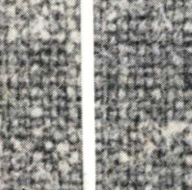
HOW OSCILLATORS OPERATE IN AM, FM, AND TV RECEIVERS

21 FR-3



NATIONAL RADIO INSTITUTE
WASHINGTON, D. C.
ESTABLISHED 1914

STEAM POWERED RADIO.COM

STUDY SCHEDULE NO. 21

For each study step, read the assigned pages first at your usual speed, then 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. Fundamental Oscillator Operation . . . . Pages 1-3

This introductory section explains how an oscillator is just an amplifier with a feedback arranged so that it will run itself. You learn where oscillators are used, and some of the requirements placed on them. Study this action carefully, then answer Lesson Questions 1 and 2.

☐ 2. How D.C. Is Converted Into A.C. . . . . Pages 4-8

Here you learn how an L-C tank can produce a constant a.c. from pulses of d.c. energy that are delivered at the proper time. This additional explanation helps in understanding the operation of the most common types of oscillators. Answer Lesson Question 3.

☐ 3. How Oscillators Are Made Self-Regulating . . . . Pages 8-12

The important self-bias arrangement that produces plate current pulses of the proper shape is explained here.

☐ 4. Basic L-C Oscillator Circuits . . . . Pages 12-18

The many L-C receiver oscillators boil down to the seven basic types described here. Study this section with care and you will be able to analyze any oscillator you will meet. Answer Lesson Questions 4 and 5.

☐ 5. Local Oscillators as Used in Receivers . . . . Pages 19-27

Practical information on types, tuning differences, and band switches is given in this important section. Answer Lesson Question 6.

☐ 6. Service Hints for Oscillators . . . . Pages 27-30

More practical facts—information on oscillator troubles and their remedies. Answer Lesson Questions 7 and 8.

☐ 7. Special Oscillator Applications . . . . Pages 30-36

In addition to its use as a local oscillator, the oscillator is also used in service signal generators, audio oscillators, television sweep generators, and television high-voltage supplies. Here you are introduced to the types used. Answer Lesson Questions 9 and 10.

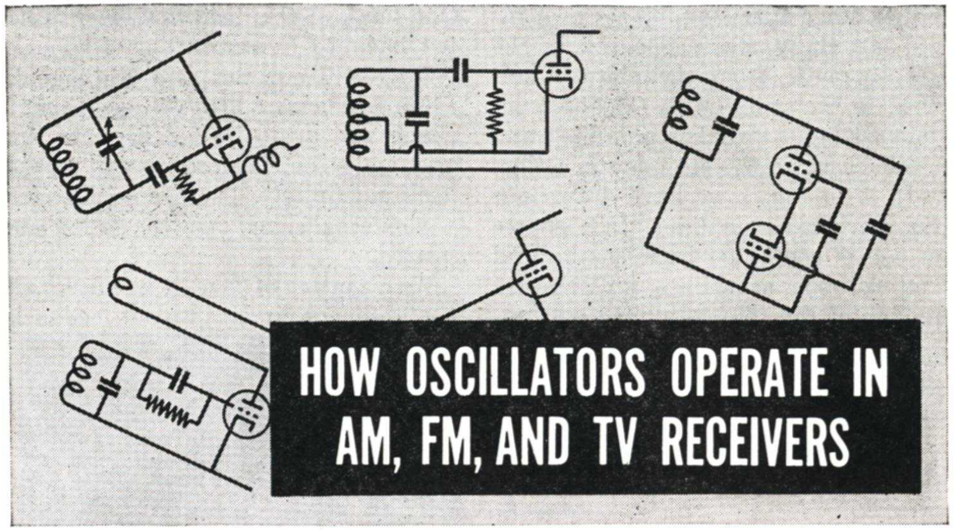
☐ 8. Mail Your Answers for this Lesson to NRI for Grading.

☐ 9. Start Studying the Next Lesson.

COPYRIGHT 1949 BY NATIONAL RADIO INSTITUTE, WASHINGTON, D. C.

FM10M849
Printed in U.S.A.

STEAM POWERED RADIO.COM



HOW OSCILLATORS OPERATE IN AM, FM, AND TV RECEIVERS

OSCILLATORS are vital to all of radio—they are found in transmitters, receivers, and test equipment. More particularly, oscillators are used in all superheterodynes, which includes practically all modern a.m. receivers and all television and f.m. receivers. As you know, a superheterodyne is a receiver in which the incoming radio or television signal is mixed with an r.f. signal supplied by a local oscillator. The mixed signal is then rectified, producing an intermediate-frequency (i.f.) signal that is amplified in a fixed-frequency i.f. amplifier. This arrangement is the best yet discovered for making a set highly selective and sensitive, which is, of course, the reason why it is so widely used.

Radio service work would be rather difficult without oscillators; the signal generator used by servicemen to supply a test signal is really just an oscillator with a controlled output. There are audio signal generators also, which are used for making fidelity tests.

In television sets, not only is an oscillator used in the superheterodyne conversion process—but also two special oscillators produce voltages that control the deflection of the electron beam back and forth across the face of the picture tube. In many television sets, oscillators are used in the high-voltage power supply as well.

Now that you know where oscillators are used, let's begin our study by learning how a basic sine wave oscillator works. One of the most important of these is the one used in sound and television receivers as the *local oscillator* (the one used in the superheterodyne frequency conversion process is identified as the "local" oscillator). It must produce an a.c. sine-wave signal at a specified frequency, or over a specified tuning range. It must produce a sufficient amount of this signal, must be reliable in its operation, and must not vary in the frequency it produces at any particular setting. Furthermore, the wave shape of the signal must be accurately reproduced, cycle after cycle. Let's see how these requirements are met.

A BASIC OSCILLATOR

One way of explaining the action of an oscillator is to say that it is an amplifier stage that supplies its own input signal by feeding energy in the proper phase from the plate circuit back to the grid circuit. This self-developed input signal is amplified and fed back again to continue the action.

In A in Fig. 1 we have drawn our familiar basic amplifier. If a source of a.c. is connected between the grid and cathode as shown, an enlarged replica of the source voltage will appear as e_2 across the load in the tube plate circuit (provided we do not overload the tube, and operate it over the proper portion of its characteristic). In most amplifiers, the load voltage e_2 is at least several times the grid signal voltage e_1.

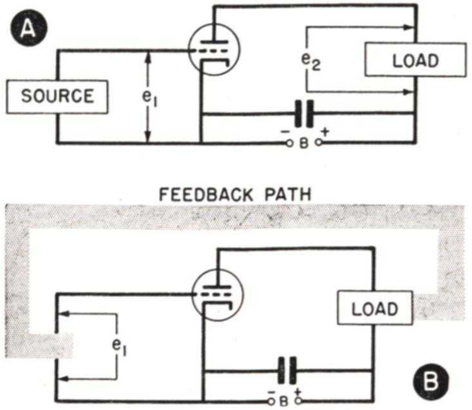


FIG. 1. If the "source" in the basic amplifier (A) is replaced by an equal feedback voltage, the circuit becomes an oscillator (B).

Let's suppose the voltage gain of this stage is 10, meaning that one volt on the grid will produce 10 volts across the load. Let's also suppose that we arrange a feedback path, as shown in Fig. 1B, over which one-tenth of the load voltage is fed to the grid. Finally, let's suppose we apply a signal to the grid.

You can see at once what will happen. The grid signal will cause a voltage to appear across the plate load. One-tenth of this load voltage will be fed back to the grid. This feedback voltage will now act as a grid signal, again producing a load voltage, part of which will again be fed back to the grid, and so on. The process will repeat itself indefinitely. There is no need for any external signal once the action has started.

As a matter of fact, if we insert an L-C resonant circuit into our feedback amplifier, we do not need an external signal even for starting. Using a resonant circuit will also make it possible for us to fix the frequency of oscillation of this stage. Let's see how.

The resonant circuit may be placed in the plate circuit, in the grid circuit, or in the feedback path, as we shall shortly learn. For our first example, let's assume the resonant circuit is used as the plate load, giving us a circuit like the one shown in Fig. 2.

When this circuit is first turned on, the plate current increases from zero, and this current flow through the resonant circuit L_2-C_2 causes a voltage to appear across this load. As you know from your previous study of resonant circuits, this will be an alternating voltage having a frequency equal to the resonant frequency of the L_2-C_2 circuit.

Inductively coupled to L_2 is coil L_1, which is in the grid circuit. If the coupling is properly arranged, the voltage in L_1 will be in the right phase to reenforce the plate current change that is producing the resonant circuit current. When the plate current increases, the grid will go positive to assist the increase; when the plate current decreases, the grid will swing negative to force the decrease. The frequency will be determined by the natural frequency of the resonant circuit.

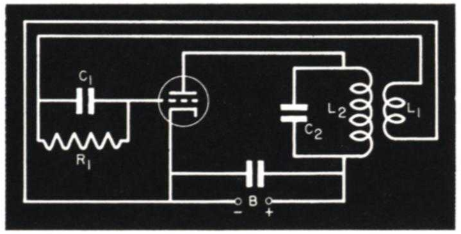


FIG. 2. A typical tuned-plate sine-wave oscillator.

To produce this action, the voltage fed back to the grid circuit must be sufficiently large to maintain the oscillation and in the proper phase to assist the plate current changes. The phase of the feedback voltage will always be correct if the leads from L_1 are properly connected to the grid circuit; if the lead connections are interchanged, however, the phase will be 180° from what it should be, and oscillation cannot occur. If the circuit is properly designed, it will be self-starting as a result of the initial plate current change through the resonant circuit.

This simple circuit has 4 of the 5 elements all oscillators contain. These are:

1. An amplifier tube (one with a control grid).
2. A feedback path.
3. A frequency-determining network.
4. A self-bias system to set the conditions of operation. (This system consists of C_1 and R_1 in Fig. 2; we will discuss self-bias later.)

In addition, all oscillator circuits contain:

5. A coupling circuit or device to transfer energy from the oscillator to the circuit with which it works.

Of course, many circuit variations are possible with even these few items, and many different oscillator circuits incorporating them have been designed. In this Lesson, we shall show that the essential differences between the various oscillator circuits are in:

1. The method of getting plate-to-grid feedback power.
2. The position of the resonant circuit.
3. The method of coupling the oscillator to other circuits.
4. The power supply arrangement.

Before we take up these practical oscillator circuits, let's study the operation of the basic oscillator from a different viewpoint.

STEAM POWERED RADIO.COM

How D. C. Is Converted Into A. C.

You have just learned that the action of an oscillator can be explained by considering the circuit to be a feedback amplifier that supplies its own input signal. An amplifier can be made to work this way, but for efficiency the stage should be operated so that pulses of current flow. Then, another explanation is sometimes more helpful in understanding the circuit action. This is to consider that the L-C tank circuit is the actual generator of the a.c. signal, and that the rest of the oscillator circuit serves simply to deliver pulses of energy from the B supply to this resonant circuit at the proper time.

Before we can go into more detail on this explanation, we must make sure that you thoroughly understand the operation of a resonant circuit. Fig. 3 shows step-by-step how one half-cycle of an alternating current is produced by the discharge of a condenser through a coil. In this figure, the condenser is initially charged at the beginning of the action, and, at the end, is recharged with the opposite polarity. The process will then be repeated to produce a current flow in the opposite direction, finally leaving the condenser charged with the initial polarity. Then the whole process will be repeated again. Study this figure carefully now before proceeding any further in this Lesson.

If we plot a curve showing the instantaneous values of current I in Figs. 3A to 3E, we obtain the solid-line curve I in Fig. 4. The numbers 1, 2, 3, etc., correspond to the conditions for Figs. 3A, 3B, 3C, etc., respectively. We see that the condenser discharge current is zero at 1, rises through 2, and reaches a maximum at 3. After this, the current decreases through 4 and becomes zero again at 5. *This current curve is a perfect half-cycle of a sinusoidal wave.*

Similarly, if we plot the change in voltage across the condenser for all parts of the discharge cycle, we get the dashed curve E in Fig. 4. Between points 1 and 5, *this curve, too, is a perfect half-cycle of a sinusoidal wave.*

But let us compare the two circuit conditions in Figs. 3A and 3E. In each case, the condenser is fully charged, the only difference being the polarity of the charge. Therefore, after the condition in Fig. 3E has been reached, the condenser will begin to discharge once more—this time with the current through the coil in the opposite direction. Except for this change in direction, the same action will be repeated until the circuit returns to the condition shown in Fig. 3A.

After this, the sequence will be repeated over and over again. In other words, the current will flow first in one direction, then in the other, continuously charging and discharging the condenser a great many times. Both voltage and current follow many cycles of a sinusoidal wave. Therefore, our L-C circuit has transformed a pulse of energy used to charge the condenser into an alternating current—it can make a.c. from d.c.

As you know, the frequency of oscillation of this circuit can be expressed by the formula

$$f = \frac{1}{6.28\sqrt{LC}},$$

in which the frequency f is in cycles per second, the inductance L in henrys, and the capacity C in farads.

This formula means, of course, that if the capacity C and the inductance L in Fig. 3 are sufficiently large, we can obtain a circuit oscillation at a very low frequency, say 20 or 30 cycles

OPERATION OF AN L-C TANK

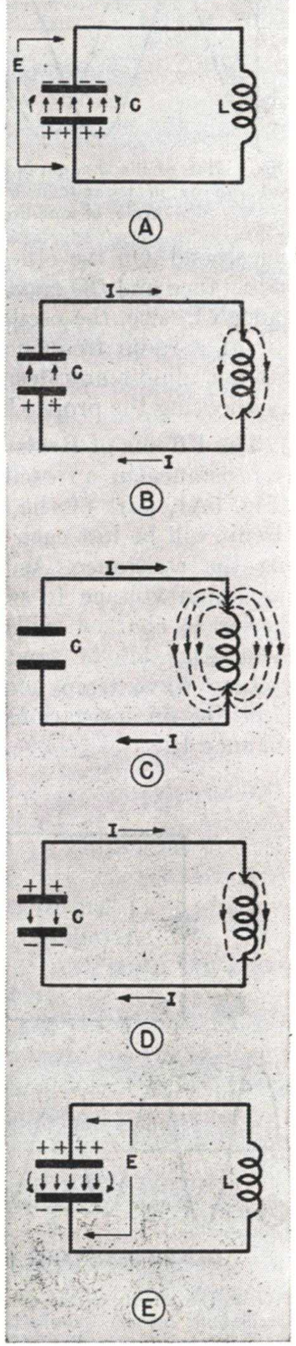


FIG. 3. Let's suppose we charge a condenser by connecting a battery across it, then remove the battery and connect the condenser into the circuit shown in (A). At the instant we make the connection, all the energy in the circuit consists of the charge on the condenser, which is represented by the electrostatic field between the condenser plates.

