for oscillation. When a parallel resonant circuit is tuned slightly above the frequency of the R.F. source, its impedance becomes highly inductive. In this circuit the grid is tuned to the desired frequency and the plate tuned for minimum D.C. plate current, which automatically sets the plate tank circuit at a high inductive value. The grid tank circuit is often replaced with a crystal oscillator and the plate circuit adjusted approximately to minimum plate current; this gives a widely used and very important crystal circuit, to which we will return shortly.

Tuned Plate, Cross-Fed, Push-Push Oscillator. In Fig. *6I* you have a circuit which is often used where both high efficiency and stability are desirable. Although a double triode tube is shown, two similar triode tubes are more often used. Each tube is automatically biased to cut-off value and each grid is fed 180 degrees out of phase with the other, so that when one tube is drawing plate current, the other tube is idle. In this way the tank circuit, which is connected directly to the two plates, is receiving energy for both halves of the cycle. If during one-half of the cycle point *1* is positive with respect to point *2*, then point *2* will be positive with respect to point *1* for the next half cycle. Point *1* being coupled to the grid of tube VT_2 through a small variable condenser C_2, this tube receives an A.C. grid voltage which is *in phase with* its normal excitation. Point *3* and the cathode are at the same R.F. potential. Another way of looking at this circuit is to remove one tube; now we have in effect an ultra-audion circuit. Increasing the capacity of feed-back condensers C_1 and C_2 increases grid excitation; both condensers are usually adjusted for minimum D.C. plate current. This circuit is widely used at high and ultra-high frequencies, because the tank circuit is shunted by only one-half the plate-to-cathode capacity; this allows operation at higher frequencies without encountering undesirable tube capacity shunting effects.

Tuned Grid, Tuned Plate Push-Push Oscillator. Here is another favorite dual tube circuit, relying on grid-to-plate tube capacity for feed-back; its circuit appears in Fig. *6J*. This circuit is essentially like the Armstrong circuit, except that the plate tank circuit is being fed with energy on both halves of the A.C. cycle, giving greater efficiency. Like all twin tube oscillators, it is a valuable circuit at high frequencies where tube capacities become important. The circuit frequency depends upon the grid tank circuit; the plate tank circuit is adjusted for minimum plate D.C. current, which sets the plate load to an inductive condition.

TNT Push-Push Oscillator. This circuit, shown in Fig. *6K*, uses a coil alone in the grid circuit, relying on distribution coil capacity for grid resonance; the frequency of oscillation is therefore limited to a narrow band. This gives a high L/C ratio for the tuning circuit in the grid, which is excited to large A.C. voltage values by the limited tube capacity feed-back. The plate tank circuit is tuned to an inductive value.

Direction of Plate and Grid Coil Windings. When the plate is inductively coupled to the grid, the feed-back voltage may be either in or out of phase. If out of phase, the oscillator will not work; in this case, reversing connections to one of the coils will make the oscillator start. A good rule to follow in connecting oscillator coils (assuming that the two coils are wound in the same direction) is to make the two outer coil terminals or leads (*1* and *4* in Fig. *6A*) the cathode and B+ terminals, leaving the grid and plate connections for the inner two coil ends, *2* and *3*.

APPLYING OSCILLATOR LOADS

Oscillator loads must be applied in such a manner that load changes have a minimum effect on frequency change, and do not destroy the stability of the oscillator. As you know, the tank circuit current and voltage are sinusoidal in wave form, and therefore are of the fundamental oscillator frequency. To feed the fundamental oscillator signal to the load, then, it is best to couple the load to a *tank circuit inductance;* several different methods are used.

Inductive Coupling to Load. This method, shown in Fig. *7A*, is very commonly used when the effective load resistance is low (is 500 ohms or less). The effect of inductive coupling is that of a resistance in series with the tank coil and condenser, the resistance increasing in value as the mutual inductance is increased. Of course, this method of coupling affects the resonance of the tank circuit, shifting the frequency of oscillation slightly when load is applied or varied.

Capacity Coupling to Load. To be sure, high resistance loads can be coupled inductively to the oscillator if a large mutual inductance is provided; in cases like this, however, the capacity coupling method shown in Fig. *7B* is more often employed. The effect of capacity coupling is that of a high resistance placed in parallel with all or a part of the tank circuit. Any parallel resonant circuit acts as a pure resistance at resonance; connecting a resistance load in parallel merely decreases the net value of resistance. This loading may be increased (by reducing the resistance of the load) nearly to the point where the circuit will no longer maintain its self-excitation. The electrical value of coupling condenser *C* is such that its reactance is negligible with respect to the reactance of the load, and hence *C* does not affect the loading on the oscillator. The loading can be increased very effectively, in cases where the value of the load is fixed, by moving the load tap on the tank coil *away from* the R.F. ground.

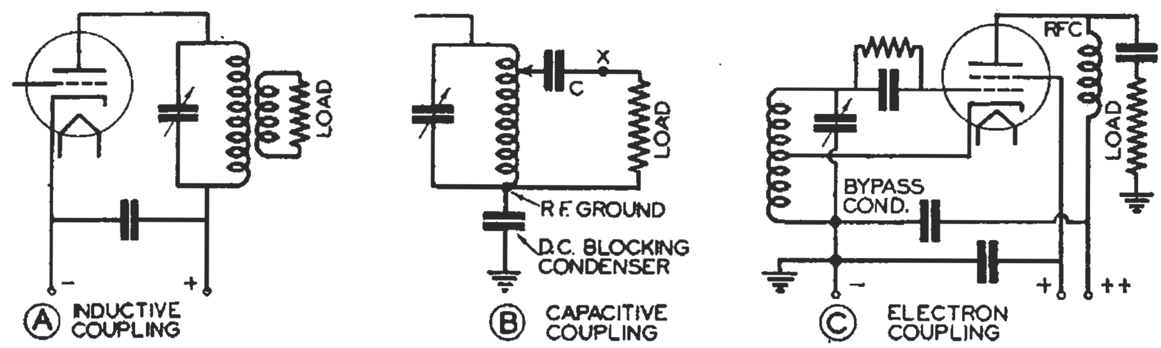


FIG. 7. Three common methods of coupling a load to an oscillator; as a rule it is best to apply the load to a circuit which has a minimum of effect upon oscillator stability and frequency.

After an oscillator is loaded, it must be adjusted for optimum operation by changing the grid bias resistor value and by adjusting the grid excitation until minimum D.C. plate current is obtained, making sure that the expected power output is obtained at all times. Where the effects of the load are to be minimized, as when the oscillator is being tuned over a given band, a series resistor of high value is placed at point *X* in Fig. *7B*, or the inductive coupling to the load is reduced. Of course, this cuts down the available output power, but stability is far more important than high power in the superheterodyne receiver and the test oscillator, where capacity coupling is often used.

Electron Coupling to Load. Practical electron coupled oscillator circuits like that shown in Fig. *7C* were first introduced by Dow, and hence are sometimes called *Dow oscillators*. These circuits are readily identified by their use of a multi-element tube in which the cathode, first and second grids are the basic oscillator elements (acting as the oscillator cathode, control grid and anode); these oscillator elements produce, just beyond the second grid, a pulsating space charge which acts as a virtual cathode. The plate of the tube, which is at a high positive potential and connects to the load through a coupling condenser, attracts electrons from the virtual cathode and passes them on to the load. The term "electron coupling" comes from the fact that a stream of electrons is the only coupling between the anode (second grid) of the oscillator circuit and the plate in the load circuit. The circuit in Fig. *7C* is that of a Hartley oscillator with the second grid placed at an R.F. ground potential so it acts as a shield between the plate (or load) and the oscillator. Electron coupling gives a high stability with a minimum of load reaction on the oscillator. Although the Hartley oscillator is shown in Fig. *7C,* any of the other oscillator circuits may just as well be used.

