TV SWEEP CIRCUITS

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STUDY SCHEDULE NO. 55

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

☐ **1. Introduction .... Pages 1–7**

Here you learn what characteristics the scanning signal in a TV receiver must possess.

☐ **2. Generating a Saw-Tooth Voltage .... Pages 7–9**

In this section, you learn how a wave-shaping circuit is made to produce a saw-tooth wave.

☐ **3. Basic Sweep Oscillators .... Pages 9–18**

This section contains descriptions of the blocking oscillator, multivibrator, and sine-wave oscillators that may be used to drive a shaping circuit.

☐ **4. Electrostatic Sweep Circuits .... Pages 18–24**

The ways in which saw-tooth sweep voltages are produced in sets using electrostatic deflection are described in this section.

☐ **5. Basic Electromagnetic Sweep Circuits .... Pages 24–29**

Here you learn how saw-tooth vertical sweep currents are produced in sets in which electromagnetic deflection is used.

☐ **6. Horizontal Electromagnetic Sweep Circuits .... Pages 30–36**

The more complex circuits needed to produce saw-tooth horizontal sweep currents are described in this section.

☐ **7. Answer Lesson Questions and Mail Your Answers to NRI for Grading.**

☐ **8. Start Studying the Next Lesson.**

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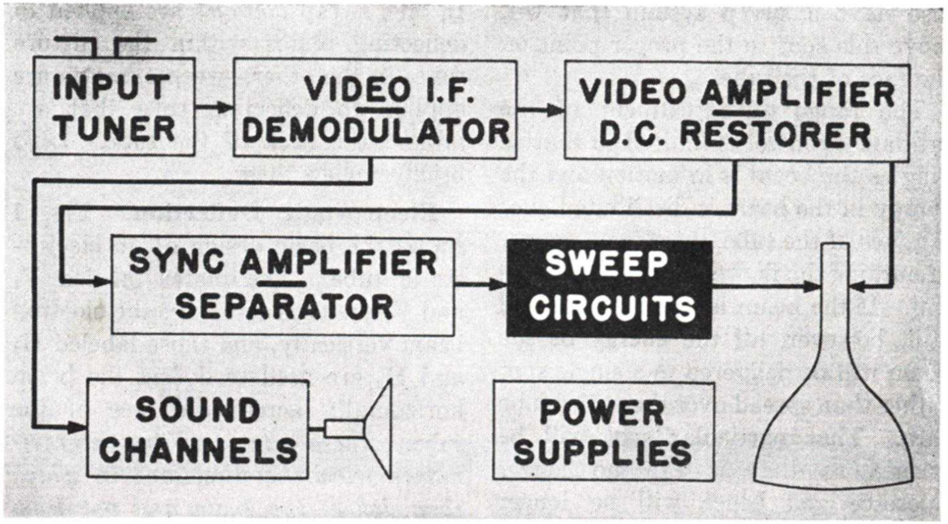


APPLYING a video signal between the grid and the cathode of the picture tube varies the number of electrons in the beam through the picture tube and thus varies the brightness of the spot struck by the beam on the face of the picture tube. As a result, the brightness of the spot at any instant corresponds to the light level at some point on the mosaic of the camera tube from which the video signal originates. To reconstruct the original scene, we must move (or sweep) the picture-tube beam across the face of the tube line by line in synchronism with the scanning of the camera tube so that the spot of varying brilliance will always be at the right point in the picture. Only in this way can we reconstruct the scene from its elements into a complete picture.

The human eye is capable of seeing an entire scene at one time because each tiny portion of the scene is carried over a separate nerve path to the brain. There are thousands of nerve channels from the eye to the brain, so it is possible for the brain to reconstruct an entire scene from the individual elements delivered to it over each nerve path. In television, it is impossible to transmit an entire scene as a single unit this way, because there would have to be a separate channel for each element of the picture. Instead, a televised scene is broken up into its individual elements, which are sent consecutively.

When the transmitter has sent a signal corresponding to all the elements along one line, it starts to send one that corresponds to those of the next line. Therefore, we must have some means of moving the electron beam within the picture tube across the face of the tube as each line signal is received and some way to move it down the face so it will be in position for the next line. In this way, we can reassemble the signals from the various scene elements in their proper order to give us a picture.

To get a picture, therefore, we must have a spot whose brightness corresponds to the brightness of an element in the original scene, and we must also have a sweep system that will move this spot to the proper point on the face of the tube.

The range of adjustment of the brilliancy control is limited so that as long as the beam is in motion and the energy in the beam is distributed over the face of the tube, there is no danger of burning the fluorescent screen material. If the beam is allowed to stand still, however, all the energy of the beam will be delivered to a single spot rather than spread over the entire tube face. That particular spot will be burned so that it can no longer fluoresce and hence will no longer produce light. *Therefore, we must have a sweep system that will keep the electron beam in motion whether we have a signal or not.* Then, when a signal is tuned in, the sweep system must fall under the control of the sync pulses that accompany the video signal, so that the lines can be made to start at the proper time. Before going on to learn more about sweep systems, let's see how the beam is moved inside the picture tube.

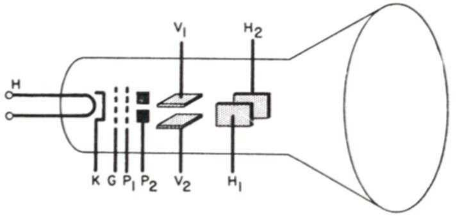


FIG. 1. Basic design of an electrostatic tube.

DEFLECTION METHODS

As you learned in your study of the picture tube, there are two basic methods of deflecting the electron beam. In one, sweep *voltages* are applied to deflecting plates within the picture tube; in the other, sweep *currents* are applied to deflection coils that are around the neck of the tube. Let's briefly review these.

Electrostatic Deflection. Fig. 1 shows the basic design of an electrostatic tube. The plates labeled V_1 and V_2 are used to deflect the electron beam vertically, and those labeled H_1 and H_2 are used to deflect the beam horizontally across the face of the tube. *These sets of plates get their names from the directions in which they deflect the beam and not from their physical positions.* (Notice that the horizontal deflection plates are vertically mounted and the vertical deflection plates are horizontally mounted.)

Since the electron beam consists of negative particles, it will be attracted toward any positive element within the tube. Therefore, let's assume that we are facing the front of the tube and have the conditions illustrated in Fig. 2. Let's first just apply a voltage between the horizontal deflecting plates H_1 and H_2 that makes the plate H_1 positive, as shown in Fig. 2A. The electron beam (indicated by a dot) will move toward this plate, the distance it is moved depending on the voltage applied between the plates.

(Of course, the distance the beam is moved also depends on its stiffness, which is determined by the accelerating voltage applied to the second anode.)

If we reverse the polarity (Fig. 2B), the electron beam will move toward plate H_2. Therefore, if we alternately make first one and then the other plate positive, the electron beam will be swept back and forth as shown in Fig. 2C, thus producing a line.

Similarly, the electron beam can be deflected up and down by voltages applied to the vertical deflecting plates V_1 and V_2, as shown in Figs. 2D, E, and F. When the proper voltages are applied to both sets of plates, the electron beam will be swept over the entire tube face, as shown in Fig. 3.

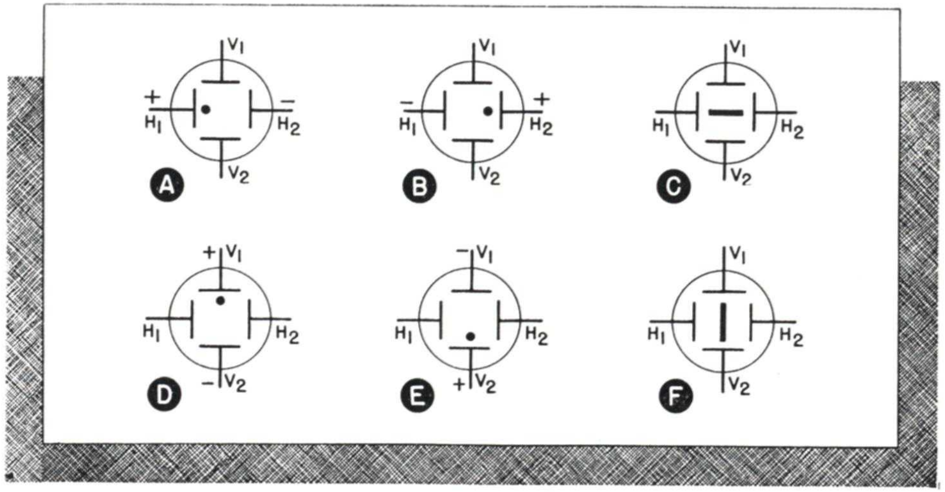


FIG. 2. How the electron beam is swept across the face of an electrostatic tube.

Electromagnetic Deflection. The other system of deflection makes use of a magnetic field set up by two sets of coils (called deflecting coils) that are at right angles to each other. The moving stream of electrons within the picture tube constitutes a current flow, and therefore it has a magnetic field associated with it. As these electrons flow through the magnetic field set up by the coil systems, the interaction between the field of the electron beam and that of the coils will cause the electron beam to move. For any particular accelerating voltage, the distance of movement will depend on the strength of the magnetic field of the deflecting coils, which is proportional to the current through them.

The vertical deflecting coils are mounted horizontally, and the horizontal or line deflecting coils are mounted vertically. The two sets of coils are arranged as shown in Fig. 4A when you look from the face of the tube toward the cathode. These coils are actually wound flat (Fig. 4B)

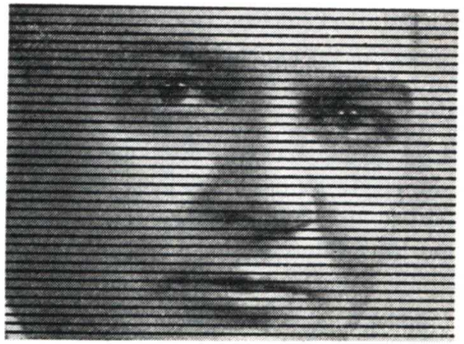


FIG. 3. This enlargement of a section of a TV picture shows that it is made up of a series of lines of varying brightness separated by fine black spaces. (Look at it from 10 feet away and you will see that the lines blend together.)