When the connection is made, the condenser immediately starts to discharge through the coil, causing the current flow shown by the arrows in (B). This current causes an electromagnetic field to start to build up around the coil.

As the condenser continues to discharge, the current flow and the electromagnetic field both increase. At the instant shown in (C), the condenser is completely discharged; the current flow and the electromagnetic field are now both maximum. All the energy in the circuit is represented by the electromagnetic field around the coil.

Since the condenser is completely discharged, the current starts to decrease. This causes the magnetic field of the coil to collapse, which, as you know, tends to make the current keep flowing in the same direction. Therefore, as shown in (D), a current flow continues that starts to charge the condenser with a polarity opposite to that of its original charge.

As the electromagnetic field continues to collapse, current flow into the condenser continues, but gradually decreases. At the instant shown in (E), the field has collapsed completely, current flow is zero, and the condenser is completely charged to the opposite polarity. All the energy has been returned to the condenser again. The condenser then starts to discharge again in the opposite direction, and the same series of events occurs until the condition shown in (A) is reached again, whereupon the cycle recommences.

STEAM POWERED RADIO.COM

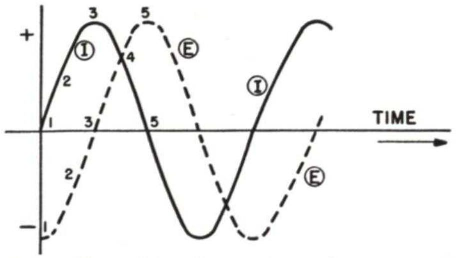


FIG. 4. Plots of the changes in condenser current and voltage in the circuit in Fig. 3 for one cycle of operation.

per second. On the other hand, if the inductance and the capacity are small enough in size, the oscillation will occur at a radio frequency. Hence, we can get almost any desired frequency by choosing the proper L-C values.

The Effects of Resistance. If there is resistance in an oscillatory circuit (Fig. 5A), part of the energy in the circuit will be lost each cycle in heating the resistance. As a result, the maximum voltage to which the condenser is charged will be less each cycle. Figs. 5B, 5C, and 5D show the voltage wave train across condenser C in Fig. 5A for various values of resistance R.

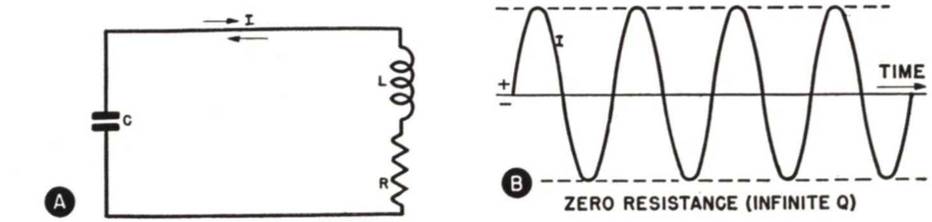
When R is zero, the "continuous-wave" train in Fig. 5B is produced. These oscillations will continue indefinitely. When the resistance is medium (Fig. 5C) or high (Fig. 5D), the oscillations die out; the higher the resistance, the more rapidly they die. The voltage trains shown by the curves in Figs. 5C and 5D are known as "damped-wave" trains.

Incidentally, the resistance R in Fig. 5A is higher than the ohmic resistance of the coil and the connecting wires; it includes, in addition, dielectric and "skin effect" losses. (Skin effect is the tendency of alternating current to flow on the surface of a wire rather than throughout the wire.) This total resistance is called the *a.c. resistance*.

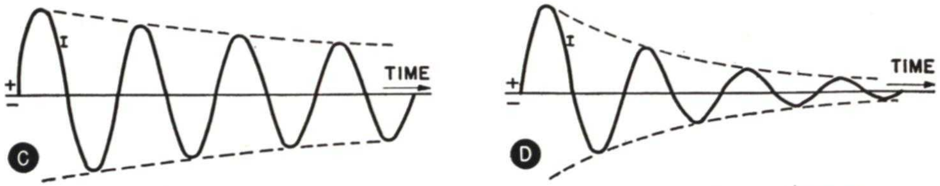
In circuits of this type, as you remember, it is customary to define the quality of the inductance coil L by its Q—which is the inductive reactance X_L (at the resonant frequency) divided by the a.c. resistance R, or:

$$Q = \frac{X_L}{R}.$$

From our examination of Fig. 5, we can say that the lower the Q of the coil, the quicker the oscillations die out.



ZERO RESISTANCE (INFINITE Q)



MEDIUM RESISTANCE (MED. Q)

HIGH RESISTANCE (LOW Q)

FIG. 5. The effects on the condenser voltage of various values of resistance in an L-C circuit (A). Oscillations continue indefinitely if the resistance is zero (B), die out fairly soon if the resistance is medium (C), die out rapidly if the resistance is high (D).

STEAM POWERED RADIO.COM

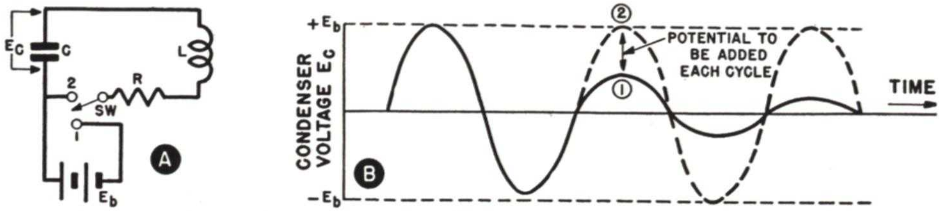


FIG. 6. If the switch could be moved back and forth in phase with the oscillations so that the condenser would be charged once each cycle, the continuous wave shown in (B) would be generated.

Supplying Energy. Usually we want an oscillator to generate continuous-wave oscillations like those in Fig. 5B. Let's see how we can make one do so.

Let us consider the oscillatory L-C circuit in Fig. 6A. If we place the switch SW in position 1, condenser C will charge. If we then move the switch to position 2, the circuit will oscillate. Because there is resistance in the circuit, the wave train of the condenser voltage will have the damped form shown by the solid curve in Fig. 6B.

Suppose, however, we do not leave the switch *fixed* at position 2. Instead, let us assume that we can move the switch back and forth at a very rapid rate. If we then move the switch to position 1, *exactly at the time the oscillating voltage starts its second swing in a positive direction,* we can charge the condenser *completely* once more. The condenser voltage, therefore, will increase from point 1 in Fig. 6B up to the maximum potential at 2. The wave now "starts over" in that it is returned to its original maximum value. If we arrange to move the switch for *every* positive swing of the oscillating voltage, we shall obtain the continuous wave train shown by the dotted lines.

Of course, the condenser will not require full charging current from the battery each oscillation cycle. The only additional charging current needed will be that necessary to bring the condenser potential from point 1 on the cycle up to point 2 each time. *The only energy drawn from the battery, therefore, will be that small amount required to replace the energy lost in heating the circuit resistance.*

Of course, no manual switch can operate millions of times a second, as it would need to do to keep in step with r.f. oscillations. The vacuum tube, however, can be made to handle this switching job easily, efficiently, and automatically.

Therefore, we can make a continuous-wave oscillator by attaching a vacuum tube to an L-C circuit in such a way that the tube will act as a switch or "trigger" and release pulses of energy from the B supply at properly timed intervals. These intermittent pulses keep oscillations going.

THE TUBE SWITCH

If you look at the oscillator circuit in Fig. 2 again, you will see that it fits the description we just gave of a continuous-wave oscillator. The initial flow of plate current when the circuit is turned on starts the L-C oscillatory action. Then, the voltage fed back to the grid circuit controls the operation of the tube, making it take current from the B supply at the proper time to recharge the resonant circuit condenser. (Because of the storage action, the L-C circuit is commonly called a "tank" circuit.) We shall describe this action in more detail very shortly, but first let's point out a few important facts about this oscillator.

For a fixed plate current, in this circuit, the a.c. voltage developed across the tank depends on the resonant resistance of the tank, the tube plate resistance and the B supply voltage. In other words, as in amplifiers, the B supply voltage divides between the load and the plate resistance. The higher the load impedance, the greater the load (tank) voltage. This load impedance is equal to the coil reactance multiplied by Q, so the higher the Q, the higher the tank voltage, up to a maximum nearly equal to the B supply value.

The grid voltage is determined by the coupling between L_1 and the tank coil L_2. Increasing the number of turns on L_1 or moving it closer to L_2 increases the mutual inductance and increases the feedback. If too many turns are used on L_1, however, it may become a resonant circuit itself, and force the oscillator to operate at an undesired frequency. Furthermore, increasing the coupling causes reflected effects that limit the frequency range and may also reduce the tank Q, as we shall see.

If this circuit is to be used as the local oscillator in a receiver, it must be tunable over a band of frequencies—sometimes over several bands. The coupling between L_1-L_2 is inductive, so, as the frequency is increased, there will be a greater energy transfer from L_2 to L_1, even though their sizes and positions are fixed. Conversely, there will be less feedback at lower frequencies. Hence, we must set the coupling for the *lowest* frequency, and then must take care of the excessive feedback that occurs at higher frequencies. As we shall now learn, an automatic bias arrangement is used to even out the oscillator performance over the tuning range, and also to prevent excessive current flow.

How Oscillators Are Made Self-Regulating

All oscillators use some form of automatic bias, for reasons we shall discuss later. The grid leak and condenser method of producing a bias is almost universally used.

AUTOMATIC BIASING

The oscillator that we have been studying (Fig. 2) is shown again in Fig. 7. Here, R_1 is the grid leak, and C_1 is the grid condenser. In this circuit, at the beginning of oscillation, the induced voltage in L_1 is in such phase as to make the grid of the tube positive. The grid then draws current, causing an electron flow through R_1 and hence creating a voltage drop across it having the polarity shown. This voltage is across C_1 also, so this condenser is charged.

On the next half-cycle of the oscillation, when the L_1 voltage drives the grid negative, the grid current flow stops, and condenser C_1 starts to discharge through R_1. This discharge current, which flows in the same direction as the grid current, maintains the voltage drop across R_1. The time constant is so high that C_1 can discharge only slightly before the next positive grid swing recharges it. Thus, for a fixed grid signal swing, the voltage across R_1 becomes a relatively constant grid bias, with the polarity shown.

You will recall that it is necessary to recharge the tank condenser for only a short time during each oscillation cycle. Therefore, to make the plate current flow no more than is necessary to maintain oscillation, the values of C_1 and R_1 are chosen to produce a bias well beyond the normal cut-off bias for the tube. Plate current can then flow only when the feedback voltage developed across L_1 makes the grid voltage more positive than the cut-off bias value.

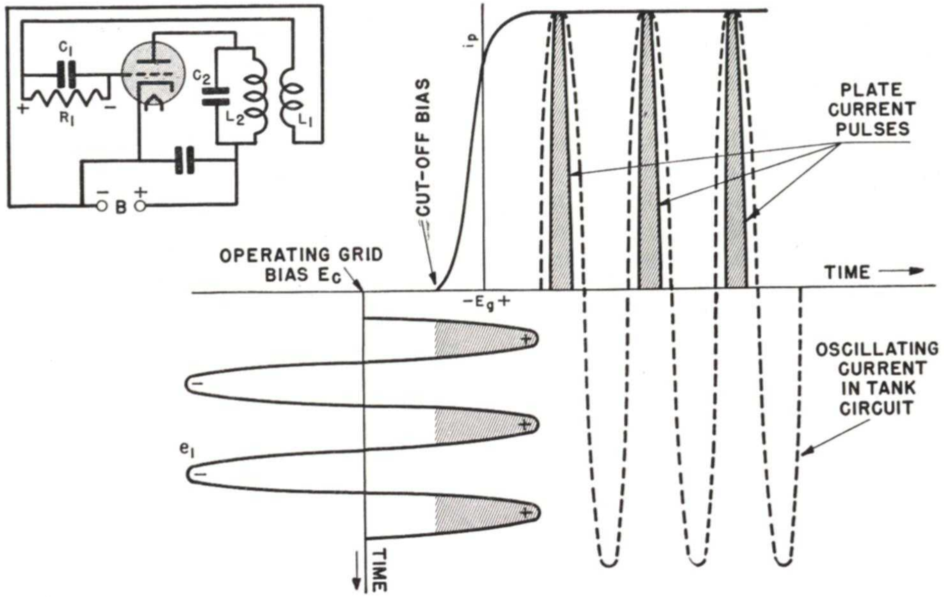


FIG. 7. When a vacuum tube is biased beyond cut-off, and the proper grid excitation is applied to it, its plate current consists of pulses that can be used to charge the condenser of an L-C circuit sufficiently to maintain continuous oscillation.

The E_g-I_p curve in Fig. 7 shows this. Here, the voltage e_1 developed by L_1 has to overcome the cut-off bias before plate current can flow. It is only during the shaded portion of e_1 shown here—when the signal swing is on the positive side of the cut-off bias point—that plate current flows. This plate current, shown by the shaded pulses at the right of the characteristic curve, is sufficient to recharge the tank condenser C_2, and maintain continuous-wave oscillations.

This operation with the bias well beyond cut-off is known as class C operation. It is very desirable for oscillators. Properly adjusted for class C operation, an oscillator has maximum efficiency, drawing no more plate power than necessary, and wasting a minimum in heating the plate resistance. Further, any upset is unlikely to stop operation, because the class C circuit is self-correcting, as we shall show.

One more point about the bias; we couldn't start oscillations if we applied a *fixed* bias greater than the cut-off value, because we should have to have a feedback voltage sufficiently large to swing at least somewhat to the right of the cut-off bias point before the circuit could start. The oscillator shown in Fig. 7, however, starts out with no bias whatever, so any small change in plate current will start a weak oscillation. This will feed back a voltage to the grid that will be amplified, thus building up the oscillation.

STEAM POWERED RADIO.COM

The bias goes up too, but the oscillation builds up faster—up to the point where the circuit stabilizes. This stabilization point is determined by the amount of bias that can be produced by the R$_1$-C$_1$ combination, by the coupling to the tank circuit, and by the peak voltage that can be developed in the tank circuit. At this stabilization point, if the plate current tries to increase, the feedback does so also, increasing the bias and holding the plate current down. If the plate current decreases, the opposite occurs.