Best Position for Load. In loading one of the standard oscillator circuits, load that tank circuit which least affects the oscillator. In Figs. *6A* to *6G,* of course, the load is applied to the only tank circuit present; in Fig. *6G,* however, the load might be coupled to the plate coil if this did not reduce the reactance of the coil too much. In Figs. *6H* to *6K* inclusive, the plate coil would be loaded, the plate tank being retuned for minimum D.C. plate current.

OSCILLATOR POWER SUPPLY CONNECTIONS

Oscillator power supplies can be considered to be essentially at ground potential, for batteries or A.C. power packs have a fairly high capacity with respect to ground. If the oscillator is not "tied down" (connected) to the same ground as the power supply, anything coming near the oscillator chassis and any slight circuit change may cause undesirable changes in frequency and power output. The power supply circuits for the various tube electrodes may introduce undesirable paths for the A.C. currents; filters and chokes are therefore used extensively to keep A.C. power where it belongs. Each type of oscillator can be fed with power from the power supply either through some signal component (known as the series feed method) or directly through a choke which keeps signal currents out of the supply (known as the shunt or parallel feed method). To get definite phase relationships the plate, the cathode or the grid may be tied to ground.

Oscillators shown in Figs. *6A, 6B, 6C, 6D, 6G, 6H, 6I, 6J, 6K, 8A, 8C* and *8D* have series fed plate supplies; note that in each case the D.C. plate current flows through a circuit part which is essential for oscillation. Oscillators shown in Figs. *6E, 6F* and *8B* are parallel or shunt fed, the D.C. plate current being fed through an R.F. choke for high frequencies, and through an A.F. choke for low frequencies. The choke allows the plate to assume an A.C. potential without feeding A.C. into the plate supply.

A study of the power supply connections in the various forms of the widely used Hartley oscillator will bring out some important principles which apply to all oscillators. Although the circuits shown in Figs. *8A, 8B, 8C* and *8D* may at first glance appear different, they are all Hartley oscillators because the tank coil is in both grid and plate circuits in each case, with the mid-tap of the tank coil connected to the cathode either directly or through a condenser to divide the two circuits.

Plate Grounded. The Hartley circuit in Fig. *8A* contains a filament type tube with the plate connected directly to ground; the grid and cathode alternately acquire positive and negative potentials, which are always out of phase with each other, and oscillation is therefore maintained. Since the filament must receive D.C. power from its supply, a choke is introduced to make the filament assume an A.C. potential and to keep the A.C. signal from feeding into the supply. The use of a heater type tube would eliminate the need for the cathode choke, as then the cathode would definitely be isolated from the A supply.

Filament Grounded. Figure *8B* shows another filament type tube in which the filament is fed with A.C. and has its mid-point tied to ground. Feed-back condenser *C* provides an A.C. path between grid and plate circuits but blocks the flow of D.C. current to ground. The tank coil center tap is grounded directly to the mid-tap of the filament resistor; each section of this resistor is shunted by a condenser to allow signal currents to flow to the filament proper.

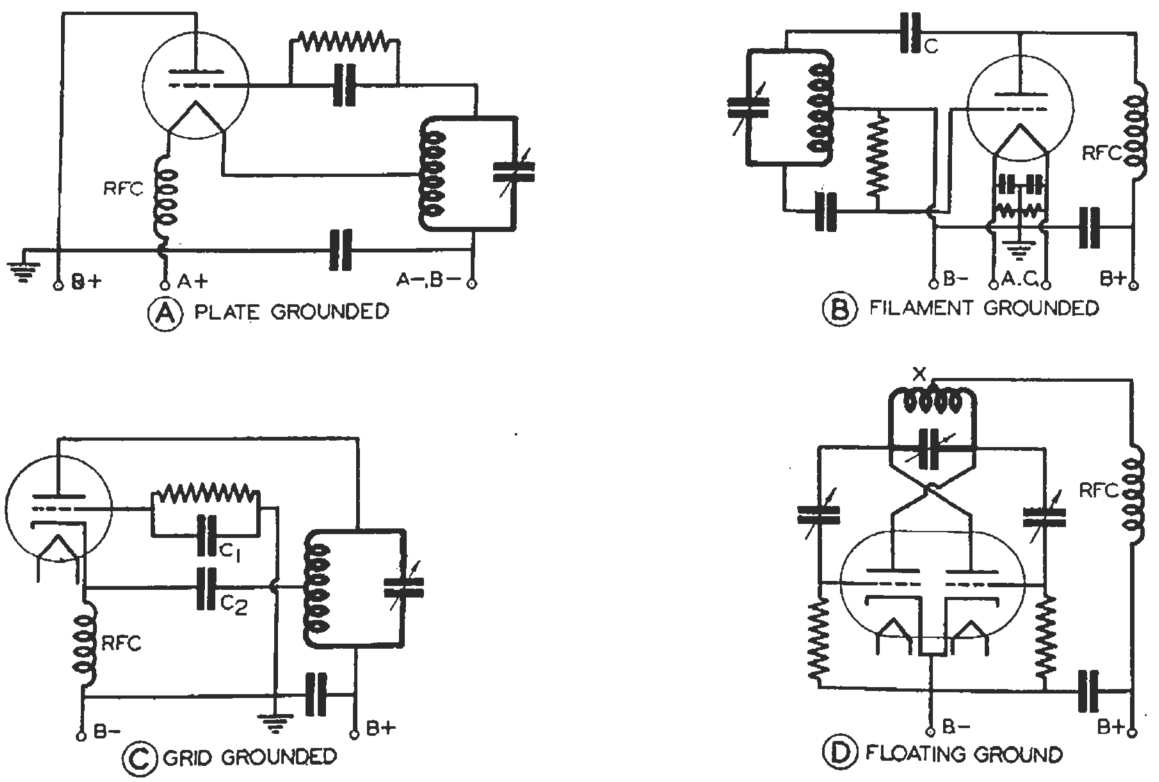


FIG. 8. Four methods of making ground connections in Hartley oscillator circuits are shown here. The frequency-controlling circuit is shown in heavy lines in each case.

Grid Grounded. Rarely is the grid grounded, but if it were necessary, the circuit shown in Fig. *8C* could be used. As far as A.C. signals are concerned, the grid is tied to ground through C_1 (shunting the grid resistor), and the mid-tap of the tank coil is connected to the cathode through condenser C_2, which prevents D.C. from flowing back to ground. The cathode circuit choke coil *RFC* allows the cathode to assume an A.C. potential without interfering with the flow of direct current from ground to cathode to plate to B+.

Floating Ground. Figure *8D* illustrates a rather well-known circuit, often called the *push-pull or push-push Hartley oscillator,* in which a floating R.F. ground connection to the tank coil is used. Tap *X* is placed as close as possible to the electrical center of its coil, making the voltages across each half of the coil practically equal at all times and opposite in polarity. But these voltages must be *exactly* equal, each section of the double triode tube getting equal excitation and equal plate currents, if the optimum operating condition is to be obtained; here is where choke *RFC* enters into the picture. Any slight difference in these tank coil voltages results in a small R.F. voltage drop across the choke, and this drop has the effect of swinging point *X* to the exact electrical mid-point of the tank coil.