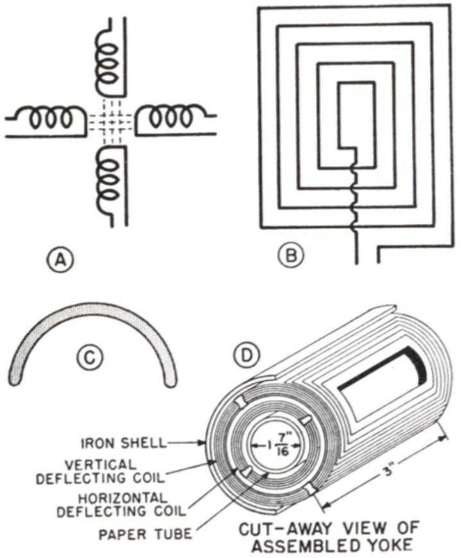


FIG. 4. How an electromagnetic deflecting yoke is made.

and then curved as shown in Fig 4C. Then the two sets are interleaved (Fig. 4D) into a single yoke assembly that slips around the neck of the picture tube.

With this brief explanation of the actual mechanics of getting the electron beam to move, we can now return to a study of the shape of the sweep signal that is needed and can learn more of its characteristics. Keep in mind that the deflection in an electrostatic deflection system is proportional to *voltage*, whereas the deflection in an electromagnetic deflection system is proportional to *current*. This important difference has much to do with the design of the sweep circuits, as we shall show later in this Lesson.

THE SCANNING SIGNAL

If we were interested only in protecting the fluorescent coating of the tube by causing the electron beam to be swept over the entire face, we should not have to worry much about the shape of the scanning signal. Since we are going to reproduce a picture, however, it is very important that the scanning signal have exactly the same characteristics as the signal that is used to sweep the face of the pickup tube at the transmitter. The control pulses that come from the transmitter determine only the frequency or rate at which the scanning occurs, not the wave shape. Fortunately, however, as we will show shortly, it is relatively easy to get the right scanning wave shape in the receiver.

At both the receiver and the transmitter, the scanning signal must move the electron beam linearly with respect to time. If the scanning signal is non-linear, so that the beam deflection is slow part of the time and fast the rest of the time, more electrons will hit the spots over which the beam travels slowly and less will hit those over which the beam travels quickly. The brightness of a spot on the tube face depends on the number of electrons hitting it; therefore, non-linearity in the scanning signal will produce brightness variations in the raster (the pattern formed when no picture is being received). If we use a sine-wave signal for scanning, for example, the beam will move slowest at the left and right of the screen and fastest in the middle, with the result that the raster will be dim in the middle and excessively bright at the sides.

To get an even distribution of the brilliancy, the scanning signal must change so that the distance moved by the beam is exactly proportional to time, as shown in Fig. 5A; the "curve" followed by the signal must be a straight line. This means that the rate of movement of the beam across the screen should be absolutely uniform; if it moves a certain distance in a certain time, it should move twice as far in twice the time.

Once we have moved the electron beam from left to right across the face of the tube, we must then get it back to the left to start the next line. The ideal action would be to make the electron beam snap back to the left instantly, because then the full scanning time could be used to transmit a signal. In this case, the movement of the beam would be as represented in Fig. 5B. The electron beam would move steadily from the left (L) through the center (C) to the right (R) as the scanning signal changed from W to X. At point X, the end of one line would be reached. Instantly, the electron beam would move from the right to the left as the scanning signal snapped from X to Y. The beam would then be back in the same relative position at the left of the tube face as it was at W. The next line would then be scanned from Y to Z, and so on.

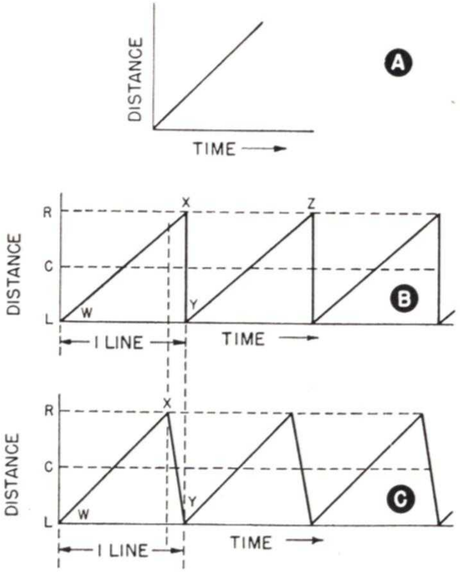


FIG. 5. Evolution of a saw-tooth scanning signal.

Unfortunately, such a very abrupt change in the position of the electron beam from right to left would call for extremely high-frequency components in the scanning signal, which would not be easy to handle. In practice, therefore, a certain amount of time is allowed for the beam to move back to the left-hand side of the screen; a scanning signal having the shape shown in Fig. 5C is used. (This is called a "sawtooth" wave, because its shape is somewhat like that of a tooth on a handsaw.) Notice that the "retrace" signal from X to Y (that is, the signal that moves the beam from right to left on the picture tube face) now has an appreciable slant. Although the retrace (X to Y) is faster than the scan (W to X), it nevertheless takes an appreciable length of time to make the retrace. It is standard practice to arrange for the retrace from X to Y to occur in about 8% to 10% of the total time required to reproduce one line. This means the scanning from left to right (W to X) must now occur somewhat faster than it did in Fig. 5B to complete each line in the same line period. This is indicated by the fact that X in Fig. 5C occurs sooner than in Fig. 5B.

To prevent the retrace (X to Y) from being seen as a streaky line from right to left, the screen of the picture tube is blanked out by the blanking pedestal and the sync pulses that accompany the signal. To be sure that the retrace will occur during this blanking, the retrace is started slightly after the blanking has begun and is finished well before the blanking period ends. This means that the blanking period, which uses up 14% of the time allotted to the reproduction of one line, cuts a slight amount off each line at both ends.

Of course, we don't want the lines to occur right on top of each other—they must be spaced down the tube face so that each line will be below the one preceding. Therefore, a vertical scanning signal is applied to the beam simultaneously with the line, or horizontal, scanning signal. As a result, the beam is moved slowly downward as it moves across the screen during the transmission of a single line, producing a slight slant in each line. Then, when one line is finished and the retrace (or "flyback," as it is sometimes called) snaps the beam back to the beginning of the second line, the second line will occur underneath the first.

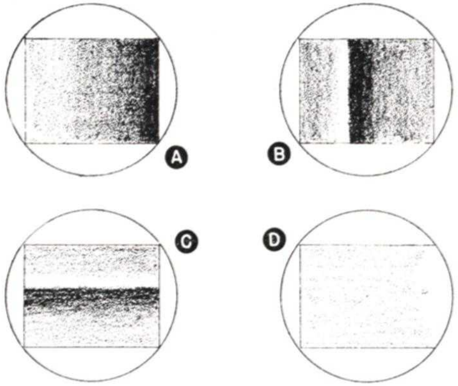


FIG. 6. Defects caused by scanning signal variations.

The vertical scanning signal has exactly the same shape as the horizontal or line scanning signal. The only basic difference between them is that the vertical scanning occurs at a much lower frequency. Under present standards, there are 525 lines for each complete frame of the television signal, and there are thirty frames per second. Because of the use of interlaced scanning, this is broken so that there are 262.5 lines per field, and 60 fields per second. Therefore, the frequency of the line scanning signal is 15,750 cycles per second (262.5 × 60), and the field frequency is 60 cycles per second.

Let's sum up what we have learned. To produce the desired scanning, we must use two scanning signals, one that will move the electron beam at a constant velocity along each line, and one that will move it downward to produce succeeding lines. The lines must be linear with respect to time, and both the scanning and retrace must be identical from line to line. Finally, we must control either the number of lines or the frequency (which effectively controls the length of each line). This control is produced with the aid of the synchronizing pulses sent out with the video signal.

Fig. 6 shows the effects of several possible variations in the scanning signals. In Fig. 6A, for example, we have a nonlinear horizontal scanning signal. Since it moves the beam slower at the left and faster at the right, the picture appears brighter at the left side. In Fig. 6B, the horizontal scanning signal moves the beam at the normal rate first, slows it down near the center of the picture, then moves it much faster than normal, and finally makes it travel at the normal rate again; this produces a bright vertical area followed by a dark vertical area in the center of the picture. Fig. 6C shows the effect of one kind of non-linearity in the vertical scan. Here the vertical signal is such that the beam moves at the normal rate first; then it moves slowly, producing closely spaced lines; then it moves rapidly, widening out the spacing; and finally it moves at the normal rate again. Fig. 6D shows what happens if each horizontal scanning signal is not the same length; as you see, a ragged edge is produced at the right. These are not, of course, the only troubles that might occur.

In this introduction, we have shown that the scanning signals or sweep signals must have a certain basic shape. Although these signals exactly duplicate the sweeps used at the transmitter, they are formed in the television receiver: the synchronizing pulses that accompany the signal from the transmitter serve only to signal the end of a line and thus start the retrace for the next line. As a matter of fact, the sweep circuits must operate all the time (whether a signal is tuned in or not) to protect the picture tube. Therefore, a television receiver must contain circuits that will generate the proper sweep signals at approximately the right frequencies by themselves. In addition, these circuits must be arranged so that they can be locked in with the synchronizing pulses when a signal is received. In this Lesson we shall cover only the production of the sweep signals—their synchronization will be covered in another text.

Generating a Saw-Tooth Voltage

The oscillators you have studied in other Lessons all generate either a sine wave or some form of square-wave signal. To get from such oscillators the saw-tooth sweep signal we need, therefore, we must use a wave-shaping circuit. Fortunately, it is simple to get the desired saw-tooth by taking advantage of the manner in which a condenser charges through a resistance. Let's see how.