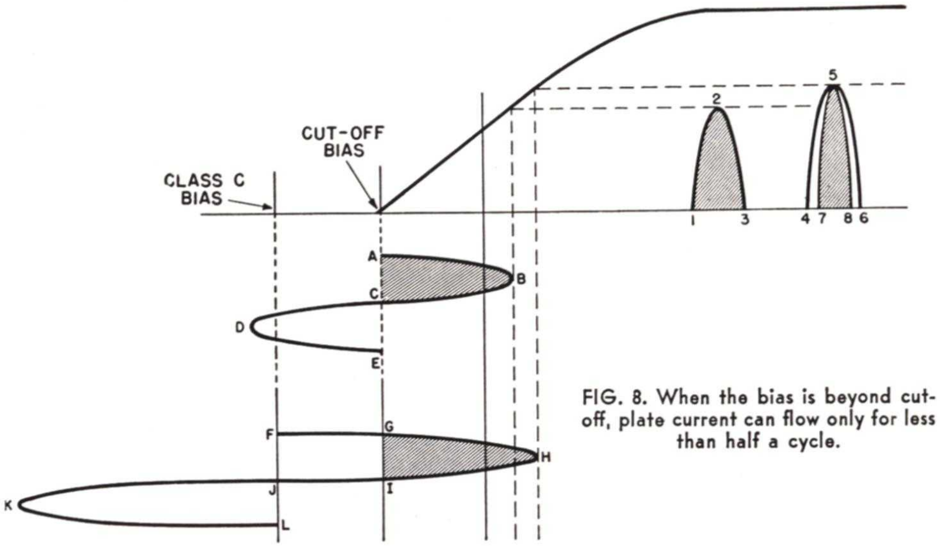


FIG. 8. When the bias is beyond cut-off, plate current can flow only for less than half a cycle.

When the circuit is operating properly, the plate and grid voltages will adjust themselves so that the tube draws no more plate current than is necessary to supply the power needed to make up for the plate dissipation, the tank circuit losses, and the load requirements.

PLATE CURRENT PULSE WIDTHS

The d.c. power drawn by the oscillator is the product of the B supply voltage multiplied by the average plate current. Since the B supply voltage is fixed, the d.c. power consumed depends directly on the plate current.

In turn, the average (or d.c.) plate current depends upon two things when it exists in the form of pulses. *The current average varies as the pulse width,* increasing as the pulse width increases, *and also depends on the peak value* or height of the pulse.

When the oscillator is first turned on, the average plate current is rather high because the bias value builds up somewhat more slowly than does the oscillation. For example, let's suppose that the grid bias has just reached the cut-off value, and that the grid voltage swing is represented by the cycle A-B-C-D-E in Fig. 8. The corresponding plate current pulse, which flows during the shaded portion of the grid voltage swing, is shown by 1-2-3. Because the bias is exactly at the cut-off bias point, exactly one-half the grid voltage swing causes plate current to flow, so the plate current pulse is a half-cycle.

As the feedback increases, however, the peak of the grid swing becomes slightly more positive; this causes considerably more grid current and thus forces the bias to become much more negative than the cut-off value. We eventually move to the class C bias value with a grid swing represented by the cycle F-G-H-I-J-K-L.

STEAM POWERED RADIO.COM

Here, the peak H is slightly more positive than the peak B of the other grid signal. However, the operating bias is now along the line F-L instead of along the line A-E. Plate current can flow along during the portion of this cycle that is more positive than the cut-off bias level, or during the time G-H-I. This is less than half the grid cycle F-H-J, so the plate current flow must be less than half a sine wave. In other words, instead of being in the shape 4-5-6, it has the shape 7-5-8.

The actual grid voltage swing, and hence the grid bias and plate current, is fixed by the mutual inductance between coils L$_1$ and L$_2$ and by the peak tank voltage. As oscillations build up, the plate current pulses become narrower, which eventually limits the tank voltage to the point where the feedback voltage no longer can drive the grid further positive. At this point, the stabilization of the grid voltage fixes the grid current, which fixes the grid bias. From then on, the oscillations are the same amplitude, so the plate current pulses remain the same until some circuit condition is changed.

PEAK PLATE CURRENT

The losses in the tank circuit help to set the stabilization point because of the effect of the tank impedance on the peak plate current value.

You will recall that a tube with a load operates over a dynamic characteristic that is much flatter than a static curve, and that the greater the load resistance or impedance, the flatter the curve. In Fig. 9, there is one curve for a high-Q tank circuit and another for a low-Q circuit. A high-Q circuit offers a higher load impedance, because the load impedance is equal to the coil reactance multiplied by Q in the case of a parallel-resonant circuit. In this figure, you can see that the peak plate current for a particular grid voltage depends upon the characteristic being used. If the grid signal reaches a value represented by the line A-A, the plate current pulse 1 represents the current for the high-Q load, and pulse 2 that for low-Q load. If we had no load at all, operation would extend up to the static curve, which is shown here for comparison. Obviously this would produce a plate current peak that would be much higher than that shown even for pulse 2.

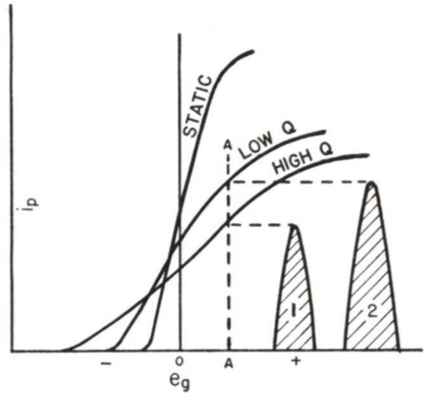


FIG. 9. When the plate tank circuit Q drops, the plate current pulse will reach a higher peak value.

Comparing pulses 2 and 1, you can see that a high-Q load permits a lower plate current peak value. You can see why this occurs by remembering that the plate current depends on both the grid and the plate voltages of the tube. Since the automatic bias sets the operating point so far negative, no plate current can flow except for the small time that the grid is more positive than the cut-off bias level, regardless of plate voltage. During this time, the plate current could reach excessive levels, except for the fact that, at this exact time, the plate voltage reaches its minimum value. This comes about because the phase is such that at the time the plate current is increasing, the load voltage is subtracting from the B supply voltage, leaving less voltage as the actual plate-to-cathode voltage for the tube. Hence, there is a lower plate voltage at the instant the grid is driven positive. The combination of the positive grid swing and the reduced plate voltage determines the actual peak plate current. Now, if the load Q is high, there is a high load voltage drop, hence a lower net plate voltage and a lower plate current peak. Therefore, the higher the Q of the resonant circuit, the less the plate current peak value.

This is obvious in another way. The higher the Q of the tank circuit, the less its resistance and the less the losses in the tank circuit. For this reason, it takes less d.c. power (B supply voltage times average plate current) to make up for the losses, so less plate current is required.

The fact that a low-Q resonant circuit has a high plate current peak value (and vice versa) is important because this shows how the circuit regulates and adjusts itself when it must supply power to an external circuit. Let's suppose we couple another coil to our tank coil L_2, and use this coil to feed a signal to the converter tube in a superheterodyne. Since a little power is now drawn from the tank circuit, a certain amount of resistance is reflected by the new coil into the tank circuit, and effectively the Q of the tank circuit is reduced somewhat. This reduced Q means less tank voltage drop, more plate voltage, and operation on a dynamic curve that allows somewhat higher peak plate current. Also, the reduced tank voltage means somewhat less feedback to the grid, hence less bias and a wider plate current pulse. Thus, both the width and height of the plate current pulse are increased, which raises the average of the plate current. This means additional power is taken from the B supply to furnish the signal power we need in our converter circuit.

Should anything happen in this circuit to require more power, the oscillator will automatically furnish it, within the limits set by its basic design. Of course, it cannot go too far—if we try to take too much power from it, the tank voltage becomes so low that there is insufficient feedback through coil L_1 to the grid of the tube to keep oscillation going. Therefore, the coupling to the external circuit and the load requirements must be carefully determined and the adjustments must be so made that the oscillator will operate well within its normal range of characteristics.

Basic L-C Oscillator Circuits

Now that you have a general understanding of how an L-C oscillator operates, let's study the various practical oscillator circuits. In the following discussion, names have been applied to the oscillator circuits to distinguish between them. It isn't nearly as important for you to memorize the exact names of the circuits as it is for you to realize that each of them works in the same basic manner—they are all amplifiers with a means of feeding back energy, they all contain a self-biasing arrangement, and they all produce frequencies that are determined by a resonant circuit.

STEAM POWERED RADIO.COM

Many different types of oscillators have been developed for radio and television sets. Most of these differ in the manner in which the vacuum tube is connected to the L-C circuit, and in the manner of obtaining feedback in the proper phase. All told, there are seven basic circuits, each of which has many variations.

OSCILLATORS USING INDUCTIVE FEEDBACK

Tuned-Plate Oscillator. The oscillator circuit that we have been studying is repeated in Fig. 10A. Because the tank circuit is in the plate circuit of the tube, this circuit is known as the tuned-plate oscillator. This oscillator may be recognized by this positioning of the tank as a load, and by the use of a feedback coil (commonly called a tickler coil) that is inductively coupled to the tank coil and is located in the grid circuit.

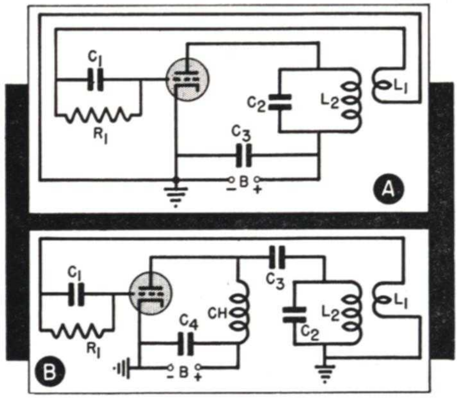


FIG. 10. Series-fed (A) and parallel-fed (B) versions of the tuned-plate oscillator.

The circuit in Fig. 10A is called "series fed," because the plate B supply reaches the tube through the tank circuit. The tank circuit has the B supply voltage between it and ground, so the tuning controls must be insulated.

To provide a more direct ground to the tank, the "parallel-fed" arrangement shown in Fig. 10B is sometimes used. Here, the d.c. supply path is through the choke coil CH. Changes in plate current produce an a.c. voltage across this coil. This voltage is fed to the tank through blocking condenser C_3. The tank and the choke coil CH are in parallel as far as a.c. is concerned, because the choke is grounded for a.c. by condenser C_4. Since the tank impedance is far less than that of the choke, the net impedance of the parallel combination is essentially that of the tank; therefore, the tank still acts as the load for the stage. Since the tank is now directly grounded, there is no d.c. voltage between it and ground.

There are several reasons for using a ground connection in an oscillator If you bring your hand near an ungrounded resonant circuit, body capacity effects will change the frequency. Furthermore, an ungrounded oscillator may radiate to cause interference with other receivers. The portion of the circuit that is grounded (directly or through a by-pass) ceases to radiate because there is then no impedance between that point and ground across which a radiating signal would be developed.

Although the ground could be at any point, it is customary to ground the B power supply. If possible, this ground is made at the tube cathode, because the grounded cathode will act as a shield around the filament to keep down energy leakage to that circuit. Then, if possible, the tank circuit will also be grounded so that common tuning controls can be used for the oscillator and other circuits without there being any interaction between them.

Returning now to our basic circuits, let's compare the tuned plate oscillator with other types.

Tuned-Grid Oscillator. We can obtain oscillation by putting the resonant circuit in the grid circuit and moving the tickler to the plate circuit. This forms the tuned-grid oscillator shown in Fig. 11A. When this circuit is turned on, changes in the plate current induce a voltage from L_1 into L_2. This induced voltage charges condenser C_2, starting the oscillatory discharge in the tank circuit L_2-C_2. The voltage across C_2 becomes the grid voltage.

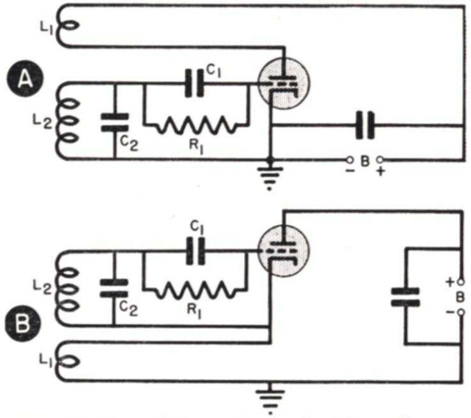


FIG. 11. Two "different" tuned-grid oscillators.

While the plate current is increasing, the induced voltage will be in such a direction that the charge across C_2 will make the grid more positive, thus increasing the plate current. On the other hand, when the plate current starts to decrease, the voltage across C_2 drives the grid negative, thus cutting off the plate current.

The "load" in the plate circuit of the tube is a reflected impedance. As you know, across any standard r.f. transformer, the secondary reflects on the primary according to the mutual inductance between the coils. Therefore, the tank circuit L_2-C_2 appears in the plate circuit as a load, and continues to act as before in setting the peak plate current value.

Fig. 11B shows a variation on the basic tuned-grid circuit. The feedback coil has been moved. However, by tracing the complete plate circuit from the plate to the B supply and through L_1 to the cathode, you will see that coil L_1 is still in the plate circuit, although it is now between the cathode and B— instead of between the plate and B+. It is just as effective in this position as it was between the plate and B+ in inducing a voltage in coil L_2. Thus, this circuit is still a tuned-grid oscillator.

Hartley Oscillator. In the oscillator known as the Hartley (named for its inventor, as are several others), there is no separate tickler winding; instead, the tank coil is used as an auto-transformer to supply the grid excitation.

If you will return to Fig. 11B, you will notice that one end of each coil is connected to the cathode. We can get the same arrangement by using a single tapped coil and connecting the tap to the cathode. This is basically what is done in the Hartley oscillator in Fig. 12A. Here the entire tank coil L_1, tuned by condenser C_2, has the oscillatory current developed within it because of plate current changes in the section 2-3 of L_1. Now, however, only a portion of this tank voltage is applied between the grid and cathode of the tube, because only the portion of the coil between points 1 and 2 is actually connected in the grid circuit. The section between points 2 and 3 is in the plate circuit and provides the feedback.