FREQUENCY STABILITY

When an oscillator circuit is adjusted to a desired frequency shortly after it has been placed in operation, and a check of frequency is made an hour or so later, you will generally find that the frequency has changed or *drifted.* This is highly undesirable, for an oscillator should maintain as near constant frequency as possible. There are three causes for frequency drift in a self-excited oscillator: *1, Changes in the electrical values of parts in the oscillator circuit; 2, changes in load; 3, changes in tube constants,* due to power supply voltage changes or to the effects of causes *1* and *2*.

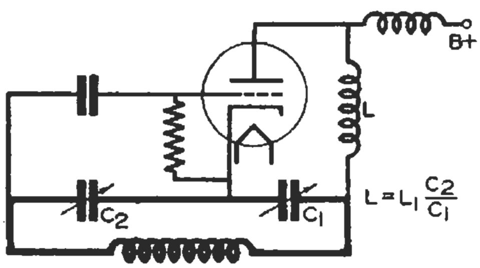


FIG. 9A. Coil *L* has been added to this Colpitts oscillator to minimize frequency drift which is caused by variations in the spacings between electrodes as tube temperature varies.

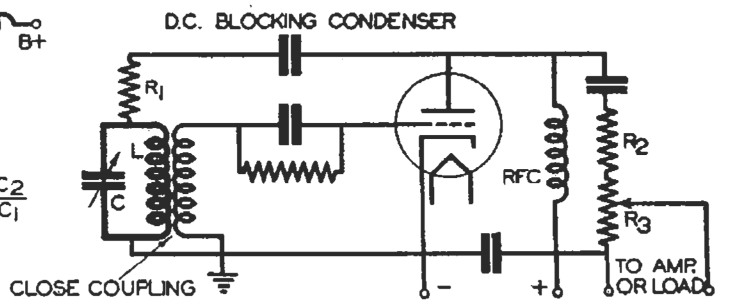


FIG. 9B. The insertion of resistor R_1 in this tuned plate oscillator improves the frequency stability of the circuit, although its use cuts down the output power.

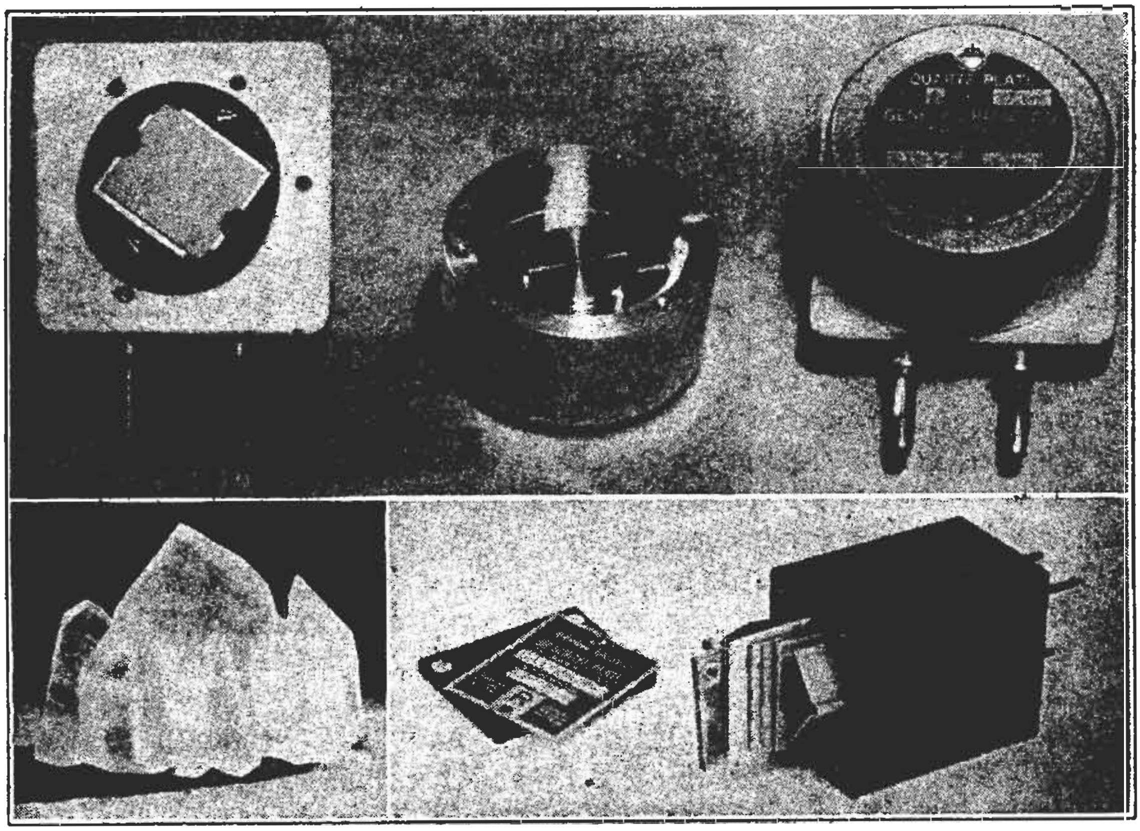
Assuming that sturdy, well designed coils, condensers and resistors which will not change in value of their own account are used, the greatest amount of frequency drift will be caused by *electrical changes* due to temperature changes; room temperature may fluctuate, and parts may heat up because of current passing through them. The solution lies in selecting parts on which temperature has little or no effect; if this proves insufficient, those parts which are most sensitive to temperature can be placed in a temperature-controlled oven.

Effects of *variations in load* can be reduced by keeping the coupling to the load as loose as possible or by using an ordinary amplifier, often called a *buffer* in this particular case, to separate the oscillator tube from its load.

Changes in tube constants are not so easily remedied; the A.C. grid-to-cathode resistance (R_g) and the A.C. plate-to-cathode resistance (R_p) have been mathematically proven to be the important factors. For a given oscillator tube and circuit the value of $R_g \div R_p$ is always a definite value regardless of the condition in the circuit; keeping the change in one as low as possible thus keeps the other one fixed and insures good stability. Frequency drift is further reduced by using a low loss tank circuit (with high Q), which in turn calls for a small load and a low loss coil and condenser.

The use of high values of grid bias resistors (but not so high that they block the circuit) makes R_g assume a high and practically constant value. If a series resistance of high value is connected between the plate and the B supply (or between the plate tank circuit, if used, and the B supply), this resistor will tend to absorb any changes in plate voltage, leaving R_p constant.

When high Q tank circuits are used, the frequency can be made practically independent of the values of R_p and R_g by inserting coils or condensers (or both) in series with the grid or plate leads (or both) of the tube. An example is shown in Fig. *9A* for a Colpitts oscillator; the electrical value required for the added coil L is determined by the values of C_1, C_2 and L_1.