SAW-TOOTH GENERATORS

To see how it is possible to get a saw-tooth wave, let's start with the circuit shown in Fig. 7A. Suppose we first close switch SW_1 (leaving SW_2 open). At the instant SW_1 is closed, current will start flowing through the circuit. However, the battery voltage will not appear instantly across the condenser. It takes the condenser a certain length of time to charge; this time is determined by the values of

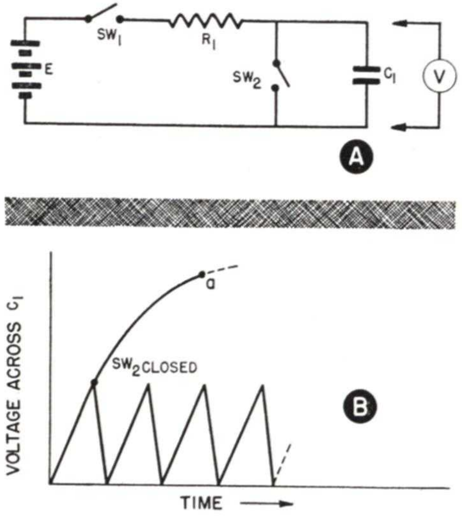


FIG. 7. A basic saw-tooth generator.

resistance and capacity in the circuit. (As you know, the product of the resistance and the capacity is called the time constant of the circuit; it is equal to the time it takes the condenser to charge to 63% of the maximum voltage it can reach in that circuit.)

The left-hand curve in Fig. 7B shows how the voltage across the condenser varies with time. At the instant that SW_1 is closed, the voltage across condenser C_1 builds up almost linearly with time. However, as C_1 becomes charged, the rate of charging gradually tapers off.

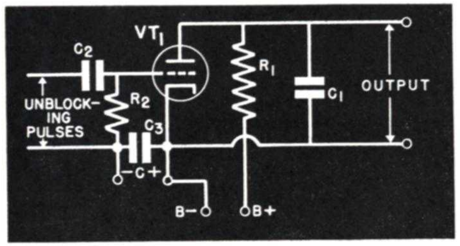


FIG. 8. Discharge circuit having a saw-tooth output.

We aren't at all interested in the full-charge condition, nor in any of the portion of the curve above the point (a) where it bends. However, the fact that the first portion of this curve is reasonably linear makes it possible for us to get our saw-tooth voltage.

All we need to do is open SW_1 and close switch SW_2 after C_1 reaches an appreciable charge. C_1 will then be discharged through the short-circuit path provided by SW_2. If we then open SW_2 and close SW_1 again just when C_1 is completely discharged, it will charge again. If we repeat the action over and over, we will get the series of curves shown at the right in Fig. 7B. Therefore, if we operate over the linear portion of the charging curve of the condenser and use the right value of resistance for R_1, we can get a saw-tooth voltage.

Of course, it isn't practical to use mechanical switches this way. Instead, we use electronic switching.

DISCHARGE CIRCUIT

In another Lesson, you learned that a special gas-filled tube was used as a sweep generator with cathode-ray tube test equipment. Such tubes are unsatisfactory for television, however, because the tube characteristics change with age and are affected by temperature.

Therefore, in television, the "switch" we need to discharge the condenser is provided by a vacuum tube that is biased so that plate current is cut off and the tube cannot conduct until a sufficiently large pulse is applied to the grid. Fig. 8 shows the basic circuit.

In the absence of an applied signal, the C bias prevents the tube from conducting, so C_1 charges through R_1. When an unblocking pulse is applied to the grid, the grid is driven sufficiently positive for the tube to conduct; C_1 then discharges through it. As soon as the unblocking pulse is removed, the tube cuts off, and C_1 begins to charge again. The rate of discharge and hence the retrace time depend on how far positive the grid is driven; an unblocking pulse of sufficient amplitude will cause the tube to conduct heavily so that C_1 will be rapidly discharged.

In this circuit, the discharge time can be made short, and the operation is relatively independent of the tube characteristics and of temperature variations. However, it does have a very important disadvantage: this circuit is not free-running. In other words, the circuit will not produce a sweep voltage at all until unblocking pulses are fed to it. Therefore, we cannot use the circuit shown in Fig. 8 by itself, because we would have no sweep until the proper signal voltage was applied to the grid of the tube.

Another difficulty with this circuit is that it is greatly dependent upon the amplitude and duration of the unblocking pulse fed to it. This means that we cannot operate it directly from the sync pulses that accompany the signals, because these pulses may vary in either amplitude or duration. For instance, the sync pulse may be small if the signal is weak: a small pulse would not make the tube conduct heavily, which means that C_1 would not discharge completely before the pulse ended. On the other hand, the sync pulse might be increased either in height or in width by, let us say, noise pulses: a wide pulse would make the tube conduct for a longer period of time than is desired, thus delaying the start of the next line.

Both these difficulties are overcome in television sets by using this circuit in conjunction with an oscillator that feeds it regulated unblocking pulses. This makes the sweep generator free running because the oscillator works whether there is a signal tuned in or not, and the pulse amplitudes are independent of the incoming signal. In such use, the circuit shown in Fig. 8 is known as a *wave shaper,* or as a *discharge* circuit. Some manufacturers call it the saw-tooth generator, but most reserve the name saw-tooth generator for the combination of oscillator and discharge circuit.

Basically, therefore, the sweep generator in the average television receiver consists of an oscillator that operates all the time plus a discharge circuit that produces a saw-tooth wave from whatever the output of the oscillator may happen to be. The sync signal is used to control the frequency of the oscillator and thus to control the output of the shaping circuit.

Now, let's study the oscillators used in these sweep generators.

Basic Sweep Oscillators

The standard oscillator with which you are familiar produces sine-wave oscillations. Other basic types are usually set up to produce square-wave outputs. Neither of these wave shapes is ideal for operating a discharge circuit, because we want pulses having shapes somewhat like the sync pulses. In addition, we want these pulses all to be of the same amplitude and the same width so that the discharge circuit will always operate in the same manner, line after line and frame after frame.

Blocking oscillators and multivibrator oscillators, which have the ability to produce pulses of the right kind, are most commonly used in television sweep generators. It is also possible to use a sine-wave oscillator in a sweep generator circuit, as we shall show after we have described these basic pulse-producing oscillators.

BLOCKING OSCILLATORS

In television, one of the most frequently used oscillators for producing the discharge of unblocking pulses is the blocking oscillator shown in Fig. 9A.

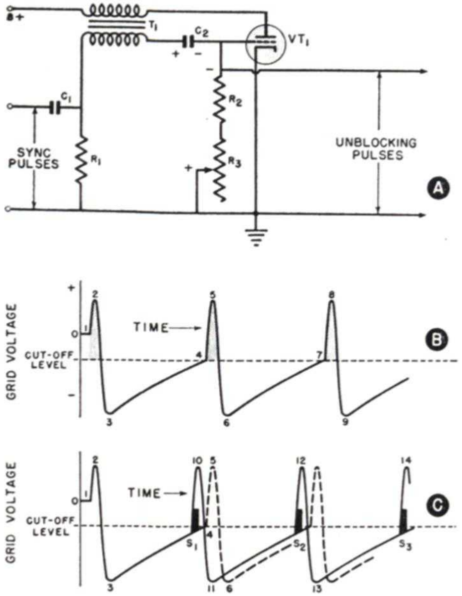


FIG. 9. Schematic diagram of a blocking oscillator.

The circuit associated with VT_1 here looks at first glance like an ordinary oscillator, and as matter of fact it is basically a standard sine-wave oscillator except for the unusual values chosen for the grid condenser C_2 and the grid resistor R_2-R_3. These parts values are so high that the oscillator blocks and is forced to operate intermittently. Notice that the voltage across the grid resistor furnishes the unblocking pulses that constitute the output of the circuit.

The oscillator operation may be explained briefly as follows, using Fig. 9B to represent the changes in the grid voltage:

Initially, plate current flowing through transformer T_1 induces a voltage in the grid that drives the grid highly positive. In other words, the circuit starts to oscillate vigorously. At the same time, this positive-swinging grid voltage makes the grid draw a high current; as a result, electrons flow through R_2 and R_3 and develop a voltage across them having the polarity shown in Fig. 9A. This current flow also charges C_2 to a voltage that is far beyond the cut-off bias for the oscillator tube VT_1.

The grid-voltage curve in Fig. 9B shows what happens. Initially, the positive pulse (point 1 to point 2) appears on the grid. When the grid swings in a negative direction to point 3, it is far beyond the cut-off level. As soon as the grid voltage falls below the cut-off level, the plate current is cut off completely, and no further current can flow until the grid voltage once again gets above the cut-off level. However, when the plate current is cut off, no further voltage is applied to the grid, so the grid current ceases. As a result, condenser C_2 can discharge through the resistors R_1, R_2, and R_3, and through the secondary of transformer T_1. The resistances of R_1 and of the transformer secondary are small, so the time it takes condenser C_2 to discharge depends mostly on its capacity and on the values of resistors R_2 and R_3. Therefore, the rate of change from point 3 to point 4 in Fig. 9B is determined by the time constant of C_2-R_2-R_3.

As soon as C_2 has discharged sufficiently for the grid voltage to be above the cut-off level, plate current will again start. The feedback to the grid circuit will then instantly build up another positive pulse from 4 to 5, and the action will repeat itself. The high grid current will produce a bias that will once again block the circuit for a time represented by the distance from point 6 to point 7 in Fig. 9B.

Here, therefore, we have a circuit that will produce a pulse and will then cut off. The spacing between the pulses is determined by the time constant of the grid leak and grid condenser. The pulse width and height are basically determined by the initial frequency of oscillation and by the supply voltages. The shape and size of this pulse will therefore remain relatively fixed once the frequency and the voltages have been set.