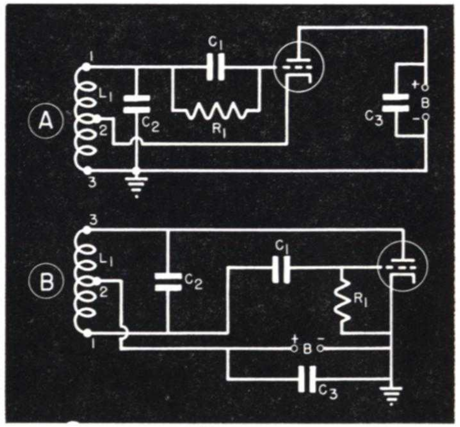


FIG. 12. Two variations of the Hartley oscillator.

Since the tap at point 2 can be placed where desired, it is possible to adjust the amount of feedback within limits. Moving the tap toward point 1 increases the size of the feedback coil section but also decreases the number of turns in the grid circuit and hence reduces the proportion of the tank voltage that is fed to the grid of the tube. Therefore, we can increase the feedback only so far; if we move the tap too close to point 1, the amount of grid drive will eventually stop increasing and start to decrease. (Incidentally, don't try to count the number of coil loops on a schematic diagram to learn where the tap is placed in a Hartley oscillator; the exact location is never shown.)

Although we developed the Hartley from our tuned-grid circuit, we did so purely to make it easier to understand. Actually we can no longer consider this to be exactly a tuned-grid oscillator, because it is quite possible for most of the tank to be in the plate circuit; however, the part of the tank that is in the plate circuit is used only to secure feedback. In fact, you can always recognize the Hartley oscillator from the fact that the tank coil has a tap so positioned that part of the tank is in the grid circuit and part is in the plate circuit.

Fig. 12B shows one of the variations of this Hartley oscillator. If you will trace from the plate of the tube through coil L_1 and the B supply, you will see that the circuit is essentially the same as that of Fig. 12A except that the plate supply is on the other side of the feedback coil.

Notice that the grid-leak resistor R_1 is connected directly between the grid and cathode. If this resistor were connected directly across C_1, as it is in other circuits, the B supply voltage would be applied through this resistor to the grid of the tube. The bias action is still the same—grid current through R_1 sets up a voltage that charges C_1 through the path C_3-L_1. When grid current does not flow, the bias is maintained by a partial discharge of C_1 through R_1. Incidentally, you will find this positioning of R_1 used sometimes even when the B supply connections do not require it.

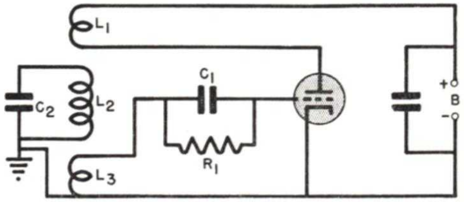


FIG. 13. The Meissner oscillator.

Meissner Oscillator. In Fig. 13 we have another basic oscillator, known as the Meissner. In this circuit, the tank circuit L_2-C_2 has no direct connection to either the grid or the plate circuits—instead it is in the feedback loop. Variations in the plate current in coil L_1 induce a voltage in tank coil L_2 to start the oscillatory current. In turn, this oscillatory current induces a voltage in coil L_3 that acts as the grid voltage on the tube.

Except for the unique manner of arranging the tank circuit, and the use of an additional feedback coil, this circuit is like the others we have just described and operates the same way. The use of the double tickler permits two adjustments to be made: the amount of energy transferred to the tuned circuit can be varied by adjusting the coupling between coil L_1 and coil L_2, and the grid excitation can be

STEAM POWERED RADIO.COM

regulated separately by adjusting the coupling between L_3 and L_2.

OSCILLATORS USING CAPACITIVE FEEDBACK

You have just studied several oscillators in which feedback is secured by using a coil. Let's take up some others in which capacitive feedback is used.

Colpitts Oscillator. The oscillator shown in Fig. 14 resembles the Hartley except that a capacitive divider is used instead of a tapped coil to supply feedback. Compare this circuit with that in Fig. 12A.

In Fig. 14, the tank coil L_1 is tuned by the condensers C_2 and C_3 in series. The grid excitation voltage is developed across C_2, and the plate feedback voltage is developed across C_3. The choke coil CH in this circuit is necessary to complete the B supply circuit: if it were not there, the cathode circuit would not have a d.c. path from the junction of the two condensers to B—.

When the circuit starts operating, the change in plate current through choke CH produces a voltage across it that is also across C_3 and is thus applied to the tank circuit to start oscillations. The feedback voltage is developed across C_2; its amount depends on the capacities of C_2 and C_3. Making C_2 larger reduces its reactance and therefore reduces the grid excitation, whereas making C_2 smaller increases the excitation. Changing the size of C_3 changes the feedback in the same way.

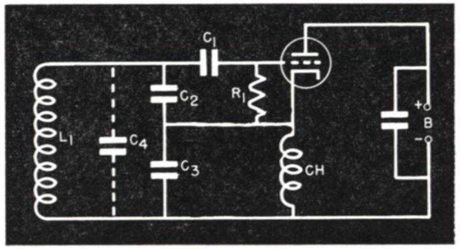


FIG. 14. The Colpitts oscillator.

If either condenser is changed to adjust the feedback, the other one must be changed in the opposite manner to maintain the desired frequency of oscillation. This inter-relationship between the feedback adjustment and the tuning of the circuit is normally avoided by adding the condenser C_4 and using it as the tuning condenser, making the tank circuit consist of C_4 and L_1. Condensers C_2 and C_3 are then made very small and act as a capacitive voltage divider across tank tuning condenser C_4. Once these capacities have been set to give the proper feedback relationship, they remain fixed, and the circuit is tuned by adjusting C_4.

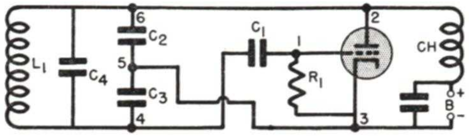


FIG. 15. A variation of the Colpitts oscillator.

Fig. 15 shows another variation of the Colpitts. Although it looks different, a careful comparison of this circuit with that in Fig. 14 will show you that they are basically the same. The plate is connected directly to one end of the tank coil instead of being connected to it through the B supply, and the choke coil is moved from the cathode circuit to the plate circuit. The plate current change through CH sets up a feedback across C_2 here, and C_3 is the grid condenser; just the opposite of Fig. 14.

The Ultra-Audion. The oscillator shown in Fig. 16 was used a long time before its operation was fully understood. For this reason, it has a different name, although, strictly speaking, it is just another form of the Colpitts oscillator. At first glance, it appears that the tank circuit L_2-C_2 is connected between the grid and the plate of the tube. It appears that the tank provides the feedback path, and this was believed for a long time. However, once you draw in the internal tube capacity C_{PK} between the plate and cathode and the capacity C_{GK} between the grid and cathode, you will see that the internal tube capacities actually form the capacitive voltage divider of the standard Colpitts circuit. That is, the capacity C_{PK} between points 2 and 3 in Fig. 16 corresponds exactly to condenser C_2 in Fig. 15, as you will see by tracing the path from 2 to 6 to 5 to 3. Similarly, the grid-cathode capacity C_{GK} between points 1 and 3 corresponds to condenser C_3 in Fig. 15 (path 1-4-5-3).

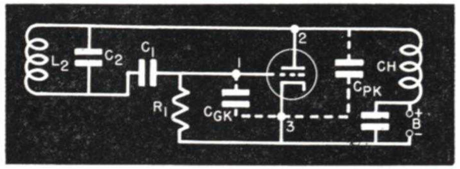


FIG. 16. The Ultra-Audion oscillator.

The fact that the internal tube capacities are the determining factors is proved by the operation of this circuit. It works only at high frequencies where these tube capacities have sufficiently low reactance to permit the proper feedback.

Since these tube capacities are fixed by the design of the tube, it is important to choose the right tube. Some variations of this circuit have an additional small condenser between the grid and cathode, or between the plate and cathode. Its capacity adds to the corresponding internal tube capacity, and it is chosen to adjust the feedback.

Since this circuit does not work very well in the standard broadcast band, it is used only in short-wave radio receivers. It is used rather commonly in television receivers as the local oscillator. At the high frequencies of the television bands, (from 50 to approximately 215 megacycles), it proves very satisfactory.

Both the Colpitts and the Ultra-Audion can be recognized by the facts that the tank circuit is effectively between the grid and plate of the tube and that the voltage division is provided by capacities that are either actual condensers or internal tube capacities.

Fig. 17A shows one Ultra-Audion that, at first, looks like a tuned-grid oscillator. However, there is no tickler coil coupled to L_1. Further, the plate is effectively grounded by C_2, and therefore it returns to the grounded end of the tank. Redrawing the essentials of the circuit (Fig. 17B) proves it to be an Ultra-Audion.

Similarly, Fig. 17C looks like a tuned-plate circuit, but again the absence of a tickler coil shows that it is not. Here, the grid returns to ground through grid condenser C so the essential circuit is the one shown in Fig. 17D.

Incidentally, don't confuse the choke coil CH with a tickler. If it were a tickler, it would be drawn next to the tank coil to indicate coupling.

Push-Push Oscillator. Fig. 18 shows our last basic type of receiver oscillator. Although two separate tubes are shown here, a single dual-triode tube is generally used for this kind of oscillator. This is called a "push-push" circuit because the tubes supply energy alternately to the tank. There are sev-

STEAM POWERED RADIO.COM

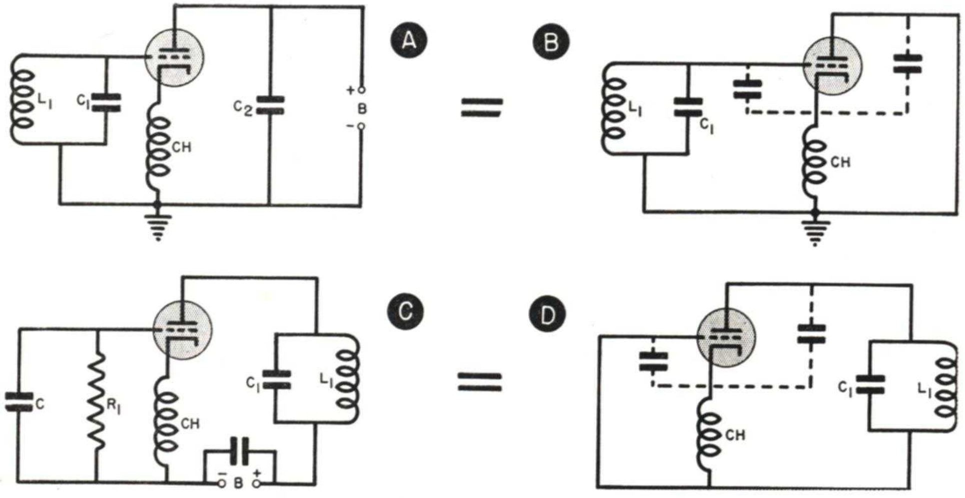


FIG. 17. Two variations of the Ultra-Audion oscillator (A and C). These are more readily recognized when the internal tube capacities are drawn in (B and D).

eral variations of this circuit, but the one shown is the most common. For identification, this circuit is considered to be a tuned-plate oscillator because the tank circuit is in the plate circuit of the two tubes. However, there is no tickler coil. The only items in the grid circuit are the grid-leak resistors and the feedback condensers, which also act as the grid condensers. Here is how the circuit works:

When the circuit is first turned on, one tube will begin drawing current before the other and will set up the first oscillation in the tank circuit C_1-L_1. Let us suppose that the first oscillation produces a voltage across the coil L_1 such that the end connected to the plate of VT_1 is positive and the end connected to the plate of VT_2 is negative with respect to the center tap.

The positive pulse applied to the plate of VT_1 is fed back through C_2 to the grid of the opposite tube VT_2, making VT_2 conduct. Simultaneously, the negative plate pulse of VT_2 is fed through C_3 to the grid of VT_1, cutting VT_1 off. On the next swing in the tank circuit voltage, the tank polarity reverses; now VT_1 conducts, and VT_2 is cut off. Thus, the tubes alternate in supplying energy to the tank circuit.

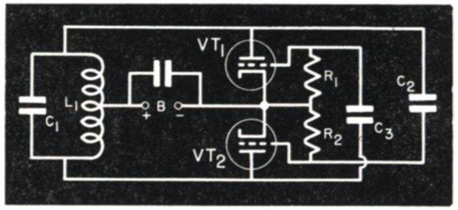


FIG. 18. Tuned-plate push-push oscillator.

Because one or the other tube is working on each half cycle, the tank circuit gets pulses of energy on each half-cycle of its oscillation rather than once in each cycle.

This particular circuit is favored at high frequencies and in television receivers, as we shall soon see.

STEAM POWERED RADIO.COM

Local Oscillators as Used in Receivers

It is possible to use any of the basic oscillators we have just studied, or any of their many variations, as the local (frequency-converting) oscillator in a receiver. Certain practical factors, however, have limited the choice of oscillators to a few basic types. In sound (a.m. and f.m.) receivers today, the tuned-grid and the Hartley are the favorites. The Meissner circuit will be found in some older sets. In television sets, the local oscillator is almost universally an Ultra-Audion or a push-push circuit. Of course there are exceptions—there are a few Hartley circuits used in television, and certain f.m. receivers use the Ultra-Audion. Let's take a look at a few practical circuits.

OSCILLATORS FOR A.M. RECEIVERS

In the early days of radio, the local oscillator and the first detector were separate stages using different tubes. Modern a.m. broadcast receivers, however, almost always contain a pentagrid converter stage in which both functions are combined. The stage is given this name because the tube used in it has five grids (penta means five) and because it converts an r.f. signal to an i.f. signal, acting as both detector and oscillator.

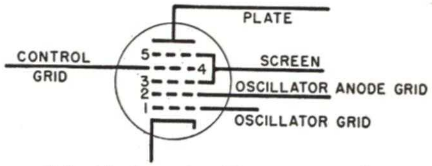


FIG. 19. A pentagrid converter tube.

The arrangement of the elements in a typical pentagrid converter tube is shown in Fig. 19. The grids are numbered consecutively, starting from the cathode and moving toward the plate. The first grid is the oscillator control grid. The second grid is called the anode grid because it acts as a plate in the oscillator circuit. Grids 3 and 5, which are connected within the tube, form the screen grid. Grid 4 is the control grid for the first-detector portion of the tube.

Fig. 20 shows a diagram of a typical pentagrid converter. You can see that the oscillator portion of the circuit is a standard tuned-grid oscillator if you consider grid 2 to be a tube plate. The tank circuit L_1-C_1 is in the grid circuit, and grid-leak bias is furnished by R_1 and C_2. The feedback coil L_2 is connected between the B supply and the anode grid.