Top row: Three views of a *General Radio* type 376-L quartz plate (crystal) holder. The quartz plate itself can be seen inside its fiber mounting ring in the view at the left. This unit is of the plug-in type; one prong connects to a metal electrode beneath the quartz plate, while the other prong makes contact with the machined metal cover (top center) which serves as the upper electrode. *Lower left:* Natural crystals of Brazilian quartz, from which quartz plates used in crystal oscillators will be cut. (*Photo supplied through courtesy of Bliley Electric Co.*). *Lower right:* A *Western Electric* quartz plate in its holder; this unit is also of the plug-in type. The quartz plate is here held in position between the two metal electrodes by a spring-steel plate bent at a right angle.

A more practical method, intended for use in cases where the tube capacities are relatively unimportant, is given in Fig. *9B;* there is a low loss (high Q) tank circuit (LC), a high resistance (R_1)* in the plate-to-tank circuit to minimize the effects of voltage and A.C. plate resistance fluctuations, and a small load. R_2 being much higher in ohmic value than R_3 and both being high with respect to the A.C. plate resistance, changes in the load have very little effect on circuit stability. This circuit sacrifices power for good frequency stability. In general, however, any oscillator

* R_1 should not be so large that it stops oscillation.

should be allowed to heat up from one to two hours before use, where minimum frequency shift is essential.

CRYSTAL OSCILLATORS

Frequency Stability Requirements. In radio transmission, frequency stability becomes of extreme importance. Each year governmental agencies, such as the Federal Communications Commission in the U. S. A., are demanding that frequency drift be reduced and that the exact frequency be nearer to the assigned station value. The present permissible drift is 20 cycles in the broadcast band; if a certain station operates at 1,000,000 cycles, this means the transmitter carrier frequency drift must be less than .005 per cent. Frequency-monitoring equipment used in the station must have even greater stability than this. It is difficult to design self-excited oscillators which will hold their frequency this closely but fortunately the quartz crystal, when properly cut and ground to size, mounted in a holder located in a constant temperature oven and connected into a tube circuit, gives an oscillator which has acceptable frequency stability.

Types of Crystals. Crystals are solids and therefore have height, width and depth; lines parallel to these three dimensions of a crystal are called the crystal *axes.* There is the *X or electrical axis,* the *Y or mechanical axis* and the *Z or optical axis,* all at right angles to each other. By cutting a quartz crystal into small slabs across the *X* axis, a so-called *X-cut crystal* is obtained; by cutting across the *Y* axis a *Y-cut crystal* is obtained; *Z-cut crystals* are of little importance in radio. When one of these crystals is placed between two metal plates, one surface of the crystal being about .003 inch away from one of the plates to allow the crystal to vibrate freely, an A.C. voltage applied to the two plates will cause the crystal to vibrate at a frequency determined chiefly by the thickness of the cut crystal. For an X-cut crystal the frequency in cycles is approximately 3,000,000 divided by the crystal thickness in millimeters; for a Y-cut crystal the frequency in cycles is about 2,000,000 divided by the thickness in millimeters. Crystals which vibrate up to 5,000 kc. are quite easily made.

The really important feature of a crystal, as used in a crystal oscillator circuit, is that it acts *as a tank circuit which has a better frequency stability than any other practical device;* only changes in crystal temperature produce frequency drift, and temperature can be easily controlled.*

Study of a Crystal Oscillator Circuit. The simple crystal oscillator circuit given in Fig. *10A* is essentially the circuit of Fig. *6H* with a crystal in place of the grid tank circuit. This crystal is cut for a certain desired frequency, and will oscillate when the plate tank circuit is made inductive (by tuning *L-C* to a frequency slightly higher than the resonant frequency of the crystal). The plate tank circuit then has the effect of feeding back to the grid circuit, through the grid-to-plate capacity of the tube, a voltage which is in phase with the crystal voltage and which therefore serves to

*When quartz is cut at an angle to both the *Y* and *Z* axes, giving what is known as a *V* or *A.T. cut crystal,* the resulting crystal is little affected by temperature changes. V-cut crystals are used where temperature-controlled ovens are not justified because of space or weight limitations.

maintain the vibrations of the crystal. Figure *10B* shows that as condenser *C* is varied from a low to a high value, oscillation starts at a certain value of *C* (point *1*) and plate current decreases to a minimum at point *3* as the value of *C* is further increased. As *C* is increased beyond point *3*, plate current suddenly rises to its original value, indicating that oscillation has stopped.

Operating Point. Although best efficiency is obtained when D.C. plate current is a minimum (at point *3*), the circuit is not stable at this operating point (slight increases in *C* will stop oscillation); point *2* is the most practical operating point, for here changes in load or plate voltage have less effect.

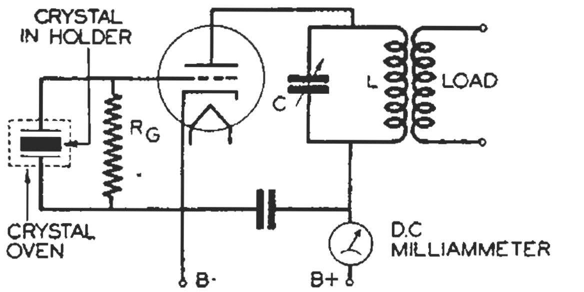


FIG. 10A. Simple crystal oscillator circuit. Rectified grid current flowing through grid resistor R_G provides the correct bias for the tube, while condenser *C* controls the starting, stopping and intensity of oscillation.

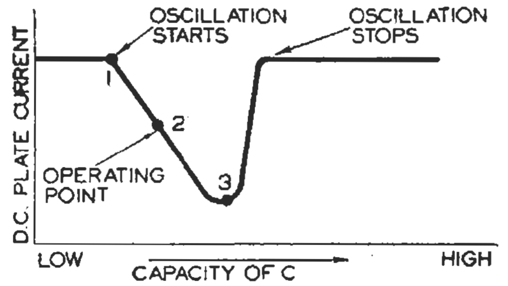


FIG. 10B. This graph illustrates how plate current in the crystal oscillator circuit at the left changes as *C* is tuned through the region of oscillation.

Crystal oscillator circuits are of many forms, the greatest variation being in the coupling to the load; electron coupling is widely used. Crystal oscillators have a very low output power, and R.F. amplifiers must therefore be used in practically every instance to get sufficient power output even for test equipment.

ULTRA HIGH FREQUENCY OSCILLATORS

Crystal Oscillators are Unsatisfactory for U.H.F. Work. Oscillators which must generate very high radio frequencies with very low frequency drift introduce many special problems. To be sure, crystal oscillators can be used with one or more special harmonic-producing R.F. amplifiers which are adjusted to double and redouble the oscillator frequency until the desired ultra high frequency (u.h.f.) is obtained. A single amplifier operated with a C bias greater than the plate current cut-off value will, if excited with a signal of some definite frequency, produce in its plate circuit the 2nd, 4th, 6th, 8th, etc. harmonics of this input frequency, the 2nd harmonic being the strongest. By using other similar amplifiers, each tuned to the 2nd harmonic of the preceding stage, the original frequency produced by a crystal oscillator can be doubled many times, but there are serious drawbacks to this doubling method. When the crystal frequency is 5,000 kc. (the practical maximum operating frequency of a quartz crystal), and frequencies of the order of 100,000 kc. are desired (such as for television purposes), it is expensive as well as difficult to build frequency doublers which will operate satisfactorily at such high frequencies.