The frequency at which this oscillator would oscillate if more normal grid-leak and grid-condenser values were used is relatively immaterial except for its effect in fixing the shape of the pulse. Generally, it is chosen (by choice of transformer inductance and distributed capacity) to be some frequency about 10 or more times as high as the spacing wanted between pulses, thus making the pulses narrow.

Since the spacing between the pulses and hence the sweep time is determined by the time constant of C_2-R_2-R_3, the variable resistor R_3 acts as an adjustable frequency control. This is usually known as a "hold" control, because proper adjustment of this resistor to a value that produces nearly the right frequency will cause the oscillator to lock in with the sync pulses.

How lock-in is produced is shown in Fig. 9C. The frequency of oscillation determined by the R-C time constant is made slightly longer than is desired. Then, when a sync pulse comes along at S_1 (between points 3 and 4 on the grid voltage curve), it will instantly force the grid to a point above cut-off. Plate current will start to flow at once, so the positive pulse produced by the circuit will occur at the same time as the leading edge of the sync pulse. Instead of the grid voltage changing from 3 to 4 to 5, in other words, it changes from 3 to S_1 to 10. The grid voltage pulse is produced exactly as before; it is again controlled by the C_2-R_2-R_3 time constant until the next sync pulse S_2 arrives, when once again the circuit is kicked off in synchronism with the pulse.

Notice that all that the sync pulse has to do to produce lock-in is to drive the grid of VT_1 slightly above the cut-off level. Once this has been done, the oscillator will take off by itself. The height and width of the sync pulse are unimportant as long as it is high enough to drive the grid of VT_1 above cut-off.

The hold control, R_3, must be set so that the frequency of the circuit will be lower than the desired frequency. The sync pulses will then take over and force the blocking oscillator to lock in with each succeeding sync pulse. If the sync pulse amplitude is reasonably high, R_3 can be varied over a fairly wide range without causing a loss of sync. The frequency set by R_3 cannot be made too low, however,

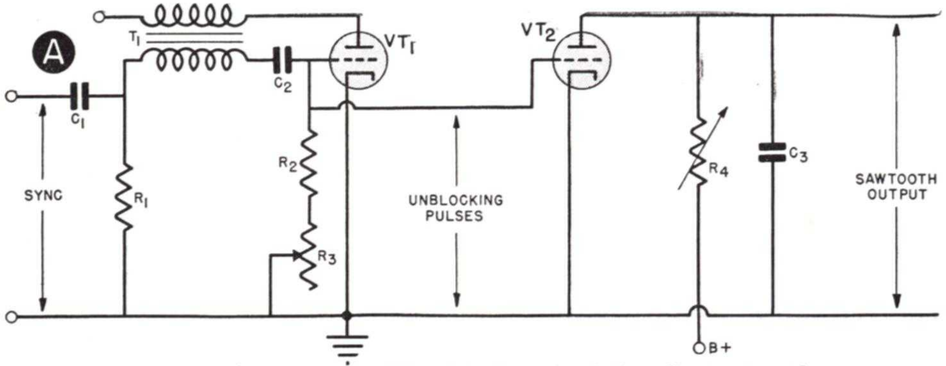
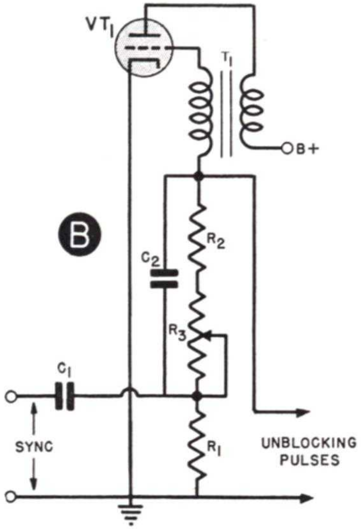


FIG. 10. Part A of this illustration shows a complete blocking oscillator-discharge tube circuit. Part B shows another form in which the same blocking oscillator may be drawn on a circuit diagram.



because then it would take a very high sync pulse to drag the frequency to the proper value. It cannot be made too high, either, because then the unblocking pulses would occur before the sync pulses, and the sync pulses would no longer be effective.

Now that we can produce controllable unblocking pulses, we can feed them into a discharge circuit as shown in Fig. 10A. The blocking oscillator in this circuit duplicates that in Fig. 9A. VT_2 is the discharge tube. No grid bias is necessary for VT_2, because the bias voltage developed across R_2 and R_3 (which is applied to this tube directly) will block it. While VT_2 is cut off by this voltage, C_3 will charge through resistor R_4 to produce the sweep portion of the saw-tooth wave. Then, when the voltage on the grid of VT_1 swings suddenly positive, VT_2 will conduct and discharge C_3. This gives the retrace portion of the saw-tooth wave. Since the amplitude of the pulses received from the blocking oscillator is fixed, this circuit produces saw-tooth pulses that are alike; and the blocking oscillator-discharge combination circuit will be self-operating and will supply the necessary sweep even if no sync pulses are tuned in.

Variable resistor R_4 controls the height of the saw-tooth pulse; varying its resistance changes the charging time of C_3-R_4 and thus determines the voltage to which the condenser will charge before the discharge tube operates. Thus, this control can be used to vary the length of a line or the height of the picture, depending on whether the circuit generates the horizontal or the vertical sweep.

The circuit in Fig. 10B shows another variation of the blocking oscillator. The operation is the same; the only difference is in the positions of the components, which bear the same labels as their equivalents in Fig. 10A. This circuit is shown to give you an idea of some of the variations you may expect in schematic diagrams.

Combination Generator. Many receivers use a combination of a separate discharge tube and a separate blocking oscillator like that shown in Fig. 10A because doing so permits the shape of the saw-tooth wave and of the control pulses to be individually adjusted. However, since the plate current of VT_1 flows in pulses that are exactly like the grid-voltage pulses, it is possible to use a single stage, as shown in Fig. 11, to produce both the pulses and the saw-tooth waves reasonably well. In this circuit, the saw-tooth-producing condenser C_3 and its associated charging resistance R_4-R_5 have been moved to the plate circuit of the blocking oscillator tube VT_1. When this tube is allowed to conduct, it will discharge condenser C_3 at the same time; when it is not conducting, C_3 will charge through R_5 and R_4 just as it would in a separate discharge circuit.

Combining functions in a single stage this way does not allow quite the fineness of adjustment of the wave shape that the use of separate circuits permits, and it requires a somewhat more critical adjustment of part values. However, it is an arrangement that is used in many receivers.

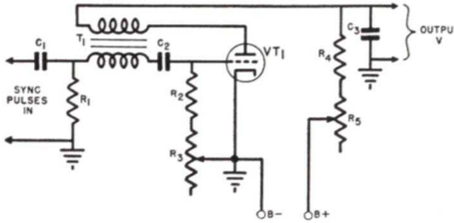


FIG. 11. A one-tube saw-tooth generator.

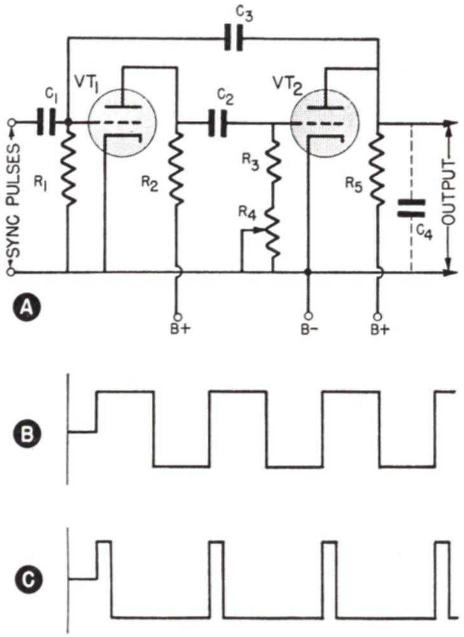


FIG. 12. A basic multivibrator circuit.

MULTIVIBRATOR OSCILLATORS

Another quite commonly used means of generating the control pulse is the multivibrator oscillator. As shown in Fig. 12, this is basically just a two-stage amplifier in which the output of the second stage is fed back to the input of the first stage. The arrangement is such that the signal fed back from VT_2 to VT_1 through C_3 is in the proper phase to produce oscillation.

If tuned circuits were used somewhere in this arrangement, this would be a sine-wave oscillator. However, because R-C elements are used instead of tuned circuits, the multivibrator basically produces the square wave signal shown in Fig. 12B. Let's first see how it produces this signal, then learn how it is possible to get the desired series of pulses shown in Fig. 12C.

The basic operation of this circuit is that the tubes conduct alternately, with conduction of one causing cut-off of the other. The increases and decreases in the plate current of each tube occur very quickly, with the result that these currents are pulses having very steep sides.

When the circuit is turned on, one of the tubes will draw slightly more current than the other and thus initiate the action. To understand the operation, let's assume that both C_2 and C_3 have an initial charge and that the plate current of VT_1 is decreasing. The conditions then will be like those shown in Fig. 13A.

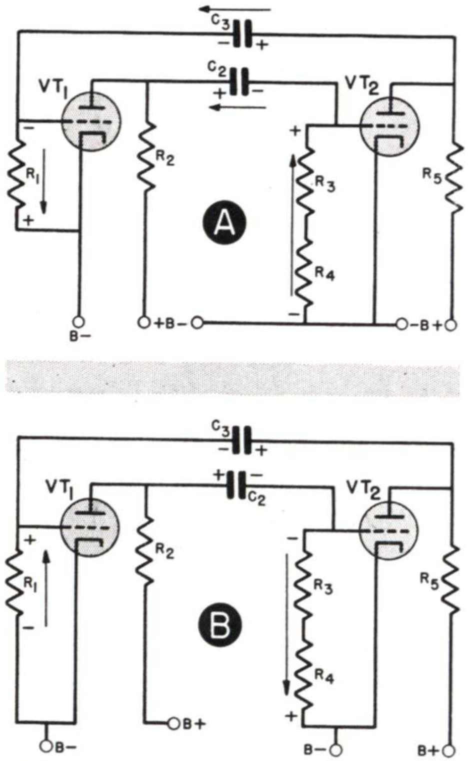


FIG. 13. How a multivibrator works.