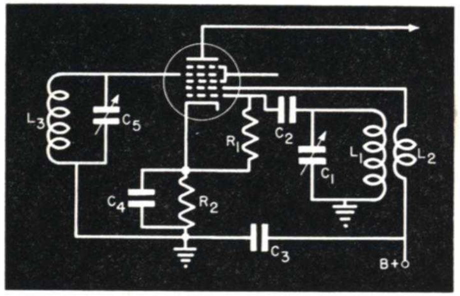


FIG. 20. A typical pentagrid converter oscillator circuit.

You will observe that grid 2 is supplied with a positive potential, just as any tube plate would be, and that its current flow through L_2 provides feedback. A grid is used as the plate here, because it is not solid and will therefore intercept only a few of the electrons in the main cathode-to-plate current—enough to sustain oscillations, but not enough to cause a serious reduction in the plate current of the tube.

The oscillator signal applied to grid 1 causes the plate current of the tube to vary at the oscillator frequency. The incoming r.f. signal applied to control grid 4 also causes plate current variations. As a result, these signals are mixed within the tube. Since the mixing occurs in the electron stream, this process is called *electronic mixing.*

In Fig. 20, resistor R_2, by-passed by C_4, furnishes the detector bias for control grid 4. This bias is set by the average plate current to the proper value to produce detector action. The oscillator grid is biased additionally by the action of R_1 and C_2.

The tube shown in Fig. 20 is of the very widely used 6A8 tube family. Fig. 21 shows a pentagrid converter stage in which a 6SA7 type is used. This tube also has five grids, but they are connected differently: 1 to the oscillator control grid, 2 and 4 (internally connected) make up the screen, 3 is the first-detector control grid, and 5 is a suppressor.

A Hartley oscillator is used in this stage. Notice that grid 1 is connected through C_2 to one end of the tank, the cathode of the tube is connected to a tap on the tank, and grid 2, which acts as the oscillator anode, is connected through by-pass condenser C_3 to the other end of the tank. (Follow the path through the ground from C_3 to the tank.) The action of this circuit is practically the same as that of the one in Fig. 20 except that here the oscillator "plate" is also the screen grid. The electron stream from the cathode to the tube plate is modulated by grid 1 at the oscillator frequency and by grid 3 at the incoming signal frequency.

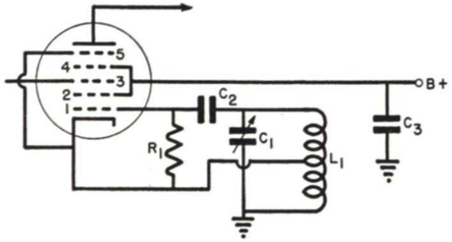


FIG. 21. A 6SA7 type pentagrid converter.

Injection Coupling. A difficulty of the pentagrid-converter tubes is that a certain amount of coupling exists in them between the oscillator and the tuned circuit of the first detector. This is no problem at broadcast-band frequencies, but it becomes one at the high frequencies used for short wave, f.m., and television. For this reason, some modern receivers produce signal conversion by using an arrangement like that shown in Fig. 22, which produces a minimum of undesirable coupling. Here VT_2 is the oscillator; its output is applied through a tap on the tank coil L_1 to grid 1 of VT_1, the first detector. Although VT_1 looks schematically just like a pentagrid converter, it is instead a pentagrid-mixer—one of a class of tubes specifically designed to have a minimum of coupling between grid 1 and control grid 3. Grid 1 is called an injector grid, because it "injects" the oscillator signal into the electron stream of the tube.

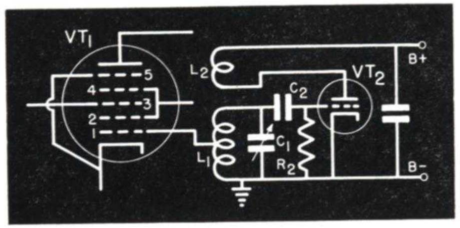


FIG. 22. An injection circuit.

OSCILLATORS FOR F.M. RECEIVERS

Although the f.m. tuning band is rather high in frequency—between 88 and 108 megacycles—an a.m.-f.m. combination set generally uses the same oscillator for both services. When the set is switched from one to the other, of course, the tank circuit L and C values are changed so that the oscillator will produce the proper frequency.

In straight f.m. receivers (those that tune only to the f.m. band, or that have separate tuning circuits for the f.m. band), it is standard practice to use a separate oscillator tube. The Hartley, tuned grid, and Ultra-Audion are the most popular circuits for such sets (in that order).

OSCILLATORS FOR TELEVISION RECEIVERS

Television receivers use the push-push circuit or the Ultra-Audion exclusively, except for a very few that use the Hartley. These oscillators are preferred because they are best suited to the high frequencies (up to about 216 mc.) used for television.

We shall go into the reasons for choosing a particular oscillator for a particular application in more detail in a moment. Before we can do so, however, we must learn more about the tuning requirements of oscillators, because the tuning range required is one of the important factors governing the choice of an oscillator.

TRACKING AND PADDING

To produce the i.f. (intermediate frequency) in a superheterodyne, the oscillator frequency must differ from that of the desired incoming signal by the amount of the i.f. It is standard practice to have the oscillator frequency higher than that of the incoming signal, but it is just as possible to make it lower as long as the proper tuning range can be obtained.

As a practical example, a standard a.m. receiver uses an i.f. of 455 kc. If we are trying to tune in a broadcast station at 1000 kc., the oscillator circuit is adjusted to 1455 kc. When this signal of 1455 kc. is mixed with the 1000-kc. incoming signal, the difference, or 455 kc., will be produced as the i.f.

To tune over the standard broadcast band from 550 kc. to 1500 kc. and produce a 455 kc. i.f., the oscillator must tune over a frequency range of 1005 kc. to 1955 kc. All standard modern radio receivers use a single tuning control, so the oscillator tuning must be varied over this range in step with the adjustment of the first detector and r.f. preselector stage (if the latter is used).

As you know, we can tune the oscillator by varying either the inductance or the capacity in the tank circuit. Both methods are used in modern receivers. For example, suppose the oscillator is tuned by one section of a tuning condenser gang having identical sections. To get the oscillator frequency above that of the incoming signal at the high end of the tuning band, the oscillator coil has less inductance than the preselector coils. However, as we tune toward the low end of the band, the oscillator and preselector frequencies will gradually approach each other when identical tuning condensers are used, so we won't get the proper i.f. frequency. (We'll learn more about this in another Lesson.) Hence, we must make the oscillator tuning capacity vary so that it is less than that of the other sections as the low-frequency end of the band is approached, in addition to using less inductance.

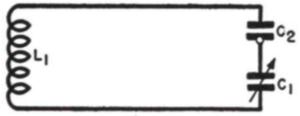


FIG. 23. How a padder condenser is used.

We can achieve this result by using a supplementary condenser, known as a padder, in the oscillator tank, arranging it as shown in Fig. 23. Here,

STEAM POWERED RADIO.COM

condenser C_1 is the regular tuning condenser and L_1 is the tank coil of the oscillator. Padder condenser C_2, a rather large capacity, is added in series with C_1. As you know, the capacity of condensers connected in series is less than that of the smallest condenser in the group. Therefore, by connecting the padder condenser in series with the tuning condenser, we have effectively reduced the capacity in the oscillator tank circuit, making the circuit tune to a higher frequency for a particular C_1 setting. If the coil and the padder condenser have the proper values, the oscillator will automatically tune to a frequency the desired amount above the frequency of the incoming signal at all settings of C_1.

This padder-condenser arrangement is used only when C_1 is exactly the same as the other sections of the tuning condenser gang. Another way of keeping the oscillator frequency higher than that of the incoming signal is to use a tuning condenser having specially-cut plates in the oscillator section. In such a tuning condenser, the rotor plates of the oscillator section are smaller than the rotor plates of the preselector and first detector sections, so the oscillator condenser automatically has less capacity at all positions of the tuning condenser control, and no padder is needed. Careful design of the shape of the plates makes it possible to keep the oscillator frequency above the incoming frequency by the required amount.

Of course, none of these methods tracks perfectly, so trimmer condensers —small adjustable capacitors—are connected across the sections of the tuning condenser gang so that small adjustments can be made to improve the tracking.

WAVE-BAND CHANGING

Once the oscillator circuit is arranged to produce the proper frequency above the desired incoming frequency, it is then necessary only to change the tuning control to adjust it to any desired incoming signal within the band limits. The frequency range to which a receiver may be tuned depends on the maximum and minimum values of the adjustable control. If a tuning condenser is used, its maximum capacity determines the lowest frequency and its minimum capacity the highest frequency; if the coil is the variable item, the maximum and minimum inductances determine the lowest and highest frequencies. Because the frequency to which a tank circuit will tune depends upon the square root of the L-C product, a 9-to-1 change in the variable will produce only a 3-to-1 change in the frequency. That is, if either the inductance or the capacity is reduced to one-ninth its maximum value, the highest frequency will be only three times the lowest frequency value.

The lowest frequency wanted for a particular band determines the maximum coil and condenser values that must be used.

Of course, there are many possible combinations of coil and condenser values that will all tune to a particular frequency. The values chosen must give a desirable L to C ratio, have reasonable Q, and provide the desired tuning range. The L-C ratio determines the load value—for example, with a tuned-plate circuit, the higher the inductance, the higher the load impedance for the same Q. However, we must not go too far because high inductance necessitates low tuning capacity and introduces a restriction on the tuning range. Further, the oscillator values are limited by the design requirements of the preselector and first detector circuits, because their L and C values set the starting points for the oscillator circuit.

The shunting effects of distributed capacity, stray circuit capacity, and the internal tube capacities make it necessary to use a larger tuning capacity to get a wide band width. For example, let's suppose we have a 400-mmfd. tuning condenser having a minimum capacity of 25 mmfd. This is a 16-to-1 ratio of maximum to minimum. A tank circuit in which this condenser is used may well have shunting capacities of as much as 15 mmfd., which add to both the maximum and minimum values. Our capacity range is now 415 to 40, or only about 10-to-1 instead of our original 16 to 1.

With a 200-mmfd. maximum and a 12.5-mmfd. minimum, we can again get a 16-to-1 range. However, if we now add the same 15-mmfd. shunting capacity, our values become 215 to 27.5,—only a 7.8-to-1 range. Obviously, we get a wider tuning band by using a larger tuning condenser; for this reason, fairly large condensers are used in a.m. sets intended for the broadcast band. However, when a short-wave band is to be covered, the tuning condenser must be smaller to permit reasonable inductance values. This compromise means that a 3-to-1 frequency range (9-to-1 capacity range) is about the best we can expect.

One reason oscillators using capacitive voltage dividers are more common in high-frequency receivers, such as f.m. and television sets, is that such circuits have less shunting capacity. The inductance of a feedback coil is reflected into the tank as additional shunting capacity; eliminating this coil thus reduces the shunting effects somewhat.

Also, tickler resonance becomes a worse problem at the higher frequencies; if it occurs, the oscillator may "lock-in" to its frequency and be uncontrollable. Finally, eliminating tickler coils means that fewer switch contacts are needed in the band-switching arrangement of the set. This last is a desirable feature because switch contacts frequently give trouble at very-high frequencies.

Thus, you may find almost any oscillator in a set designed only for the broadcast bands; certain types are more apt to be used if the set can receive short waves also; and, in f.m. and television sets, you generally will find only capacitive-feedback oscillators.

It is interesting to note that the push-push circuit reduces the effects of tube capacities by having the two tubes effectively in series across the tank insofar as shunting effects go. This reduces the total tube capacity to one-half that of a single tube. (The total capacity of equal condensers in series is half that of one of them.) This accounts in part for the popularity of this circuit at high frequencies.

PRACTICAL WAVE-BAND SWITCHING

Fig. 24 shows the two standard methods of changing the frequency band, both of which change the tuning inductance. In one, a different coil is switched in for each band.

In the other, the tuning coil is tapped, and a switching arrangement is used to disconnect a certain number of

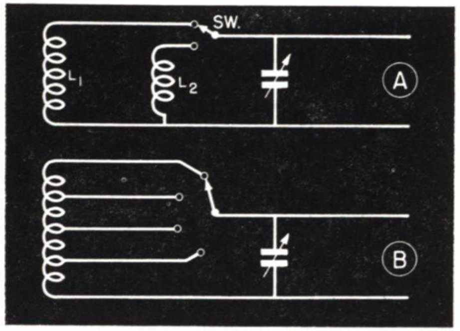


FIG. 24. Two basic wave-band switching circuits.

STEAM POWERED RADIO.COM

turns (thus reducing the inductance) when a higher-frequency band is wanted.

Both these methods are in use in a.m. sound receivers and combination a.m.-f.m. receivers. In sets in which the f.m. oscillator circuit is used for both same oscillator circuit is used for both a.m. and f.m. bands, however, it is common practice to change the tuning condenser on the f.m. band to a smaller size also so that a practical inductance value can be used with it.

Of course, in the straight f.m. radio, or in those using separate tuning units for the f.m. bands alone, the coil and condenser combination is designed to cover the entire f.m. band. This is not too difficult, as the frequency range from 88 to 108 mc. is only 1.23 to 1.

Television presents a different problem, because television station channels are not arranged in continuous bands. There is an a.m. channel every 10 kc. in the broadcast band. In television however, there may be a gap of 10 mc. or more between stations. (As a matter of fact, when you tune from channel 6 to channel 7 on a television set, you skip over the entire f.m. band as well as the bands covered by several other services.) Therefore, what amounts to a wave-band changing arrangement is used in most television receivers to switch from station to station.

Now, let's study some practical diagrams of oscillator circuits in which wave-band switching is used.