Self-Excited U.H.F. Oscillators. Acorn type tubes are used extensively with very high Q tank circuits for *low power*, self-excited u.h.f. oscillators. The tank coils are wound with stiff, solid wire which requires no supporting form, thus keeping the distributed capacity and the losses of the coil at a minimum. Midget tuning condensers can be used, but often the required tank capacity is obtained by varying the spacing of the coil turns. This form of u.h.f. oscillator is used in television receivers.

Tank Coil Voltage Distribution. When the mid-tap of the tank coil in a self-excited u.h.f. oscillator is grounded as in Fig. *11A*, the coil ends are alternately positive and negative*; when one end of the coil is grounded, as in Fig. *11B*, the other end likewise changes in polarity. The distribution of voltage is sinusoidal, hence Fig. *11A* shows half-wave ($\lambda/2$) and Fig. *11B* shows quarter wave ($\lambda/4$) voltage distribution. This does not necessarily mean that the coil itself is a half or quarter wave length long in physical size; the physical and electrical lengths of the coil can be made the same, however, by using straight metal wires or pipes, as shown in

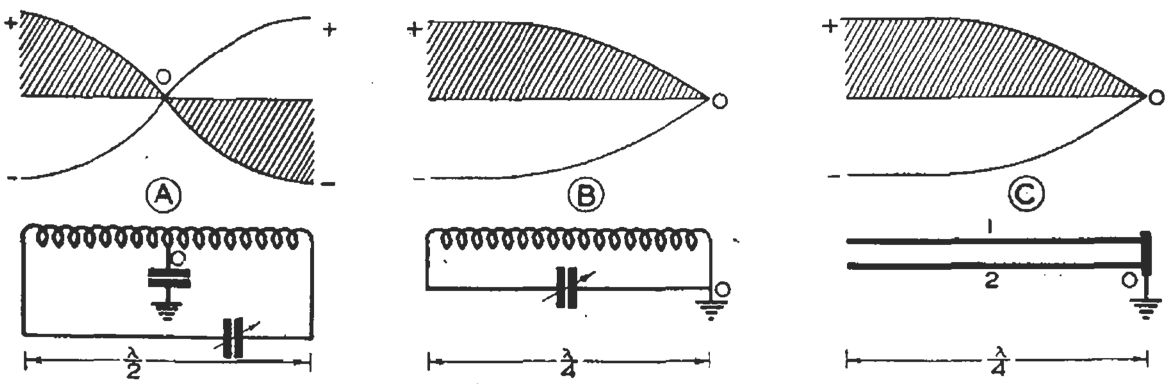


FIG. 11. The curves shown here give the voltage distribution across: *A*, the coil of an oscillator tank circuit when the coil mid-tap is grounded through an R.F. by-pass condenser; *B*, the coil of an oscillator tank circuit when one end of the coil is grounded; *C*, one of the pipes in a u.h.f. tank circuit using two parallel or concentric metal pipes. In each case the horizontal reference line represents ground potential or zero voltage; in each case the curve surrounding a shaded area represents conditions for that half of a cycle when the left-hand end of the tank coil is positive, and the other curve (the *minus* curve) portrays conditions for the other half of the cycle. The curves at *C* are for one pipe (No. 1) only; curves for the other pipe would have exactly the same shape but opposite polarity.

Fig. *11C*. Here pipes *1* and *2* are separated from one to four inches by air. When very high frequency, low wave length circuits are desired, simple pipes are used without tuning condensers.

High Power U.H.F. Oscillators. For high power u.h.f. oscillators, coils are made of copper tubing; sometimes two straight copper pipes side by side or one inside the other are used to provide the required inductance and capacitance. A single turn of tubing or even less is generally sufficient. Push-push tube circuits like that shown in Fig. *12A* are customarily used; to get close grid-to-plate coupling (unity coupling), the grid wire is run inside the length of copper tubing which connects the plates together. Notice how electrode voltages are fed to the mid-points of the plate and grid loops or coils.

The circuit shown in Fig. *12B* is a tuned grid, tuned plate oscillator (essentially the same as the fundamental Armstrong circuit shown in Fig. *6H*), but using parallel pipes which may or may not be concentric. So-called quarter wave length lines are used to tune the grid and plate circuits. Since the grid tank circuit governs the frequency, it should be mechanically designed so that temperature changes do not affect its physical length. The

*The coil tap can be grounded directly or through a condenser; either procedure places the coil tap at zero A.C. potential with respect to ground.

plate tuned line can be replaced with a coil and condenser (or coil alone) to conserve space, for it merely needs to be tuned slightly inductive.

Fig. *12C* is the ultra-audion circuit shown in Fig. *6F* with parallel lines substituted for a coil-condenser tank circuit; whereas the grid and plate in Fig. *12B* were tapped along the line and the filament was connected to the end of the line, in Fig. *12C* the grid and plate are tapped opposite each other along the line. The latter method gives twice the A.C. tank voltage. The taps are made variable so a better impedance match can be obtained, giving better circuit efficiency and stability. Points *1* and *2* in either circuit are load-coupling points and are usually variable as to position.

The three circuits in Fig. *12* are widely used in television transmitters, where high power and good frequency stability are required. They will operate at from 50 to 200 megacycles, the higher frequencies generally

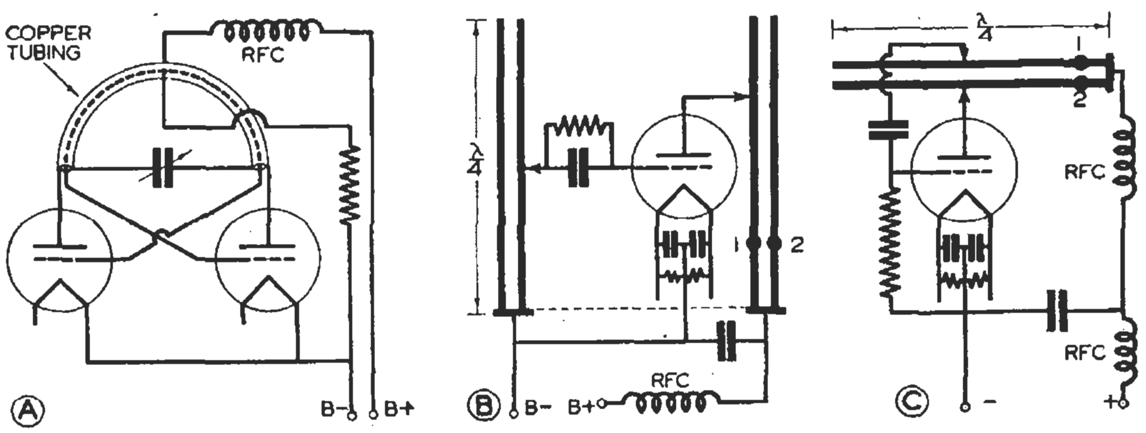


FIG. 12. Three high power ultra-high frequency oscillator circuits which are widely used in television transmitters.

being used to relay a program from a pick-up point to the main studio or from studio to transmitter. Amateurs use these circuits for communication in the 5 meter (56 megacycle) band. Air core coils and midget variable condensers are preferred in television receivers, although lines are occasionally used where space permits.