Condenser C_2 is connected across the B supply through resistors R_3, R_4, and R_2. The voltage applied to C_2 when VT_1 is conducting is equal to the difference between the B voltage and the voltage drop across R_2 caused by plate current flow through it. When the plate current of VT_1 decreases (this is what we have assumed is happening), the drop across R_2 will decrease. C_2 will therefore start to charge, causing an electron flow through the grid resistors for VT_2 in the direction shown that will make the grid of VT_2 positive. With a positive grid, there will be an appreciable grid current flow; in other words, the internal resistance between the cathode and grid of VT_2 will become a low resistance through which C_2 can and will charge rapidly.

At the same time, this positive grid potential will make VT_2 pass a high plate current, so the drop across resistor R_5 will increase greatly. As you can see, condenser C_3 is connected across the B supply through R_1 and R_5. Since the voltage drop across R_5 caused by plate current flow is opposed to the B voltage as far as C_3 is concerned, this increase in the drop across R_5 will cause a decrease in the net voltage applied to C_3. Therefore, C_3 will start to discharge, causing an electron flow through R_1 in the direction shown. This will drive the grid of VT_1 negative, thus making the tube cut off.

Since R_1 is a high resistance, C_3 will discharge slowly. When it eventually reaches a voltage equal to the difference between the B voltage and the drop across R_5, its discharge current will cease to flow, and the voltage across R_1 will disappear. VT_1 will then be able to conduct again, so it will draw current through R_2.

The conditions in the circuit when VT_1 conducts again are shown in Fig. 13B. Since there is now a voltage drop across R_2 caused by the plate current flow, the voltage across condenser C_2 is reduced. Therefore, it will discharge through R_3 and R_4 in the direction indicated, thereby making the grid of VT_2 negative. Since this will cut off the plate current of VT_2, the drop across R_5 will disappear. The voltage applied to C_3 will therefore increase; consequently, C_3 will begin to charge, causing an electron flow through R_1 in the direction indicated. This will make the grid of VT_1 positive, thereby creating a low-resistance grid-cathode path in VT_1 through which C_3 can charge rapidly.

At the same time, C_2 will discharge relatively slowly through the high resistance R_3-R_4. It will eventually become stabilized, whereupon its discharge current will cease. The grid of VT_2 will then change from a negative potential back to zero, and VT_2 will again begin to conduct. The circuit conditions will then become those shown in Fig. 13A, and the cycle of events will start again.

You can see from Fig. 12A that the output pulses of this circuit are produced by the flow of the VT_2 plate current through R_5. If both tubes conduct for equal periods of time, the output will consist of the square-wave pulses shown in Fig. 12B. To get the pulses we want (Fig. 12C), we must make VT_2 conduct for a much shorter period than VT_1 does. We can do so by making the time constant of C_3 and R_1 far shorter than that of C_2-R_3-R_4. Check back through the preceding description of the action of the circuit, and you will see that adjusting the time constants this way will permit VT_2 to conduct for only relatively brief periods. The voltage across R_5 will then consist of the unblocking pulses we need to operate a discharge circuit.

A separate discharge circuit may be used with this oscillator, or the circuit can be made to act as its own saw-tooth producer. We can produce the latter circuit by adding a condenser C_4 across the output as shown by the dotted lines in Fig. 12A. This condenser will charge through R_5, the value of which can be adjusted to give the required charging time, and it will be discharged when tube VT_2 conducts: this charge-discharge action will give us the saw-tooth output we want.

Sync pulses may be fed in across R_1 as shown in Fig. 12A. If they occur at the proper time, they will drive the grid of VT_1 negative just before it would normally go in this direction, thus initiating the charging action of C_2 and hence causing plate current to flow through VT_2.

Cathode-Coupled Multivibrator. A simpler and somewhat more common variation of the multivibrator is shown in Fig. 14. This is known as a cathode-coupled multivibrator because the feedback voltages are produced across the bias resistor R_4, which is in the cathode circuits of both VT_1 and VT_2.

The action is basically like that just described except for the way in which VT_1 is prevented from conducting. Briefly, the action is as follows:

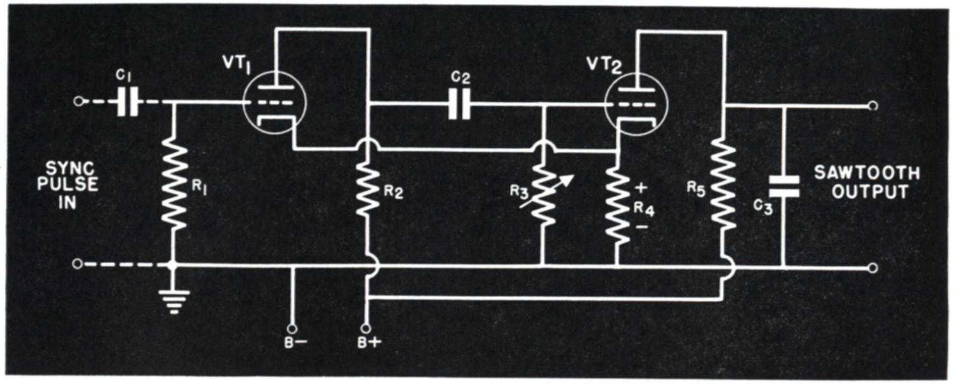


FIG. 14. A cathode-coupled multivibrator.

Condenser C_2 charges from the B supply when the circuit is turned on, producing an electron flow upward through R_3 that makes the grid of VT_2 positive and makes the grid-cathode path of this tube conductive. Condenser C_2 thus charges rapidly through a low-resistance path consisting of R_4, the internal grid-cathode tube resistance of VT_2, and R_2.

While C_2 is charging, VT_2 passes a high plate current. The grid and plate currents of VT_2 passing through R_4 create a high bias voltage drop across this resistor having the polarity shown in Fig. 14. Since the grid of VT_1 is tied to the negative end of R_4, this bias cuts off the plate current of VT_1. (VT_2 conducts because the voltage drop across R_3, produced by the charging action of C_2, is greater than the voltage developed across R_4.)

When C_2 approaches a full charge, the current flow through R_3 becomes less; the bias voltage across R_4 then becomes greater than the voltage drop across R_3, so VT_2 is cut off. Current flow through R_4 then ceases; the bias voltage across R_4 vanishes, and VT_1 is able to conduct. Conduction of VT_1 causes a drop across R_2, reducing the voltage across C_2, which then begins to discharge. Its discharge current produces a voltage drop across R_3 that keeps VT_2 cut off.

When the discharge of C_2 ceases, the drop across R_3 disappears, and VT_2 is again able to conduct. As soon as it does, a bias is built up across R_4 that begins to cut off VT_1. When this happens, condenser C_2 starts to charge, and the cycle repeats.

Since VT_2 cannot conduct while C_2 is discharging, we can control the interval between the plate current pulses of VT_2 by varying R_3, the high resistance through which C_2 discharges. R_3 thus acts as a hold control for the circuit.

The output of the circuit consists of the voltage pulses developed across R_5 by the plate current pulses of VT_2. Once again, we can either feed these voltage pulses to a discharge tube circuit or use a condenser C_3 in conjunction with R_5 to generate a saw-tooth output.

SINE-WAVE GENERATORS

Sine-wave oscillators are used in some television sweep circuits. Because of the extra effort needed to convert a sine wave into the right wave form, such oscillators are used only if another advantage, such as better synchronization, can be obtained through their use.

Fig. 15 shows a somewhat idealized sine-wave oscillator. Here, VT_1 is used in a Hartley oscillator circuit, with the screen grid acting as the plate. The signal produced across the L-C circuit is a sine wave (Fig. 15B). However, the bias and strength of oscillation are adjusted so that the tube reaches plate-current saturation early in each cycle; as a result, the plate current of the tube is squared off into the form shown in Fig. 15C.

This nearly square-wave pulse is fed into C_3 and R_4. Since these have a very short time constant, C_3 charges or discharges very rapidly, producing a brief pulse across R_4, every time the applied voltage charges. As a result, the square-wave voltage from VT_1 is converted into a series of sharp pulses as shown in Fig. 15D. These pulses can be used to operate the discharge tube VT_2.

Such sine-wave oscillators are allowed to operate at exactly the frequency desired for the sweep. So elaborate an oscillator chain is practically never used for frame scanning; only the horizontal or line sweep must be controlled so accurately that such an arrangement is desirable.

When a sine-wave oscillator is used, a sine-wave signal is coupled from L into a frequency-discriminating network where it is mixed with the sync pulses. An automatic frequency control (a.f.c.) arrangement is then used to set the sine-wave oscillator exactly on frequency, as you will learn when we study control circuits. This arrangement permits very accurate control of the fundamental frequency.