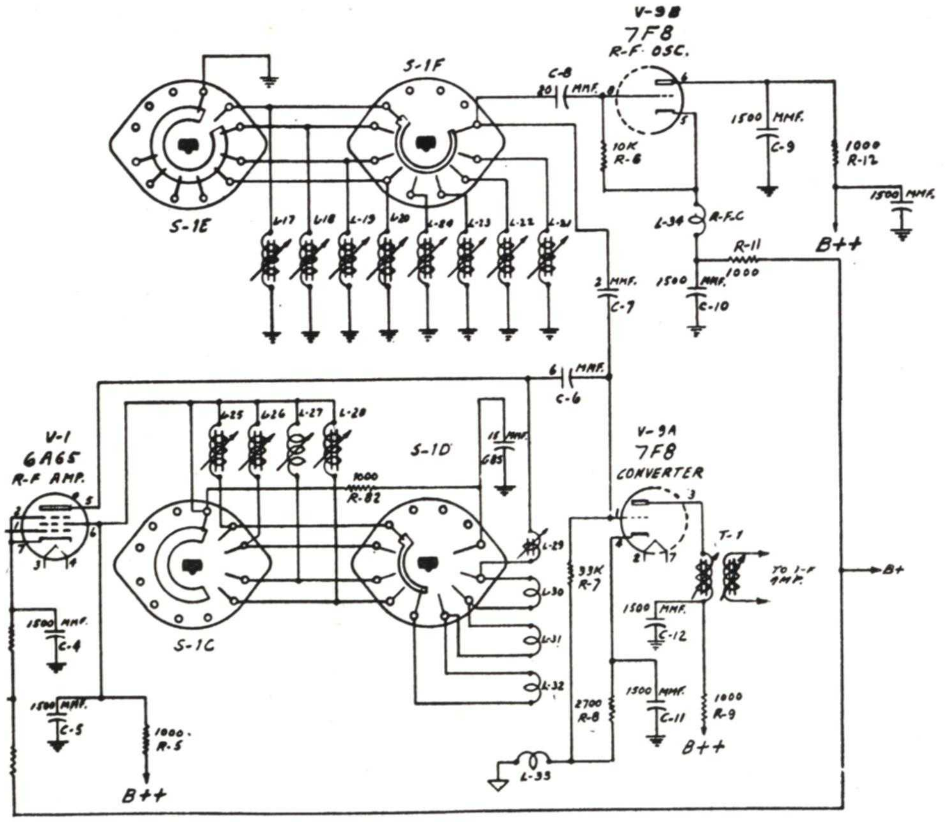


FIG. 25. The oscillator and converter sections of the wave-band switching arrangement in a Motorola television set.

STEAM POWERED RADIO.COM

TYPICAL SWITCHING DIAGRAMS

Wave-band switching diagrams are complicated by the fact that draftsmen frequently try to show the mechanical appearance of the switch. This makes it harder to read the schematic, but, on the other hand, makes it somewhat easier to locate connections in the receiver. Fig. 25 shows a typical schematic. We are using a television set in this example, but the same style of drawing will be found on schematics of a.m. or f.m. receivers.

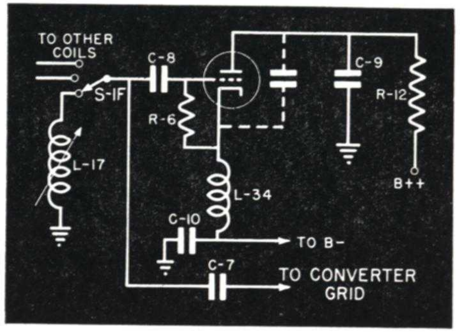


FIG. 26. Oscillator circuit of the set shown in Fig. 25.

In Fig. 25, we have reproduced both the oscillator and converter switches —similar switches are also used in this receiver in the r.f. amplifier. Let's concentrate on the oscillator.

In this diagram, the oscillator switching sections are the sections S-1E and S-1F. S-1E is a shorting switch; its purpose is to short-circuit completely coils that are not connected in the circuit by switch S-1F. This arrangement is used to prevent any coil from becoming self-resonant and absorbing energy from the oscillator circuit. This prevents undesirable loading of the oscillator.

Switch S-1F permits any one of the coils L-17 through L-24 to be selected. Coil L-17 is shown connected in the diagram.

The essentials of this oscillator circuit are shown in Fig. 26. As you can now see, with the switch S-1F in the position shown, coil L-17 is the tuning inductance. It is variable, as indicated by the tuning symbol, so that a final adjustment can be made by varying the core position. As the switch is set to other positions, other coils, and hence other tank circuits, are connected to the oscillator. Stray capacities that exist across the tank coil and in the switch, together with the distributed capacity in the coil make up the tank circuit "condenser." These capacities, though small, are sufficient for the television channels.

In Fig. 26, coil L-34 is just a choke coil. The plate of the tube is essentially grounded through condenser C-9, so in effect it is connected to the end of the tank coil. Condenser C-8 and resistor R-6 are the grid leak and condenser. Condenser C-7 serves as the coupling condenser to couple the oscillator energy to the converter tube grid for mixing with the incoming signal.

If we now draw in the internal capacities of the tube (Fig. 27), we find this to be an Ultra-Audion oscillator. The tank circuit consisting of L-17 and stray capacity C is effectively between the grid and plate. The amount of feedback is determined by the internal tube capacities. To assist in producing feedback, some of the later models of this set had an additional condenser, shown in Fig. 26 by dotted lines, connected between the plate and cathode.

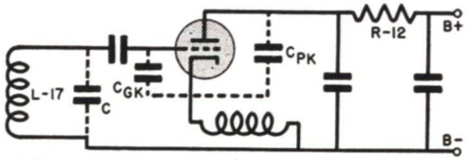


FIG. 27. Drawing in the internal tube capacities shows the circuit in Fig. 26 to be an Ultra-Audion.

Fig. 28 shows another circuit and a different way of showing the wave-band switching. Once again we have chosen a television set for our example.

You will notice at once that there are three different tuning circuits, which look somewhat alike. The manufacturer's labeling tells us that tube V1 is the r.f. amplifier, so the tuning circuit connected to it must be the preselector. Tube V2, at the center, is the converter; this identifies the corresponding tuning unit. Tube V3 is the oscillator.

If the manufacturer hadn't labeled the circuits so conveniently, we could identify the oscillator by its connections. Notice that the r.f. amplifier tube is connected to the antenna circuit and the converter tube is connected to the i.f. amplifier. Since the oscillator is never connected to either of these circuits, the remaining tube must be the oscillator.

An examination of this oscillator circuit shows it to be a tuned-plate, push-push oscillator. The wave-band switching arrangement is very clear here. As the switch is moved along from position 1 at the left toward position 13, it short-circuits sections of the tank coil. When the switch is in position 1, as shown in the diagram, the tank coil consists of all the coils from plate 1 of tube V3 starting at L77 through L53, L54, and all the intervening coils through L78 to plate 2 of this tube. This entire string of inductances is tuned by the fine tuning control C15. The B+ connection is made through resistor R7 to what amounts to the coil center tap. Feedback is through a link coupling coil between this oscillator inductance string and the grid coil of the converter tube. As you can see, this circuit is like the one shown in Fig. 18 if we consider the string of inductances to be one coil.

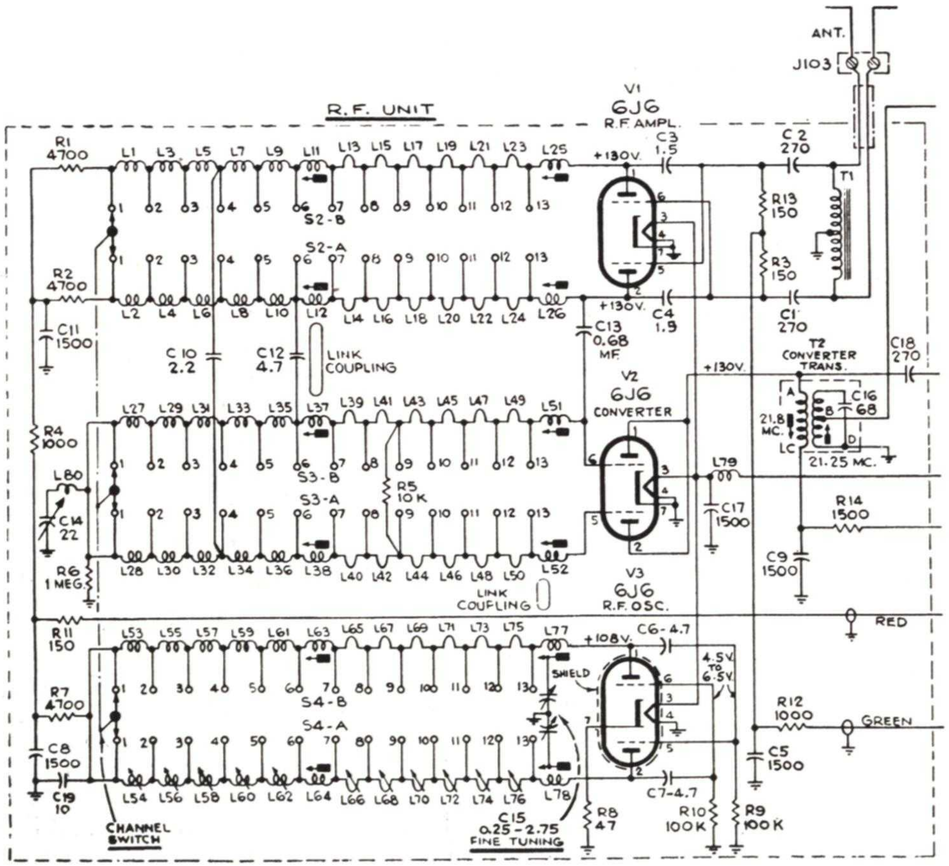


FIG. 28. R.F. amplifier, converter, and oscillator sections of an RCA television set.

STEAM POWERED RADIO.COM

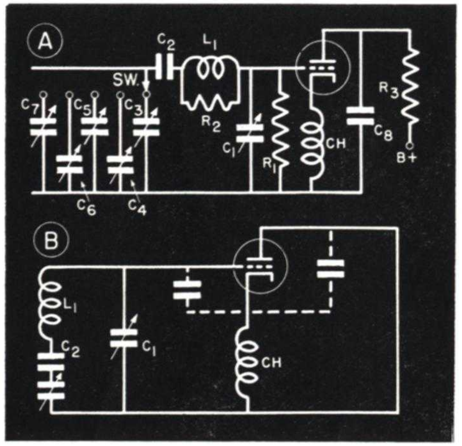


FIG. 29. Wave-band switching system in which the oscillator frequency is changed by changing the tuning condenser.

As the wave-band switch is moved toward position 13, the inductance in the tank circuit is reduced, making the oscillator tune to higher frequencies. The inductances are chosen so that the set tunes to the television stations and skips over the undesired in-between bands.

Fig. 29A shows a circuit in which the frequency is changed by switching in the proper condenser C_3 to C_7. The actual tank, therefore, consists of coil L_1, the tuning condenser C_1,—one of the condensers C_3 to C_7, and the blocking condenser C_2. Once this circuit is redrawn (Fig. 29B), we find that the oscillator is an Ultra-Audion.

Although we have chosen television receivers in our examples of wave-band switching and tuning methods, the same principles apply to a.m. and f.m. sound receivers. In general, when you are analyzing the circuit diagram of a set you are servicing, you need to concentrate only on the circuit that is defective. If you have a defective oscillator, you must wade through the wave-band switch connections to determine just what circuit is being used. However, if the trouble is elsewhere, there is no reason to worry about the oscillator unless you are curious about its operation.

Service Hints for Oscillators

In this Lesson, we shall not attempt to cover completely the subject of how to service defective oscillator stages. Instead, we shall point out the most common oscillator defects so that you can learn what they are while the theory of oscillators is fresh in your mind.

FREQUENCY DRIFT

You have learned that the oscillator is supposed to operate above the incoming signal frequency by a fixed amount. Therefore, the oscillator must produce one particular frequency when the tuning dial is set at a particular point. The manufacturer adjusts the circuit so that it does so when the set leaves the factory. Unfortunately, however, aging of the set may cause changes in the inter-electrode capacity of the oscillator tube, changes in the tank circuit Q, and changes in the supply voltage; heat may warp condenser plates or cause shifts in the positions of coil wires, thereby causing changes in the capacity and inductance of the circuit; and any or all of these effects may cause the frequency of the oscillator to drift from what it should be at any specific setting of the tuning controls.

Any such changes that have gradually developed over a long period of time can be compensated for by replacing the tube and correcting operating voltages if these are at fault, or by re-adjusting the trimmer condensers if the circuit constants have changed slightly.

Certain f.m. and television receivers use temperature-compensating parts, which are usually fixed condensers whose capacities change as the temperature varies. It is possible to make them so that they will either increase or decrease in capacity as the temperature increases. Such parts are used to compensate for the actions of other parts in oscillator circuits. For example, if the capacities of other parts in a circuit tend to increase as the temperature rises, use of a condenser whose capacity decreases with temperature will make the overall capacity relatively constant and so keep the frequency fairly well fixed.

DEAD OSCILLATOR

Most radio stages will work to some extent if the applied voltages become less than the design values. An oscillator stage may stop altogether, however, if the plate or filament voltage drops appreciably, especially if the coupling to a feedback coil is kept at a low value by design, if the tank circuit has low Q (is heavily loaded), or if the grid resistor is fairly high in value. For this reason, you should make careful voltage readings on a dead oscillator stage and compare them closely with those given in the manufacturer's service notes.

Most receivers (see Fig. 30) contain a resistor R_1 in series with the anode grid (or plate) of the oscillator to stabilize the plate voltage. The plate current, flowing through R_1, provides a voltage drop. Now, should anything happen to reduce the B+ voltage, the plate current will drop; this will reduce the drop across R_1 and so tend to keep the anode voltage more nearly the same.

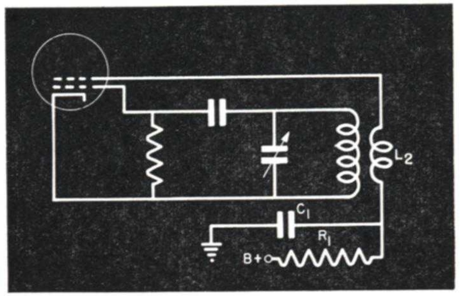


FIG. 30. Use of a stabilizing resistor to keep the plate voltage of an oscillator stage constant.

A reduction in filament voltage is not likely in a standard a.c. receiver that uses a power transformer. However, in a.c.-d.c. and battery receivers that use series filaments, an increase in the series resistance may reduce the filament voltage on the oscillator tube so much that oscillation stops. In many of the modern three-way portable (a.c.-d.c.-battery operated) receivers, the filaments of several of the tubes (including the oscillator) operate from the plate current of the power output tube when the set is operating from a power line. A typical arrangement is shown in Fig. 31. As you can see, the plate current of power output tube VT_1 flows through the filaments of the other tubes. This is an efficient arrangement, because the plate current flow is enough to heat the filaments of the other tubes, which are of the low-current battery type, and the drop across these tube filaments biases the output tube.

However, should anything happen to reduce the plate current of VT_1, the voltage developed across the series tube filaments will fall. The oscillator tube may be critical about this. In such cases, you may find that the set works satisfactorily on batteries, where the tube filaments are connected in parallel, but fails to work when power line operation is tried. In such cases, suspect the oscillator stage and check carefully on the filament voltage.