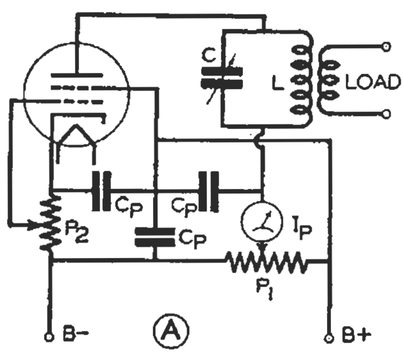
DYNATRON OSCILLATORS

When the voltage applied to a resistor is increased, we naturally expect the current through the resistor to increase. Likewise, when the plate voltage of a tube is increased (the grid bias being at less than cut-off), we expect that plate current will increase. But under certain circumstances, especially with vacuum tubes, it is found that the current actually *decreases* when the voltage is increased. This can mean only one thing, that somehow the vacuum tube is feeding energy back into the circuit. A circuit acting like this is said to have *negative resistance.** Naturally, when an

*By definition, resistance is voltage divided by current. A generator can be looked upon as a resistor whose ohmic value is equal to the generated voltage divided by the current flowing; since this voltage is equal and opposite to a real or positive voltage drop in a resistance, the generated voltage has a *negative resistance* effect; it cancels the effects of real resistance, supplying the power required by the real resistance.

oscillator tank circuit is connected to terminals which are acting as generator terminals and which have this negative resistance effect, the oscillator circuit will be fed with energy to overcome its resistance loss and oscillation will take place.

A Dynatron Oscillator Circuit. A screen grid tube is one device which can act as a negative resistance. When the plate is at a lower positive voltage than the screen grid, considerable secondary emission will take place at the plate, and these secondary electrons will be attracted to the screen. An increase in the plate supply voltage (but not above the screen grid voltage) increases the secondary emission, thus making the plate current decrease; the screen therefore gets more electrons than the plate. A typical oscillator circuit using a screen grid tube is shown in Fig. *13A;* this is known as a *dynatron* oscillator circuit. For a given C bias voltage (determined by the setting of P_2) a plate voltage-plate current characteristic like that in Fig. *13B* is obtained. Notice that after E_P reaches about



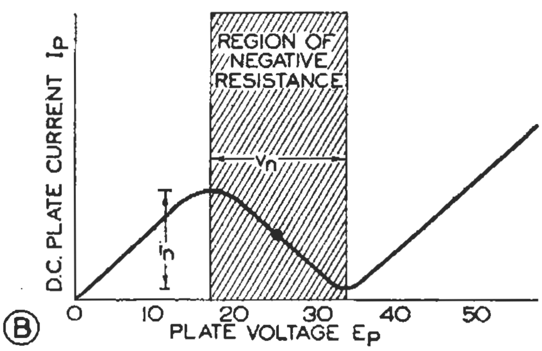


FIG. 13. A dynatron oscillator circuit (*A*) and its plate-voltage plate-current characteristic (*B*).

17 volts, further increases up to about 34 volts actually reduce I_P. This means that when the plate voltage of a screen grid tube varies within the shaded region in Fig. *13B,* the tube will behave as if it had a *negative resistance* equal in ohmic value to v_n divided by i_n.

In the dynatron circuit of Fig. *13A* this negative resistance characteristic makes the tube act as a generator which supplies energy to the *L-C* tank circuit to overcome resistance losses. *Oscillation will occur in a dynatron circuit whenever the resonant resistance of the L-C tank circuit is numerically greater than the negative resistance of the tube.* The minimum oscillator output voltage, v_n, is obtained when the two resistances are practically equal; increasing the resonant resistance makes the oscillator output voltage swing beyond the shaded area in Fig. *13B.* Oscillation is most stable when the D.C. plate voltage is in the middle of the region of negative resistance. A dynatron oscillator delivers a nearly pure sine wave voltage to a load which is inductively coupled to the tank circuit coil.

Oftentimes we get dynatron oscillator action in a vacuum tube circuit where it is not desired, resulting in squeals. The undesired oscillations are then known as *parasitic oscillations;* they can be stopped by increasing the D.C. plate voltage to get it beyond the region of negative resistance in Fig. *13B,* by adjusting the C bias to get this same result, or by inserting in the plate lead of the tube a resistor which will make the negative resistance of the tube too high for oscillation to occur.

RELAXATION OSCILLATORS

The cathode ray tubes used in television pick-up cameras, in television picture reconstructors and in cathode ray oscillographs used for testing purposes, require a special kind of oscillator, one which will produce a "saw tooth" voltage or current characteristic like that shown in Fig. *14A*. This saw tooth wave form is needed to sweep the electron beam at a uniform rate across the cathode ray tube screen, then return it almost instantly to the starting point for another sweep. Oscillators capable of producing a saw tooth wave form are known as sweep oscillators or as *saw tooth oscillators.* In radio circuit testing work, oscillators capable of producing the *square top* wave form shown in Fig. *14B* are required, for this wave form results in strong harmonics.

In general, circuits for these saw tooth and square top oscillators use a condenser which is alternately charged up by a D.C. voltage and discharged by an electrical device such as a gaseous glow tube. The output voltage drops to zero or *relaxes* for a definite fraction of each cycle, and such units are therefore called *relaxation oscillators.*

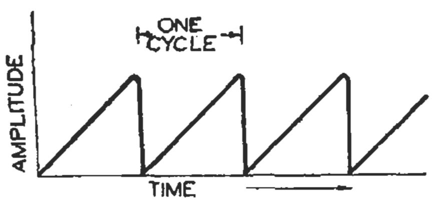


FIG. 14A. One type of relaxation oscillator produces this *saw-tooth* wave form, which gives the sweep voltage required for cathode ray tubes.

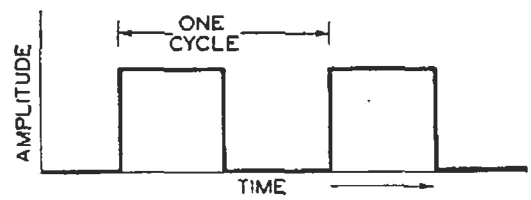


FIG. 14B. Another form of relaxation oscillator produces this *square-top* wave, used in laboratory oscillators because it produces very strong harmonics.

The simplest circuit for generating a saw tooth voltage is given in Fig. *15A.* In this circuit *N* is a neon glow tube consisting of two electrodes in a glass envelope filled with neon gas. This tube will not conduct electricity until a definite voltage, called its *firing* or *ignition* voltage, is applied; the tube resistance then becomes very low and a large current can flow unless it is limited by a resistance. Thus, when a condenser *C* is charged through resistor *R*, the condenser voltage gradually builds up (depending on the time constant; *R* in megohms times *C* in microfarads gives time in seconds), until the voltage across *C* is high enough to ignite the neon tube. The resulting flow of current through *N* lowers its resistance materially, thus shorting the condenser and dropping its voltage practically to zero (most of the line voltage being taken by *R*); the neon tube then stops glowing or firing and the action starts over again. The frequency is controlled by the characteristics of *N*, the values of *C* and *R*, and the value of the D.C. supply voltage.

Gaseous Triode Circuit. A gaseous triode tube is often used with a condenser-resistor charging circuit to produce a saw tooth wave, it being easier to control the firing voltage of this tube than of a diode. In Fig. *15B, T* is a Thyratron tube (mercury vapor-filled) or a grid glow tube (filled with neon gas). Conduction through the tube depends upon the ratio of plate to grid voltages; the more negative the C bias, the higher the plate voltage must be before the tube will conduct current. Once conduction starts, only the reduction of plate voltage to a very low value will stop current flow. In this circuit the condenser voltage builds up gradually through *R* until sufficiently high to fire the tube; the condenser is momentarily short-circuited by the tube as it discharges, the tube stops conducting and the charging of C starts over again. The frequency is essentially controlled by the values of *C* and *R*, for the plate and grid voltages are usually adjusted to correspond to the desired time constant. A controlling signal, such as the line or picture frequency of a television broadcast, can be introduced at point *X*, if the C bias is made sufficiently high so that the tube will discharge only when the controlling impulse is applied. The circuit can thus be made to produce a saw tooth signal output which is in synchronism with an input signal.