SUMMARY

We have learned that a saw-tooth voltage is produced by charging a condenser fairly slowly through a resistor and discharging it rapidly through a tube. Pulses obtained from one of three basic oscillators are used to con-

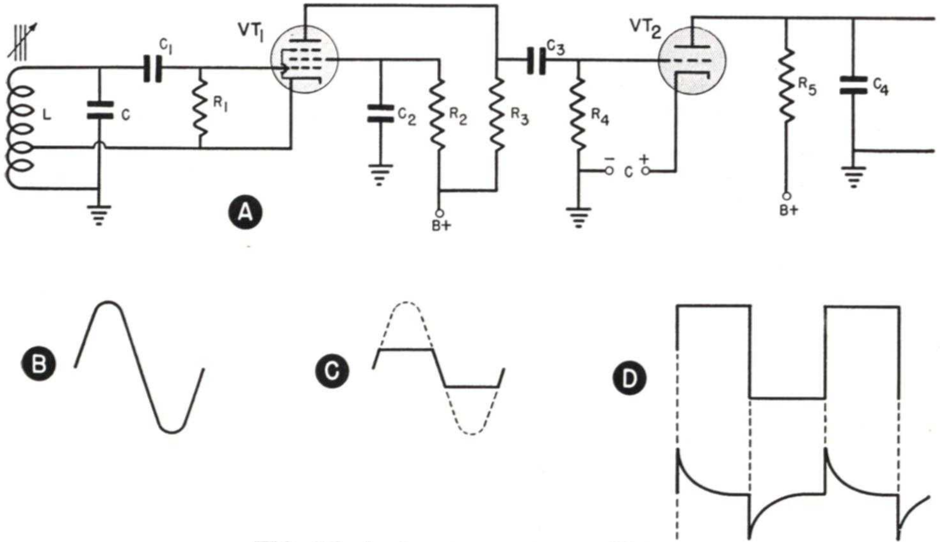


FIG. 15. A sine-wave sweep oscillator.

trol the discharge. This arrangement makes it possible for the circuit to produce the sweep voltage even when no control pulses are fed in from an external signal. Each of the three oscillators is arranged so that it will lock in with the signal when one is received and will therefore operate in synchronism with the lines or frames of the incoming signal.

The saw-tooth voltage that we have produced so far has nearly the right shape for use in all electrostatic systems and in certain electromagnetic circuits. (In other electromagnetic deflection systems as you will learn farther on in this Lesson, additional shaping of the wave is necessary.) Let's see how such a voltage is used to produce electrostatic deflection.

Electrostatic Sweep Circuits

The saw-tooth voltage that we described in the previous section is of the proper shape for an electrostatic deflection system, but it has two things wrong with it. First, it is not of sufficient amplitude, which means that it requires amplification. (Incidentally, the amplitude of a saw-tooth voltage is always measured from peak to peak—that is, from its least amplitude to its greatest amplitude.) Second, each discharge circuit we have pictured so far has one end of the wave-forming condenser going to ground, so one of the deflection plates to which the saw-tooth voltage is fed would have to be grounded also—an undesirable arrangement. Let's briefly study both of these problems.

Deflection Voltage. The voltage needed to deflect the electron beam in an electrostatic tube depends on the velocity attained by the beam, which is determined by the voltage applied to the second anode. In fact, there is a direct relationship between the second anode voltage and the deflection voltage needed: in a typical tube, the horizontal deflection voltage needed is about 30 volts for each inch of deflection, per kilovolt of second anode voltage.

To produce the 5½-inch line commonly secured on a 7-inch tube, assuming the tube has this 30-volts-per-inch rating, we need 165 volts per thousand volts on the second anode. This means that the horizontal deflection voltage must be 3 × 165 or 495 volts if the second anode is run at 3000 volts—and 990 volts if the second anode is run at 6000 volts!

We want high second-anode voltages to improve the picture brightness, and we want large picture tubes so we can have a big picture. We are limited in both respects, however, by the deflection voltages that it is possible to get. As a matter of fact, the deflection-voltage problem has limited electrostatic tubes to a maximum size of 10 inches. All picture tubes above 10 inches in diameter (and most of the 10-inch ones) use electromagnetic deflection.

Since the sweep voltages needed are much higher than the discharge circuit can furnish, there must be voltage amplifiers between the discharge circuit and the picture tube deflection plates. We'll study deflection amplifiers in a moment.

Balanced Deflection. There are several reasons why it is desirable to feed a pair of deflection plates with equal and opposite voltages with respect to ground rather than to have one plate grounded.

One reason stems from the fact that the second anode must be connected to the deflection plates so that the deflecting voltage will add to and subtract from the second anode voltage, rather than be entirely independent of it. This arrangement is necessary to minimize the electric field that forms between the second anode and the deflection plates and causes defocusing. If one of the plates were grounded, therefore, the second anode would have to be grounded also, which would mean that the cathode would have to be highly negative with respect to ground. The tube would operate all right this way, but the filament of the tube could not be operated from the same filament supply as other tubes, because it would not be safe to have a great difference in potential between the cathode and the filament of the picture tube. A separate filament winding would therefore be necessary, which is undesirable. Hence, the usual practice is to ground the cathode so there is a minimum difference between the cathode and filament potentials; this means the second anode cannot be grounded, and because of the common connection, the deflection plates cannot be directly grounded either.

More important, not grounding either deflection plate makes it possible for us to supply them from a push-pull stage in a balanced arrangement. The advantage of the push-pull drive is that one plate goes positive at the same time that the other goes negative, so the effective voltage between the plates at any time is twice as large as the voltage output of either tube alone. Remember, the deflection is proportional to the difference in voltage between the deflecting plates; for a given input signal to the driver stage, therefore, the push-pull circuit gives us twice as much deflection as a single-ended driver stage would.

Fig. 16A shows the basic connections for a balanced deflection system. The vertical sweep is applied to plates P_1 and P_2 through coupling condensers C_1 and C_2. The a.c. sweep voltage is developed across resistors R_1 and R_2.

Similarly, the horizontal sweep is applied to plates P_3 and P_4 through

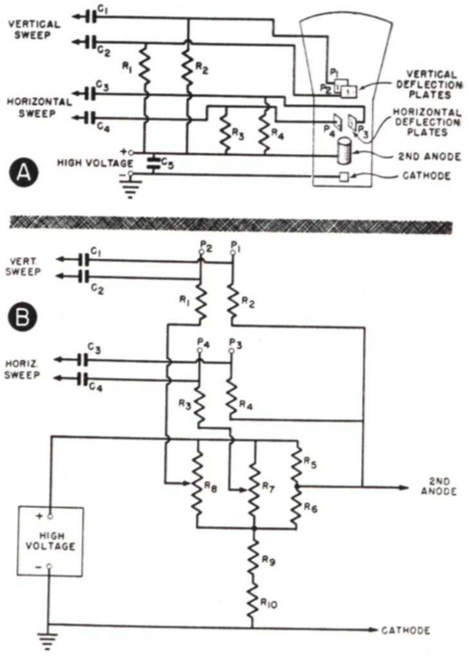


FIG. 16. The elements of an electrostatic deflection system.

condensers C_3 and C_4 and appears across R_3 and R_4.

The return circuits for both sets of deflecting plates are tied to the high voltage, which is applied directly to the second anode. Insofar as the sweep signal is concerned, the path is completed to ground through C_5. Since the impedance from each of the deflecting plates to ground is the same, this is a balanced system.

The actual connections are somewhat more elaborate than those shown here; Fig. 16B is more realistic. In this case, plate P_1 (through R_2) and plate P_3 (through R_4) are tied to the second anode, which goes to a junction of resistors R_5 and R_6 across a section of the voltage divider on the high-voltage supply. Shunting these two resistors are two variable resistors, R_7 and R_8, to which the other deflection plates are connected.

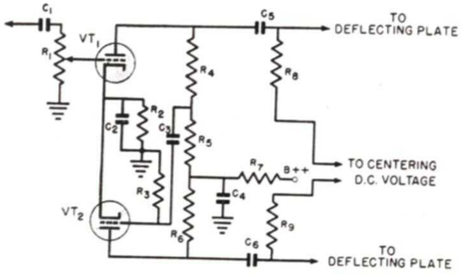


FIG. 17. A basic vertical deflection amplifier.

These variable resistors serve as centering controls; adjustment of either applies a d.c. voltage between the plates with which it is associated and thus moves the picture horizontally or vertically. In this circuit, adjustment of R_7 will move the picture horizontally, and adjustment of R_8 will move it vertically.

Electrostatic deflection systems vary in their complexity. In general, however, all of them have these features:

1. There is a d.c. path from the deflection plates to the second anode so that the deflection voltage will add to and subtract from the second anode voltage.

2. There is some means of varying the d.c. voltage applied to the plates to center the image.

3. The sweep voltages are applied to the deflecting plates through coupling condensers (such as C_1, C_2, C_3 and C_4 in Fig. 16), which must have voltage ratings high enough so that they can withstand the voltage applied to the second anode. These coupling condensers are special oil-filled paper types having voltage ratings of as much as 10,000 volts.

DEFLECTION AMPLIFIERS

The high sweep-voltage requirement means that we must have an amplifier following the discharge circuit. Therefore, in all practical television receivers, the sweep circuit is actually a chain of stages that include a sweep oscillator, a discharge circuit, and an amplifier. The amplifier stage of the sweep chain in the electrostatic system uses a push-pull arrangement to get a balanced output. Since it is necessary to use a great many tubes in a television receiver, every effort is made to reduce the number of tubes needed in the sweep chains; as a result, there are some rather unusual designs in use. Let's study some of these.

Vertical Deflection Amplifier. Fig. 17 shows a basic amplifier of the kind used in the vertical or frame sweep chain. Tubes VT_1 and VT_2 are in push-pull. In a sound receiver, this stage would be preceded by a separate tube used for phase inversion, but here tube VT_1 acts as a combination amplifier and phase inverter. Its load is the combination of resistors R_4 and R_5, which act as a voltage divider and are arranged so that the signal voltage drop across R_5 applied through C_3 to the grid of VT_2 will feed just enough signal to the grid of VT_2 to cause its output across R_6 to be equal to that across R_4-R_5. Of course, VT_2 inverts the phase of this signal 180°, so we get normal push-pull operation—at the moment the plate of one tube is at its maximum positive point, the signal output of the other is reaching a maximum negative value.

This one amplifying stage is all that is needed. We have a reasonably high input from the discharge circuit—perhaps as much as 100 volts is available. It is customary, however, to take only about 20 volts from the discharge stage and then to use high-gain triodes or pentodes in the amplifier to give a stage gain of at least 20.