An oscillator may fail, particularly at the low end of its tuning range, if the tank circuit resistance increases, reducing the Q of the tank. If the tank Q is reduced, the voltage across the tank is reduced and hence the feedback falls off. The most common reason for a reduced Q is a poor connection at a coil or tank condenser terminal. Occasionally it is caused by the oscillator coil's having absorbed moisture.

Of course, any defect such as a bad oscillator tube or an open feedback coil will kill the oscillator stage. These are, in fact, among the most common causes of oscillator failure; we mention them last simply because their effect is obvious.

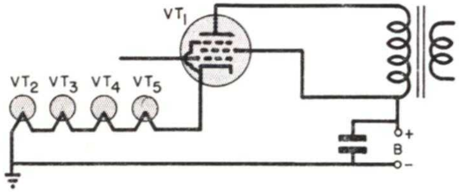


FIG. 31. Arrangements of the filament string in this fashion are common in a.c.-d.c.-portable sets.

Replacing the oscillator tube in a television set (and certain f.m. types) isn't just a case of plugging in a new tube, because the internal tube capacities affect the tuning of the resonant circuit. In the Ultra-Audion, for example, the grid-cathode and plate-cathode capacities set the feedback, but are in series across the tank. Also, the grid-plate capacity is across the tank, so all the tube capacities affect the tuning. Therefore, because tubes have variations in their interelectrode capacities, it is frequently necessary to try several tubes of the same type to find one that affects the tuning the least. Tubes that are unsatisfactory in one set may be perfect for another that is aligned for a different tube capacity. Of course, if necessary, the set can be realigned to suit any ordinary range of tube capacities, but this process takes so much time that servicemen avoid it if possible.

OSCILLATOR MODULATION

The local oscillator must produce a pure r.f. signal; any hum or noise would be mixed with the incoming signal in the conversion process, and would come through with the desired modulation. Condenser C_1 shown earlier in Fig. 30 is used to prevent this. It is usually a large by-pass or filter condenser, connected so that C_1 and R_1 act as an R-C filter to keep hum voltages and other power supply disturbances from the oscillator. Should the by-pass condenser C_1 open or lose capacity, this filtering will be poorer, and a certain amount of hum may get into the oscillator circuit. You should therefore check this by-pass condenser, as well as test the tube for cathode-to-heater leakage, when hum is traced to the oscillator.

Incidentally, C_1 and L_2 also act as a filter to keep the oscillator signal from getting into the power supply and hence into other stages over undesired paths. Hence, the R-C filter R_1 and C_1 in Fig. 30 enter into three different actions: 1, They both form an R-C filter to keep hum out of the oscillator;

STEAM POWERED RADIO.COM

2, the condenser acts with L_2 to keep the oscillator signal from the B supply; and 3, the resistor serves to stabilize the plate voltage on the oscillator tube because current variations produce corrections in its voltage drop.

Self modulation of the oscillator produces a blocking action that can be described as a "roar" resembling a rasping hum if of sufficiently high frequency. This occurs when the grid resistor that furnishes the bias in an oscillator circuit increases in value. If so, it will develop more bias than is normal for a particular amount of feedback signal. This bias may be so high that the plate current will be completely cut off after the oscillator has run for a few cycles. This of course will kill the feedback, and the grid current flow will cease. The charge stored in the grid condenser will then leak off through the grid leak until it becomes so low that oscillations can start again. The blocking-unblocking action will then occur again and again; in effect, the oscillator output will be modulated at a rate determined by how long it takes the blocking and unblocking to occur. If slow, the signal will be chopped or interrupted at the blocking rate. If at an audio frequency rate, the oscillator is modulated at this rate. This modulation of course will travel along with the incoming signal, eventually becoming audible as an undesirable tone.

This condition is caused, as we said, by an increase in the value of the grid-leak resistor. It could also occur if the grid condenser increased in capacity, but it is extremely unlikely that a mica condenser will do so.

Incidentally, it is also possible for the grid-leak resistance to decrease rather than increase. If this occurs, insufficient bias will be produced, and the tube will pass more plate current than it should. As a result, the oscillator tube will age more rapidly than is normal. If you are servicing a set that has a defective oscillator tube, and find that it has a history of frequent tube replacements, check the value of the grid-leak resistance—it may be lower than was originally intended.

Special Oscillator Applications

So far, we have discussed only sine-wave r.f. oscillators used as local oscillators in superheterodyne receivers. Such oscillators are also used in r.f. signal generators—the test instruments used by servicemen in aligning radio receivers. These test instruments are essentially miniature broadcast stations of known frequency having a fixed tone modulation (see Fig. 32). We shall learn all about them in later Lessons on alignment.

There are several other important uses for oscillators, some of which use different basic circuits. We shall now briefly cover some of these. Later Lessons will go into more details, particularly on television applications.

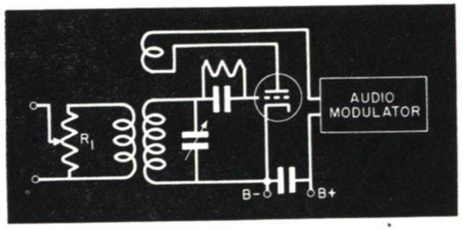


FIG. 32. A basic signal generator. The audio modulator supplies a tone modulation, and the output signal level is controlled by R_1. Band switching is used so that all desired frequencies can be obtained. Such oscillators are carefully calibrated, because accurate signals are needed to adjust receivers properly.

AUDIO OSCILLATORS

There are three basic types of audio oscillators, all of which are used to check the frequency response of audio amplifiers. In general, any of the standard oscillator circuits we have studied can be used to generate audio oscillations, provided the tank circuit L and C values are properly chosen. Since these values must be very large, however, it is not practical to make them variable to get a continuous tuning range. Usually such audio oscillators are limited to a few fixed frequencies that can be obtained by switching in fixed condensers. Either the beat-frequency or the Wien bridge oscillator is used when continuous tuning over the audio range is wanted.

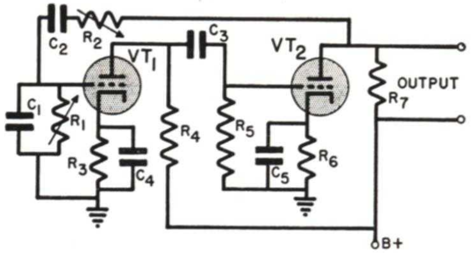


FIG. 33. The Wien bridge audio oscillator.

Beat-Frequency Oscillator. Two r.f. oscillators are used in the beat-frequency oscillator. One is tuned to a fixed frequency, and the other is variable. The two oscillators feed into a detector circuit from which their difference or beat frequency is obtained. For example, suppose the fixed oscillator is tuned to 1000 kc. and the variable is 1001 kc. The output of the device is then 1 kc. (1000 cycles), the difference between the two. It is possible to obtain a complete audio frequency range by having the variable oscillator tunable from the same frequency as the fixed one to a value 10 kc. or 15 kc. away.

The great difficulty with this kind of oscillator is in making the fixed oscillator remain absolutely fixed in frequency. Only rather costly means of stabilization make this type reliable.

Wien Bridge Type. Today, the most popular audio oscillator operates on an entirely different principle from any that we have studied. An adaptation of the Wien bridge into an oscillator is shown in Fig. 33. Essentially, this oscillator consists of a two-stage amplifier so arranged that it will amplify most strongly at one particular frequency. By adjusting the controls that set the frequency, we can make such an oscillator produce the desired frequency over the audio tuning range.

As shown in Fig. 33, the frequency-determining network is the combination of C_1-R_1 and C_2-R_2. The two condensers C_1 and C_2 are equal in capacity, and the resistors R_1 and R_2 are also equal. No expensive inductances are necessary here, and common fixed condensers can be used as C_1 and C_2. Here is how the circuit works:

Any signal applied to the input of VT_1 is amplified by this tube and reversed 180° in phase. VT_2 amplifies this signal and also inverts its phase 180°; the signal across R_7 is therefore a doubly amplified copy of the grid input voltage on VT_1, and is $180° + 180°$ or 360° different in phase. This of course means that the signal across R_7 is again in phase with the grid voltage of VT_1. Therefore, if we feed back from the plate circuit of VT_2 to the grid of VT_1, the feedback voltage will be in the proper phase to produce oscillations.

The C_1-R_1 and C_2-R_2 combinations are used to determine the frequency of the feedback voltage. Let's see what they do.

STEAM POWERED RADIO.COM

As you know, the reactance of C_1 goes down as the frequency increases. Therefore, this condenser becomes more of a by-pass condenser between the grid of VT_1 and the chassis as the frequency is increased. Hence, it *reduces* the input at higher frequencies.

The reactance of C_2 also decreases as the frequency increases. Since C_2 is in the feedback loop, however, its reduced reactance permits *more* feedback as the frequency is increased. Thus, C_2 permits less feedback at a low frequency and more at a high frequency, whereas C_1 permits more at a low frequency and less at a high frequency. There is one intermediate frequency at which maximum feedback, and therefore maximum oscillatory output occurs. Above this frequency, C_1 acts as a better by-pass and reduces the input to VT_1; below this frequency, C_2 provides less feedback by offering more impedance.

Varying the values of resistors R_1 and R_2 changes the frequency at which the best feedback will occur. As R_1 and R_2 are decreased in resistance, the frequency at which C_1 and C_2 begin to be effective is increased. (The final limit is determined by the fact that resistor R_1 cannot be reduced to zero, because then there would be no input to VT_1.) On the other hand, increasing these resistances makes C_1 and C_2 effective at lower frequencies and therefore decreases the frequency at which feedback is best.

In this text, we won't go into the arrangements for controlling the output and stabilizing this kind of oscillator, because this will all be taken up when you study test instruments. For now, it is sufficient that you know how the circuit works as an oscillator.

TELEVISION SWEEP GENERATORS

The electron beam in the picture tube of a television receiver must be swept back and forth and up and down over the face of the tube to produce a picture. Two special oscillators called sweep oscillators are used in the process of generating the signal that sweeps the beam back and forth.

In one television system, a voltage is used to move the electron beam. The picture tube is arranged so that an increase in this voltage moves the beam to the right and a decrease moves it to the left. To produce the desired motion of the beam, the voltage must increase steadily until the beam is all the way to the right edge of the tube face and then must decrease suddenly to bring the beam back quickly to the left edge.

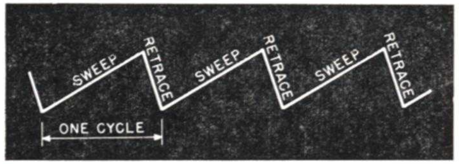


FIG. 34. A sawtooth wave.

A voltage wave that meets these requirements is called a "sawtooth" wave because of its shape. An example is shown in Fig. 34. During the section marked "sweep," the voltage increases gradually and steadily until it reaches a maximum value corresponding to a complete deflection of the electron beam. Then, during the section marked "retrace," the voltage drops suddenly to its original value, bringing the electron beam all the way to the left of the tube to start the next line. This sweep-retrace cycle is repeated constantly, making the electron beam trace a series of horizontal lines across the tube. At the same time, a vertical sweep voltage brings the beam relatively slowly downward from top to bottom. When the beam reaches the bottom of the picture, a vertical retrace voltage snaps it back up to the top of the picture.

The sweep voltage wave shape must be accurately maintained and the frequency must be exact. The latter requirement is so severe that "sync" (synchronizing) pulses are sent in the television signal to lock the sweep circuits to the proper frequencies. The sweep circuits are accurately controlled in modern sets by using a sawtooth generator circuit to produce the sawtooth wave shape and a pulse-generating oscillator to furnish a control pulse to this sawtooth generator. In turn, the pulse oscillator is controlled by the transmitted sync pulses.

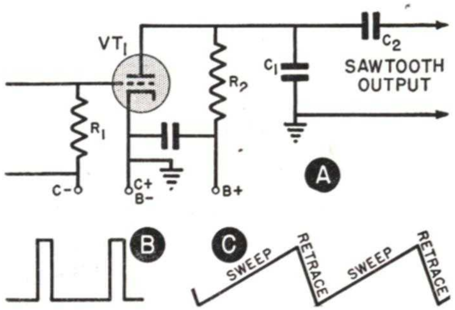


FIG. 35. A basic sawtooth generator.

Sawtooth Generator. A simple way to produce a sawtooth voltage is to use a circuit like that shown in Fig. 35. Tube VT_1 is biased by a separate C supply so much that no plate current can flow. With no plate current flow, when the circuit is first turned on, condenser C_1 is charged to the full B supply voltage through the plate load resistor R_2. (C_1 connects to B— through the set chassis.)

A brief, highly positive control pulse (Fig. 35B) is applied to the grid of VT_1 at regular intervals. This pulse drives the grid so far positive that the tube becomes an extremely low resistance right across condenser C_1, which then discharges rapidly through the tube. At the end of the control pulse, the grid is returned to its original negative bias value and plate current is again cut off. The B supply then recharges condenser C_1 through resistor R_2.

The higher the resistance of R_2 or the capacity of C_1, the longer time it takes to charge C_1. The discharge time depends similarly upon the plate resistance of VT_1 and the capacity of C_1. Since VT_1 has a far lower resistance than R_2, condenser C_1 discharges rapidly through the tube and charges more slowly through R_2. The output voltage of the circuit (the voltage across C_1) therefore has the wave form shown in Fig. 35C.

We can get exactly the sweep wave form we want from this circuit if we make sure that the grid control pulses shown in Fig. 35B are all of equal amplitude and duration. To insure this, an oscillator is used in television sets to generate pulses of fixed amplitudes; the frequency of this oscillator is controlled by the sync pulses sent out by the transmitter. Let's see how it works.

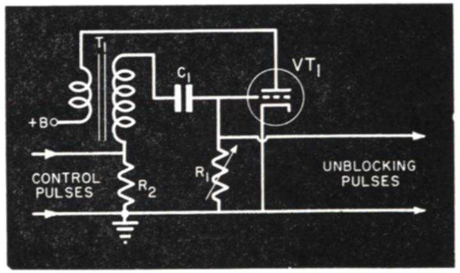


FIG. 36. A blocking oscillator.

Blocking Oscillator. One of the very common pulse-producing oscillators is shown in Fig. 36. This is known as a blocking oscillator, because the grid bias produced by C_1 and R_1 is deliberately made excessive so that the circuit will block or operate intermittently.