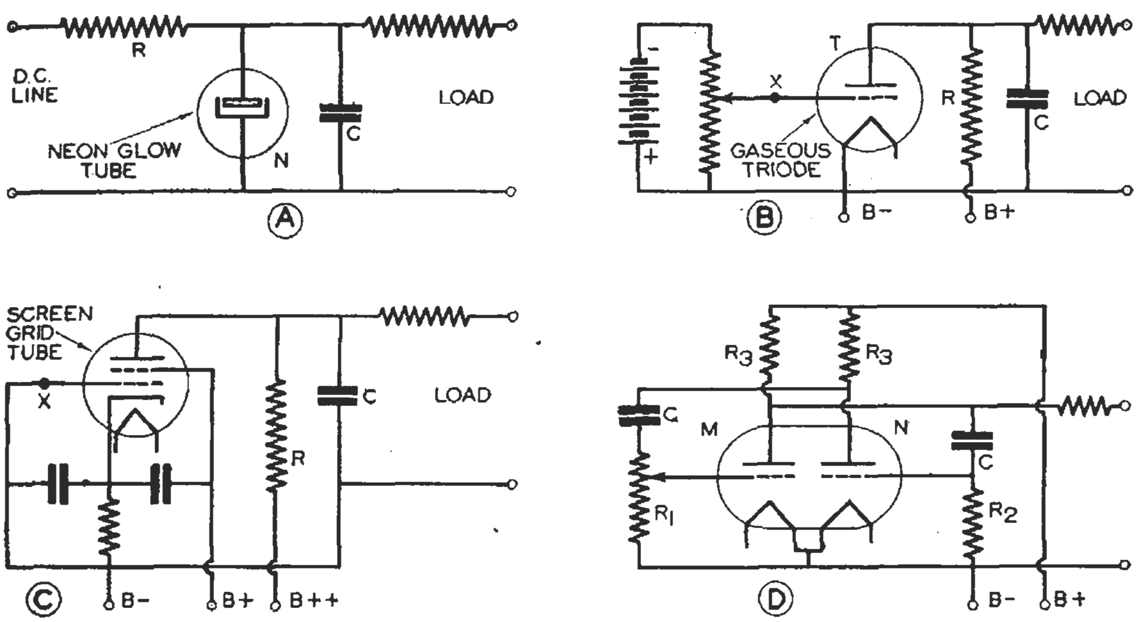


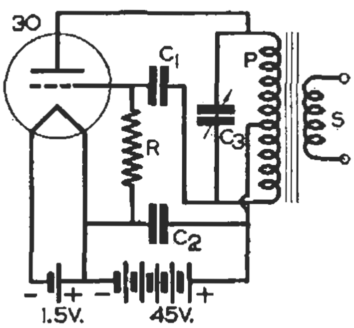
FIG. 15. Relaxation oscillator circuits.

An electron-coupled vacuum tube amplifier may be used instead of the gaseous tube signal circuit; a screen grid tube circuit is shown in Fig. *15C*. Space (cathode) current is made to flow by applying a positive voltage to the screen and a negative C bias voltage to the grid. Only a negligibly small current flows to the plate until it is placed at a very high voltage; at that point the plate-to-cathode resistance drops to a low value. Again a condenser charged through a resistor is used to build up a voltage which will break down the resistance of the tube (which is in parallel with the condenser).

In the circuits of Fig. *15A*, *15B* and *15C*, the desired saw tooth voltage is obtained by connecting the load across condenser *C*. A resistor of high ohmic value (10 to 30 times the value of *R*) is placed in series with the load to insure a uniform build-up of voltage across *C*. Quite often, charging resistor *R* is replaced by a vacuum tube, the cathode-to-plate resistance of the tube serving as a self-regulating high resistance. The tube has the characteristic of making the condenser charge more evenly with time; in either case the presence of the charging resistor prevents the condenser from being charged to line voltage.

The Multivibrator. This important type of relaxation oscillator, which produces the square top wave form shown in Fig. *14B*, depends for its operation upon the fact that the input and output voltages of a resistance-coupled amplifier are 180 degrees out of phase. The multivibrator circuit consists of two amplifiers connected as in Fig. *15D*, each amplifier using one section of the double triode tube.

The operation of this circuit is a sort of "see-saw" affair in which first one tube and then the other passes plate current to produce the desired square top wave. When the circuit is first placed in operation, an increase in plate current in one tube causes a decrease in plate current in the other (because the two stages are out of phase with each other), and this initial increase is reamplified almost instantly to make the current in that tube rise to a maximum while the plate current in the other tube drops to



R = 50.000 OHMS
C_1 = .005 TO .05 MFD.
C_2 = 1.0 MFD., 200V.
C_3 = .01 TO .1 MFD.

Fig. 16A (above). A typical audio frequency Hartley oscillator circuit.

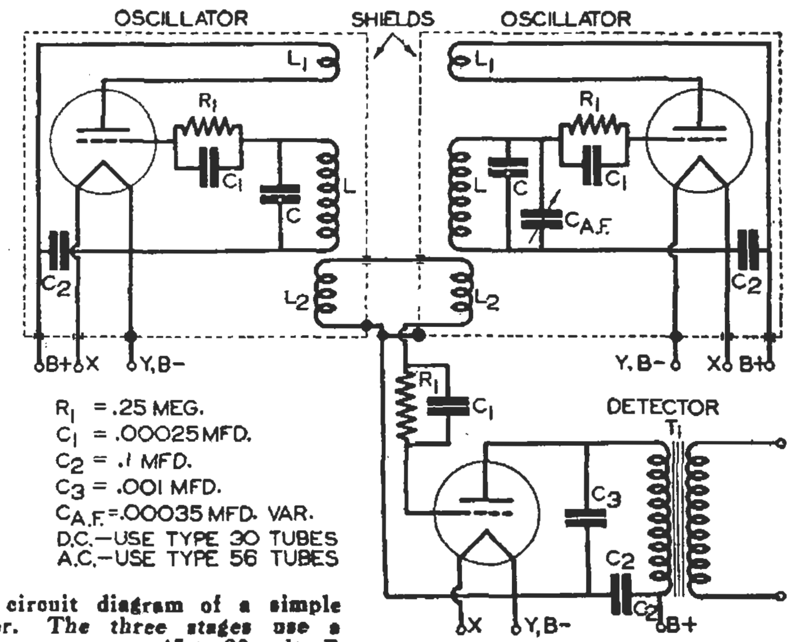


Fig. 16B (right). Schematic circuit diagram of a simple beat frequency A.F. oscillator. The three stages use a common filament supply and a common 45-to-90-volt B supply battery. *L*, *L*$_1$ and *C* in each oscillator circuit comprise a tuned grid, low frequency I.F. transformer such as is used in inexpensive midget receivers; coil *L*$_2$ consists of 25 turns wound over coil *L*.

zero. Current continues to flow through the tube, forming one square-top portion of the wave, until such time as leakage through the resistor and condenser cause a slight plate current increase in the non-conducting tube; this increase is almost instantly amplified and reamplified, forcing current in the first tube down to zero. The time interval for which the current flows in each tube depends upon the values of R_1, R_2, R_3, and C, unless an A.C. control voltage is applied to one of the grids to set the rate of oscillation. This controlling signal may be the fundamental frequency or any harmonic of the natural frequency of the multivibrator; the input signal, which may come from a crystal oscillator, therefore controls the stability of the multivibrator.