Of course, the amount of gain in an amplifier stage depends on the load—the higher the load resistance, the more nearly the gain equals the amplification factor of the tube. If, for example, we feed a voltage of 20 volts into VT_1 by adjusting the input control R_1 properly, and the stage has a gain of 20, the voltage across the load will be 400 volts. The exact amount we want depends on the needs of the picture tube, of course; we can get what we want by adjusting R_1 to provide the proper input. Hence, this control will set the picture height or width, depending on whether this is a vertical or a horizontal sweep chain. Since the picture width is greater than the picture height by a ratio of 4 to 3, more voltage is needed for the horizontal sweep than for the vertical sweep.

However, the output voltage can reach such levels only if the B supply voltage is high enough to provide the plate voltage needed to deliver the high signal we want and also to make up for the loss in the high-resistance load. The B++ voltage applied through R_7 may be as high as 500 to 1000 volts; such voltages are usually obtained from the high-voltage supply that operates the picture tube.

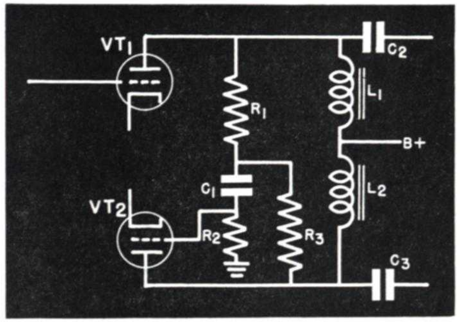


FIG. 18. Diagram of a horizontal deflection amplifier.

The amplified sweep voltage that exists across R_4-R_5 and R_6 is applied to the deflecting plates. These voltages are balanced with respect to ground; the ground circuit for the a.c. sweep signal is from the common point of the load resistor through C_4 to ground. The filter circuit (C_4 and R_7) keeps the sweep voltage out of the B supply.

Condensers C_5 and C_6 are coupling condensers used to feed the sweep signal to the deflecting plates. Because of the high voltages that come from the anode supply to the deflecting plates, these condensers must have high voltage ratings.

Horizontal Deflection Amplifier. The circuit shown in Fig. 17 can also be used for the horizontal sweep, but the one in Fig. 18 is more commonly used for this purpose because it is better able to deliver the high voltages needed for horizontal deflections. In this circuit, inductances L_1 and L_2 serve as the loads. These choke coils are made to have very high reactances at the sweep frequencies, so the tubes are offered a full load and therefore deliver maximum signal output. The only d.c. voltage loss occurs in the relatively low resistances of these coils, so not much of the B supply voltage is wasted.

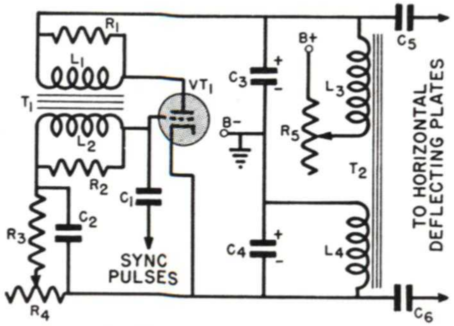


FIG. 19. Single-tube sweep circuit.

The network of R_1, blocking condenser C_1, and R_2 acts as a voltage divider to supply the signal necessary to operate tube VT_2. Resistor R_3, connected from the plate of VT_2 back to this network, provides degeneration by feeding back a voltage to the grid of VT_2 that is out of phase with the incoming voltage. This degeneration not only flattens the response of VT_2 but also makes the gain of the stage more independent of minor changes in the characteristics of the tube. This is one form of balanced phase inversion.

Single-Tube Sweep. The amplifiers in Figs 17 and 18 are usually preceded by a sweep oscillator (either a multivibrator or blocking type and by a discharge circuit that may be a part of the oscillator. In the unique circuit shown in Fig. 19, however, a single tube acts as a combination blocking oscillator-discharge-push-pull amplifier!

In the blocking oscillator section of this circuit, transformer T_1 provides the feedback path from plate to grid, and condenser C_2 along with resistors R_3 and R_4 provide the blocking action in the grid circuit. R_1 and R_2 are damping resistors that smooth out the oscillatory pulse produced by the blocking oscillator.

The sync pulses necessary to control the oscillator are fed in through C_1.

Instead of being produced by the usual R-C charge circuit, the sawtooth wave is formed by a resonant circuit that, by resonance step-up, gives the needed amplification. Let's start our study of the action of this circuit during a time when VT_1 is cut off or not conducting. At such times, condenser C_3 is charged through R_5 and L_3 because it is across the B supply, as shown in Fig. 20A. (Notice that B+ is connected to R_5.) The charging current for C_3 that flows through L_3 induces a voltage in L_4, with the result that condenser C_4 is charged at the same time and to the same voltage as C_3. The polarity of the condenser voltages is such that the voltage applied between the deflection plates through the coupling condensers C_5 and C_6 is the sum of the two condenser voltages.

Returning now to the blocking oscillator action, when the charge stored in the grid condenser C_2 (Fig. 19) leaks off enough so that VT_1 suddenly starts to conduct, it effectively ties the upper end of C_3 to the lower end of C_4 through the combination L_1-R_1 and through the tube resistance (see Fig. 20B). Since the positive terminal of one condenser is thus tied to the negative terminal of the other through this low-resistance path, the condensers discharge rapidly; this gives the retrace portion of the cycle. Then, when the tube cuts off again, condenser C_3 again starts to recharge and the scanning voltages build up again.

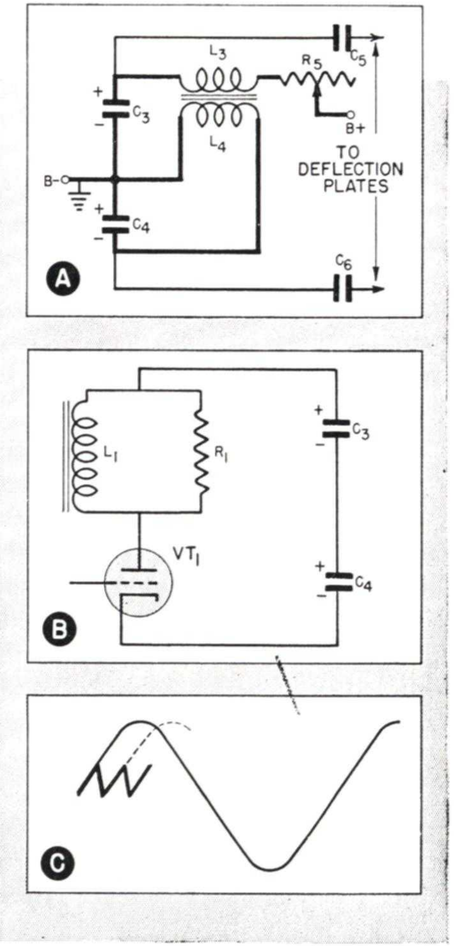


FIG. 20. How the single-tube sweep works.

In this circuit, resonance step-up is used to make the output voltage several times that of the B supply so that sweep voltages of 800 to 1200 volts can be obtained with a B supply of 250 volts.

The tube and blocking oscillator parts effectively disappear on the charging cycle, so the circuit is then like that in Fig. 20A. The parts C_3, L_3, and R_5 form a series-resonant circuit across the B supply. This is a high-Q circuit, capable of producing a sine-wave voltage across C_3 of five or ten times the supply voltage if it were allowed to reach its peak. However, the parts values of the circuit are chosen so that resonance is at a frequency far lower than the horizontal sweep frequency: long before the voltage across C_3 can reach its peak sine-wave value, therefore, the discharge action is initiated. As a result, only the relatively straight portion of the sine-wave voltage across C_3 is used (Fig. 20C). Even so, the peak reached can be two or three times the supply voltage. This peak voltage is applied across each condenser (remember, C_4 is charged to the same voltage as C_3 because of the interaction between L_3 and L_4). This circuit is normally used for horizontal deflection because of its ability to deliver such a high voltage from a normal plate supply.

If the blocking oscillator should fail to discharge C_3 and C_4, they could charge to the high peak value determined by the Q of the resonant circuit. For this reason, the condensers used in this circuit must have high voltage ratings to prevent breakdown if the blocking oscillator should fail to function.

Resistor R_5 is the horizontal size control; its setting determines the amount of the B supply voltage applied to the circuit and hence controls the amplitude of the sweep voltage. Resistor R_4 (Fig. 19) is the hold control.

From the foregoing, the number of tubes used in an electrostatic deflection system may be as few as one (in a circuit like that in Fig. 19) or as many as five (two tubes in a multivibrator, one in a discharge circuit, and two in a push-pull amplifier. Of course, these can be multi-purpose tubes, with at least two in the same envelope). The practice of using a separate discharge tube is gradually dying out; most commonly, deflection circuits now consist of a single-tube blocking oscillator or a dual-tube multivibrator with a built-in discharge circuit driving a dual-tube amplifier.

In any case, the output will be a saw-tooth voltage of rather high peak value. The frequency of the output will depend upon whether it is for horizontal or vertical deflection; this frequency will be controlled by the sync pulses.

Basic Electromagnetic Sweep Circuits

In an electromagnetic deflection system, one pair of coils is used for horizontal deflection and another pair for vertical deflection. These coils, which are wound around the neck of the tube, establish a strong electromagnetic field within the picture tube.

This deflection electromagnetic field does not have any relationship to the focusing and accelerating fields, so it is unnecessary to tie the coils to the second anode. This is a major difference between the electrostatic and electromagnetic systems that simplifies the latter considerably, because it allows the deflection coils to be operated more nearly at ground potential and makes for simpler connections to them. It also permits the use of single-ended output stages, which proves quite helpful in the design of these circuits.

Another important basic difference between electromagnetic and electrostatic deflection is the fact that the deflecting field in the former is proportional to the number of turns in the coils and to the *current* through them—not to the applied voltage. Therefore, we don't need particularly high voltages across the deflection coils, but we do need high currents. The driving tubes in an electromagnetic system must therefore be power tubes instead of the voltage amplifiers used in electrostatic systems.

As a matter of fact, the power demands in an electromagnetic system are rather considerable, particularly in the horizontal sweep circuit. Here, a rather husky power tube is always used, and sometimes two are used in parallel.