When the circuit is first turned on, plate current flow through the primary

STEAM POWERED RADIO.COM

of the transformer T_1 causes a voltage to be induced in the secondary. This voltage, which is the grid input signal for the tube, causes a high grid current flow through R_1. The voltage developed across R_1 charges C_1 with a polarity such that the grid is made negative. The values of C_1 and R_1 are deliberately chosen so that this grid bias will be large enough to cut off plate current. Therefore, this oscillator produces just a pulse and is then cut off completely. C_1 discharges through R_1, R_2, and the secondary of transformer T_1 until the grid bias becomes so low that VT_1 again becomes conductive. At that time, the plate current rises again and the cycle is repeated.

Since the rate or frequency at which this circuit produces pulses is determined by C_1 and R_1, we can make this circuit produce pulses at different frequency rates by varying R_1. We don't care what the exact frequency of oscillation is as long as it is high—we are interested only in how *frequently it is allowed to oscillate.* Hence, although this circuit is like that of any standard L-C oscillator, we have higher than normal grid leak and grid condenser values, so the circuit is deliberately made to block at regular intervals, rather than produce a continuous sine-wave signal.

The pulse produced during the time of oscillation is known as an unblocking pulse. Since the unblocking pulses produced by this circuit are of constant amplitude and duration, they can be used as control pulses for a sawtooth generator.

To fix the frequency of the blocking oscillator, R_1 (in Fig. 36) is adjusted until the unblocking pulses occur at a frequency that is slightly less than the sweep frequency we want. Then, sync pulses from the received television signal are fed in across R_2 in the grid circuit. Each sync pulse "triggers" the blocking oscillator—that is, by making the grid sufficiently positive to cause plate current flow to start, the sync pulse makes the oscillator unblock a fraction of a second before it would of its own accord. The oscillator then produces a pulse, blocks up again, and remains blocked until the next sync pulse occurs. Thus, the sync pulses (which are very precisely timed at the transmitter) control the rate at which the blocking oscillator operates. They do not determine the amplitude and duration of the unblocking pulses, however—the oscillator itself does that.

Multivibrator Sweep Generator. In Fig. 37 is shown a combined blocking oscillator and sawtooth generator that is called a multivibrator. The two tubes in this circuit conduct alternately, with VT_1 conducting most of the time and VT_2 conducting for only brief intervals. The sawtooth output is secured from C_2 and R_5; C_2 charges relatively slowly from the B supply through R_5 and discharges rapidly through VT_2 when the latter conducts. All the rest of the circuit is used just to make VT_2 conduct at the proper time. Let's see how it works.

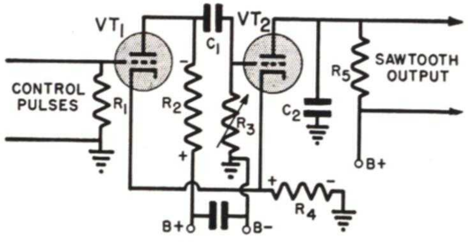


FIG. 37. A multivibrator sweep generator.

Part of the circuit has been redrawn in Fig. 38 to assist in explaining its operation. The basic action that occurs is that C_1 charges rapidly and discharges slowly; the circuit is so arranged that VT_2 conducts and VT_1 does not while C_1 is charging, and VT_1 conducts and VT_2 does not while C_1 is discharging. Let's see what the circuit operations are that produce these effects. First, we'll see what happens when C_1 charges from the B supply (Fig. 38A):

1. Electrons flow through R_3 (a relatively high resistance) in the direction shown by the arrow, creating a voltage drop of such polarity that the grid of VT_2 is driven positive.

2. Because the grid of VT_2 is positive, the path from the cathode to the grid becomes conductive, causing a grid current flow.

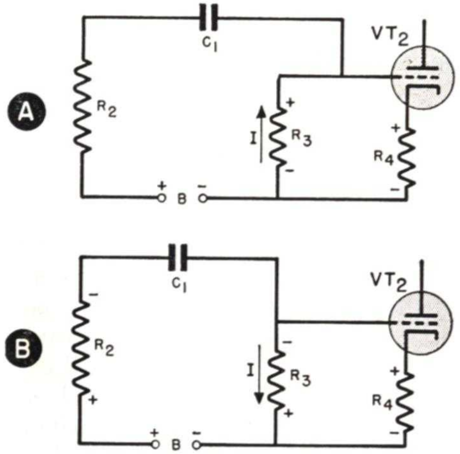


FIG. 38. The charging (A) and discharging (B) actions in the multivibrator sweep generator circuit shown in Fig. 37.

3. Because this path is low in resistance (about 100 ohms), and R_4 is also fairly low, C_1 charges very rapidly through R_4 and the cathode-to-grid path.

4. Because the grid of VT_2 is positive, a very high plate current flows through the tube. This plate current flowing through R_4 creates a voltage drop across it having the polarity shown. Since R_4 is also in the cathode circuit of VT_1 (see Fig. 37), this voltage acts as a bias on VT_1, and is great enough to cut the plate current of VT_1 off completely.

Only a very short time is required for C_1 to charge almost to the full B supply voltage. As the voltage on C_1 approaches this maximum, both the current flow through R_3 and the voltage across it decrease sharply. As soon as the voltage across R_3 decreases so much that the grid ceases to be positive, the cathode-to-grid path in VT_2 ceases to be conductive and instead becomes highly resistive. The following sequence of events then occurs (see Fig. 38B):

1. The plate current of VT_2 drops, because the grid is no longer positive.

2. This causes the voltage across R_4 to decrease, reducing the bias applied to VT_1 and permitting that tube to conduct again.

3. The plate current of VT_1 creates a voltage drop across R_2 having the polarity shown.

4. The voltage drop across R_2 bucks the B supply voltage, thus reducing the net voltage applied to C_1.

5. C_1 starts to discharge to meet this new voltage level, creating a current flow through R_3 having the direction shown.

7. This voltage drop drives the grid of VT_2 so far negative that the plate current of VT_2 is cut off.

This whole chain of events takes place very quickly—almost instantaneously, in fact. Tube VT_2 remains cut off until C_1 discharges to the voltage corresponding to the difference between the B supply voltage and the voltage drop across R_2; when this point is reached, current flow through R_3 ceases, VT_2 begins to conduct again, and the cycle repeats. Since C_1 discharges through R_3 which is relatively high in resistance, it takes very much longer to discharge than it does to charge. As a result, VT_2 is cut off most of the time and conducts only for a very brief period.

STEAM POWERED RADIO.COM

The timing of the circuit is fixed by the circuit constants and also by the control pulses applied to the grid of VT_1 (see Fig. 37). Each control pulse drives the grid of VT_1 negative, cutting off its plate current and removing the voltage across R_2. This triggers operation of the circuit, since it permits the full B supply voltage to be applied to C_1 and starts the flow of current upward through R_3, as shown in Fig. 38A, thus initiating the charge cycle and causing VT_2 to conduct.

This multivibrator circuit will produce a sweep even when there are no control pulses, a very desirable feature while tuning the television set in that it safeguards the picture tube by preventing the electron beam from standing still and burning the screen. Then, when the pulses are derived from an incoming signal, they control the frequency; the amplitude of the sweep is fixed by the multivibrator design.

TELEVISION HIGH-VOLTAGE POWER SUPPLIES

Television receivers require high voltages for the picture tube—between 4000 and 9000 volts for direct-view tubes, and up to 30,000 volts for projection types. Rather than use costly, heavy iron-core transformers to obtain such voltages from a 60-cycle, 110-volt power line, many designers use r.f. high-voltage supplies in their sets. A typical supply of this kind uses an oscillator to produce voltage in the r.f. range around 100 kc. to 250 kc. This voltage is stepped up by an r.f. air-core transformer to get the high voltage, which is then rectified and filtered. This not only permits use of an inexpensive air-core transformer, but also makes it possible to use relatively low-capacity filter condensers because it is far easier to filter such high frequencies, and minimizes insulation problems because the windings on the transformer are separated by air spacing. This power supply oscillator is usually also made to furnish power to the rectifier tube filament through the use of a low-voltage step-down winding.

The oscillator frequency is not critical except in some types that use a tuned high-voltage winding to get increased voltage through resonance step-up. The output of such types will be reduced if the oscillator frequency is allowed to drift too much. To prevent this, some use the high voltage winding as the tank, with the other winding then acting as a tickler.

A variation on this idea makes use of the sweep generator as the source of the a.c. In a set using electro-magnetic fields to deflect the picture tube electron beam, the deflection coil *current* must have a sawtooth wave shape. Such a current wave can be produced only by a voltage that has a sharp change, as you will see in a later Lesson. This voltage is applied to the deflection coils though a transformer, and the sudden change produces a high voltage peak. If the transformer is equipped with an extra high-voltage winding, this peak can easily be stepped up to the required value for rectification and filtering. The horizontal sweep frequency used today is 15,750 cycles per second, which is easier to filter than 60 cycles.

Use of this circuit protects the picture tube, because the high voltage is automatically cut off if the sweep fails. This prevents sweep failure from letting the beam stand still and burn the fluorescent screen of the tube.

STEAM POWERED RADIO.COM

Lesson Questions

Be sure to number your Answer Sheet 21FR-3.

Place your Student Number on every Answer Sheet.

Send in your set of answers for this Lesson immediately after you finish them, **as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. What five elements are found in all practical oscillators?
1. AMPLIFIER TUBE (ONE WITH CONTROL GRID)

2. What will happen if the connections to the feedback coil are reversed?
~~STATE~~ 180° OUT OF PHASE

3. When a tube is connected into an L-C oscillator circuit, is energy to compensate for losses in the L-C circuit demanded from the B supply *constantly* or *intermittently?* INTERMITTENLY

4. How does the Hartley oscillator differ basically from the Colpitts oscillator? THE COLPITTS OSCILLATOR HAS A CAPACITIVE DIVIDER WHILE THE HARTLEY HAS A TAPPED COIL.

5. Why is a low-capacity condenser connected from plate to cathode or from grid to cathode in some Ultra-Audion oscillators?
TO PERMIT FEEDBACK

6. When you see that the oscillator section of the tuning condenser gang has specially cut rotor plates, much smaller in area than the rotor section tuning the preselector, would you expect to find a "padder" condenser in the oscillator? NO

7. In a television receiver using an Ultra-Audion oscillator, why will replacing the oscillator tube affect the tuning?
TUBES HAVE VARIATIONS IN THEIR ELECTRODE CAPACITIES

8. Give three reasons why an R-C network such as C_1 and R_1 in Fig. 30 is used in the plate supply of the oscillator tube. 1. TO KEEP HUM OUT OF THE OSCILLATOR
2. TO KEEP THE OSCILLATOR FROM THE B-SUPPLY 3. THE RESISTOR SERVES TO STABILIZE THE PLATE V.

9. How does a blocking oscillator such as is used in television sweep generators differ from an ordinary L-C oscillator?
SYNCHRONIZING PULSES

10. How does obtaining the high voltage from the sweep generator serve as a protection to the picture tube?
BECAUSE THE HIGH VOLTAGE IS AUTOMATICALLY CUT OFF, IF THE SWEEP FAILS THUS PREVENTS TUBE FROM BURNING OUT

SOME INFORMATION WHICH MAY BE HELPFUL IN THE NEAR FUTURE. IT CONCERNS TEST INSTRUMENTS WHICH MAY BE PURCHASED THROUGH NRI

At this point in your Course you probably are visualizing yourself doing some spare time Radio work soon. In fact this spare time Radio servicing may develop into a full time service business for you. It is great fun to plan these things.

To carry our servicing effectively, a technician must have reliable professional servicing instruments. You may have some test equipment in mind. More likely, however, you are insterested in getting some advice as to the type of instruments you should select. Our Instruction Department will gladly give careful, unbiased attention to any of your requests. But before you go too far in your planning we want you to know that there is available, through NRI, a complete line of test instruments.

Over the years students and graduates have asked that NRI bring out test equipment of our own, designed according to the ideas of our technical staff and at moderate prices. To supply this popular demand, NRI engineers, in cooperation with factory engineers, designed test equipment of highly professional quality that we are able to offer at prices considered very reasonable.

We are able to offer such basic instruments as a Signal Generator, a Tube Tester, a Volt-Ohm-Milliammeter (Multimeter), a Signal Tracer and a Resistor-Condenser Tester, at prices well below the established serviceman's price for comparable material. These savings are made possible because NRI buys these instruments in lots of hundreds at a time - usually we contract for one thousand in an order. They come direct from the manufacturer. The result is that there is only one handling between the manufacturer and you, and - no middleman profits.

Our policy is that only NRI students and graduates may buy such equipment from us. We feel that it would be unfair to the industry as a whole to extend the same privilege to those who have no connection with NRI.

You may be interested in some of these testers at the present time or perhaps you are just beginning to think about them. Frankly speaking, it is rather early, at this point, to buy test equipment, if you are a beginner and have had no previous experience in Radio servicing. However, the time is not far off when you will be giving serious thought to test instruments. We wish you to know that NRI is prepared to send you circulars, specifications and prices on the type of instrument mentioned in this memorandum. Just keep that in mind.

The coupon on the bottom of this page is for your convenience. Send it now or whenever you feel you are ready to consider test equipment.

- -

Supply Division
National Radio Institute
16th and You Street, N.W.
Washington 9, D. C.

I am interested in the items I have checked on the right hand side. Without obligation send me circulars giving specifications and prices.

Name____________________ Student No.__________

Address____________________________________

City____________________ Zone___ State_________

☐ NRI Professional Radio Tube Tester
☐ NRI Professional Signal Tracer
☐ NRI Professional Volt-Ohm-Mil-Ammeter
☐ NRI Professional Resistor-Condenser Tester
☐ NRI Professional Signal Generator

Diagram Manual & Tools Also Available

☐ NRI Service Manual, Volume 1

☐ NRI Professional Tool Kit

SD51-1-449

Printed in U.S.A.

STEAM POWERED RADIO.COM

THOROUGHNESS

Whatever you do, do well if you would stay on the straight road to success. The habits of carelessness and slipshod work are all too easy to acquire; beware of them as you would the plague. Men who are thorough in their work cannot remain undiscovered for long, because the demand for such men is greater than the supply.

Thoroughness is just as important in study as it is in work; what you get out of a Lesson depends upon how completely you master the material presented in it. Some books, as fiction, are read hurriedly and only once, then cast away; the enduring works of literature are carefully read and reread many times but always essentially for the pleasure they give; textbooks, however, must be read quickly, to get the basic ideas, then carefully many times until every important principle has been mastered.

Thoroughness in study habits leads to thoroughness in work habits, and eventually to a thorough success.

J. E. Smith

STEAM POWERED RADIO.COM