AUDIO AND BEAT FREQUENCY OSCILLATORS

Oscillators which produce signals in the aural band (from about 30 to 16,000 cycles) differ in no way from R.F. oscillators; it is merely a matter of getting a sufficiently high inductance and capacity in the tank circuit. For a 100 cycle oscillator the inductance should be about 25 henrys if the capacity is .1 mfd., and 2.5 henrys if the capacity is 1 mfd. Air core coils with inductances of this order would be enormous. Saturation in iron core coils introduces distortion, but if an appreciable air gap exists in the magnetic path an A.F. signal which is entirely satisfactory for radio testing (defect isolation) purposes can be had.

A typical Hartley audio frequency oscillator circuit is shown in Fig. *16A*. The iron core coil can be the output transformer of a push-pull amplifier. Grid condenser C_1 must be rather high in value, for it must offer a low reactance to low frequency audio signals. Tuning is accomplished by varying C_3, the maximum frequency being governed by the distributed capacity of the transformer windings.

Beat Frequency A.F. Oscillators. Iron core coils having a low distributed capacity and operating below saturation are costly and even difficult to build in units which will cover satisfactorily the entire A.F. band with a single tuning condenser. For this reason audio oscillators generally employ the beat between two low R.F. signals. For example, if a 100 kc. and

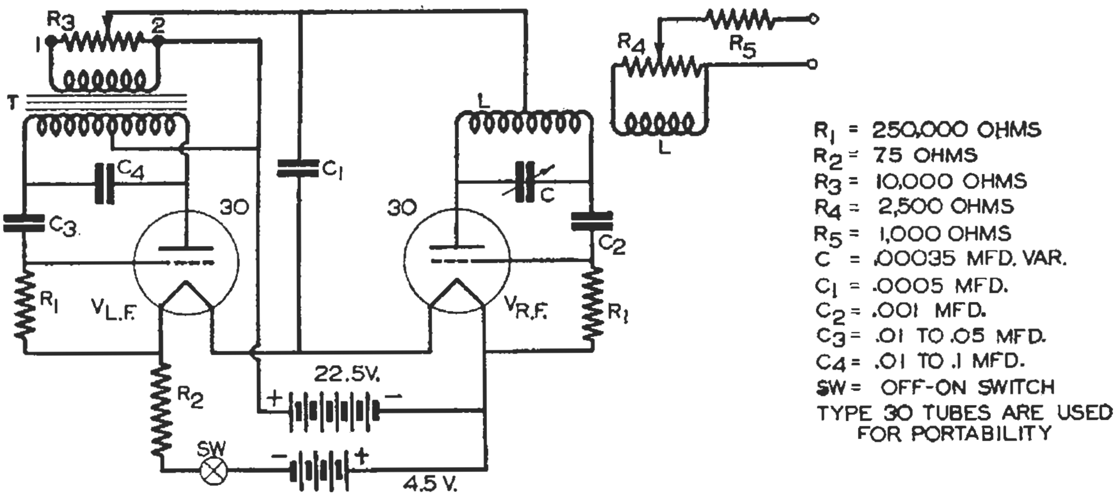


FIG. 17. Schematic circuit diagram of a typical modulated R.F. oscillator.

a 102 kc. signal are fed to a detector, the 2,000 cycle difference frequency will appear in the plate circuit. If the load is coupled to the detector plate circuit with an iron core transformer having a condenser shunted across its primary, the two fundamental frequencies and the 202 kc. sum frequency will automatically be shorted out or by-passed. Beat A.F. oscillators are widely used for testing and for precision checking work. The great difficulty lies in preventing the two R.F. oscillators from drifting in frequency.

The circuit of a beat frequency oscillator, built from parts found in the average radio shop, is given in Fig. *16B*. Each R.F. oscillator should be placed in an individual shielded compartment. With C_{AF} set at minimum capacity, adjust either of condensers C until the D.C. plate current in the detector is at its no-excitation value; this places both oscillators at the same frequency and there will therefore be no audio output.

Calibration of this oscillator is rather difficult with ordinary equipment, but a rough calibration can be obtained by comparing the audio beat output notes for various settings of C_{AF} with notes produced by tuning forks of known frequency. For precision results, it is far better to buy a commercial A.F. oscillator than to build your own.

A SERVICEMAN'S MODULATED TEST OSCILLATOR

All of the oscillators discussed so far produce constant amplitude A.C. signals. In testing radio receivers, however, the modulated radio signal ordinarily picked up must be replaced by an equivalent test signal. An R.F. oscillator which is modulated with an audio or video signal is, therefore, needed by a serviceman. There are many ways of producing this, but in a test oscillator (or signal generator) the easiest way to get this is to vary the D.C. plate voltage applied to the R.F. oscillator by introducing an A.C. voltage of an audio or video frequency. Figure *17* shows a typical modulated R.F. oscillator extensively used by servicemen; the low frequency or modulating signal is produced in the V_{LF} oscillator, the output from transformer *T* being connected in series with the D.C. plate supply to tube V_{RF} in the R.F. oscillator circuit. The degree or percentage of modulation is varied by varying R_3, which changes the amount of low frequency voltage.

The low frequency oscillator could just as well be replaced by an electric phonograph reproducer whose output was fed to points *1* and *2*. For testing all-wave receivers, coils *L-L* should be of the plug-in type; otherwise an arrangement whereby a switching mechanism inserts the proper coils must be used. Calibration of the oscillator is quite a tedious and exacting process, and since test oscillators are inexpensive, commercial equipment is always preferred.

TEST QUESTIONS

Be sure to number your Answer Sheet 21FR-2.

Place your Student Number on every Answer Sheet.

Never hold up one set of lesson answers until you have another ready to send in. Send each lesson in by itself before you start on the next lesson. In this way we will be able to work together much more closely, you'll get more out of your Course, and you will receive the best possible lesson service.

1. In a *vacuum tube* oscillator, are the power losses in the L-C oscillatory circuit compensated for *constantly* or *intermittently*?
2. What, in a self-excited vacuum tube oscillator, essentially governs the frequency?
3. Give another name for the oscillatory circuit.
4. In the oscillator circuit of Fig. *4*, what two parts automatically supply a steady D.C. bias voltage to the grid?
5. What happens if the ohmic value of the grid resistor in a self-excited vacuum tube oscillator (such as R_C in Fig. *4*) is made too high?
6. When a load is applied to the tank circuit of a self-excited vacuum tube oscillator, will the D.C. plate current *increase* or *decrease*?
7. Can the power output of a self-excited vacuum tube oscillator be increased by increasing the D.C. plate supply voltage?
8. How can the Hartley oscillator circuit be identified?
9. What is the purpose of the parallel resonant plate circuit in the tuned grid, tuned plate Armstrong oscillator?
10. To what part of a self-excited oscillator circuit should the load be coupled in order to feed it with the fundamental oscillator signal?