TRAPEZOIDAL WAVES

Since the deflection field in an electromagnetic system is proportional to the current through the coils, we need a saw-tooth current to produce the proper deflecting action. Because a coil resists sudden changes in voltage, such a saw-tooth current cannot be produced by applying a saw-tooth voltage to the coil. Let's see what shape the applied voltage must have to make the coil current a saw-tooth current.

Let's suppose we have a perfect coil (no resistance) as shown in Fig. 21A and want the saw-tooth current shown in Fig. 21B to flow through it.

If we apply a d.c. voltage (Fig. 21C) to a coil, the current through the coil will build up as shown in Fig. 21D. The rate at which this current rises depends on the inductance, on the voltage, and on how long the voltage is applied. In a perfect coil, this current could reach infinity if the voltage were applied long enough.

If we apply the voltage for just a short period of time, then cut it off for an equal period of time (Fig. 21E), we will get the triangular current flow shown in Fig. 21F. We can change this into a saw-tooth current by finding some way of making the right-hand edge of the wave more nearly vertical.

A voltage having the form shown in Fig. 21G will do the trick. The high, short negative pulse will make the coil current drop suddenly, producing the saw-tooth current in Fig. 21H.

The voltage shown in Fig. 21G is very similar to the output from a blocking oscillator or multivibrator. Therefore, if the output of one of these devices could cause enough current to flow, and if the coil had negligible resistance, we could get a saw-tooth coil current without using a discharge circuit.

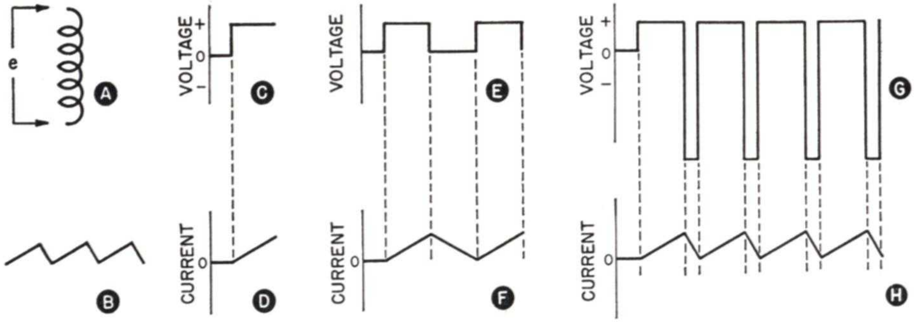


FIG. 21. How a saw-tooth current can be made to flow in a perfect coil.

However, the coils with which we are dealing have appreciable resistance (which, as we shall show later, is needed to damp out oscillations). A practical coil is therefore like the combination shown in Fig. 22A.

A voltage having a rather unusual wave shape must be applied to get a saw-tooth current to flow through this combination. A voltage having the form shown by curve 1 of Fig. 22B must be used to create a saw-tooth current in an inductance, and one having the shape shown by curve 2 must be used to create such a current in a resistance; therefore, the two voltages must be combined, producing the

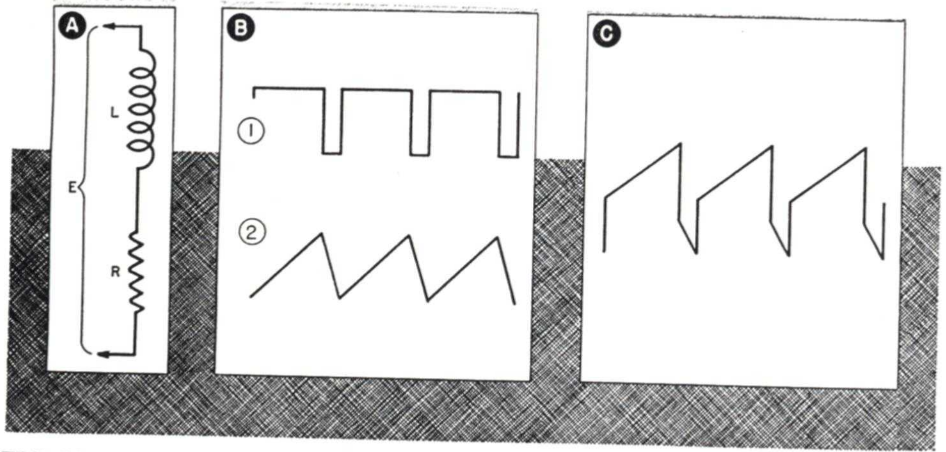


FIG. 22. A trapezoidal voltage wave must be applied to a practical coil to produce a saw-tooth current.

"trapezoidal" wave shown in Fig. 22C, to create a saw-tooth current through a combination of inductance and resistance.

The proportion of pulse voltage to saw-tooth voltage needed in the trapezoidal wave depends on the relative proportions of inductance and resistance in the coil. Therefore, the circuits used to shape this trapezoidal wave must be designed to suit the particular deflection coils to be used with them and may be widely different in parts values in different receivers.

The trapezoidal wave shape wanted can be obtained by making a simple modification in the discharge circuit that we studied earlier. A typical arrangement is shown in Fig. 23. This is a standard discharge circuit except that resistor R_3 has been added in series with C_2. The effect of this addition is to produce the trapezoidal output voltage e_0 shown in Fig 23B. Let's see why.

When the circuit is turned on, condenser C_2 starts to charge through R_2 and R_3 in series. The condenser current flowing through R_3 causes a voltage drop that is in series with the saw-tooth condenser voltage and is maximum when the circuit is first turned on. This voltage drop gives us our initial vertical rise in e_0 from point 1 to point 2 in Fig. 23B, after which the condenser charges in a normal manner from 2 to 3. Of course, as the condenser charges, its current continues to flow through R_3, maintaining the drop across the resistor.

When VT_1 suddenly conducts to discharge C_2, the discharge current flows in the opposite direction through R_3, reversing the polarity of the drop across it. Since a maximum current flows at the start of the discharge cycle, the output voltage drops suddenly down from its highest peak value (3) to value 4. Condenser C_2 then discharges rapidly through the relatively low resistance R_3, and the tube to form the portion 4-5, which is the retrace part of the saw-tooth cycle. The cycle then starts over again when VT_1 is cut off.

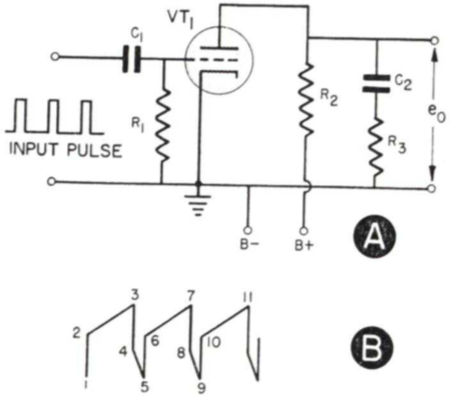


FIG. 23. Trapezoidal discharge circuit.

The slopes of the saw-tooth portions of the wave depend on the values of R_2 and C_2, and the heights of the vertical rises and drops depend on the value of R_3. (Because of the special shape of the output, the resistor R_3 is known as a "peaking" resistor.) If the proper values are chosen for these parts, it is possible to produce the exact wave shape required for the particular deflection coils that are to be used.

Although we have shown a separate discharge tube in Fig. 23, the action might equally well be produced by modifying a built-in discharge circuit.

Now that we have the required trapezoidal wave, we need a power amplifier to get the current we need. Since the vertical or frame sweep is simpler in design than the horizontal sweep, let's study it first.

MAGNETIC SWEEP CIRCUITS FOR VERTICAL DEFLECTION

The wave produced in Fig. 23 has the right form, but it must be amplified to furnish the fairly high current needed to deflect the electron beam. A power amplifier much like the output stage of a sound receiver is used to produce this amplification. A typical circuit is shown in Fig. 24.

The vertical deflection coils, L_3 and L_4, are not high inductances because there is practically no iron in their core—only that provided by a bundle of iron wire that is wound around the deflection yoke assembly. Common inductance values for these coils are around 50 millihenrys. At 60 cycles, this inductance has a reactance of only about 20 ohms—in fact, the resistance of one of the coils may easily be 3 or 4 times its reactance.

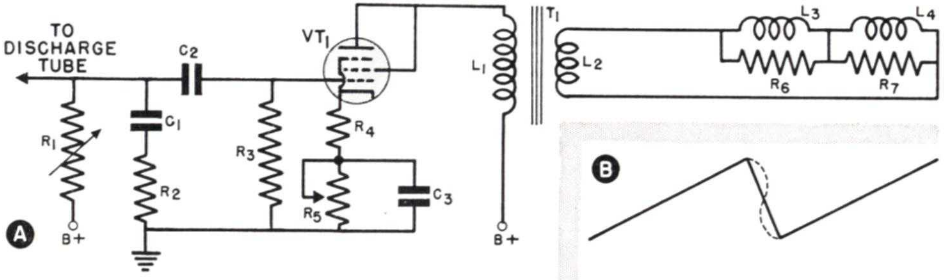


FIG. 24. A typical vertical deflection sweep amplifier.

Notice that the screen grid and the plate of the pentode power tube VT_1 are tied together. This lowers the plate resistance of the tube enough to permit it to be matched to the low-impedance coils by a transformer having a reasonable turns ratio.

Let's run through the operation of the circuit in Fig. 24 briefly:

Condenser C_1 and resistor R_1 are the basic wave-shaping parts, and peaking resistor R_2 produces the trapezoidal wave shape from what would otherwise be a saw-tooth wave. This circuit is operated by a discharge tube (which may be a part of the sweep oscillator).

The signal is applied to the grid of the power output tube through coupling condenser C_2 and appears across R_3. Resistor R_5 is a linearity control; adjusting it changes the bias on VT_1 and thus makes it possible to find the most linear part of the characteristic of the tube. Since varying the bias will change the gain of this stage and therefore change the height of the picture, the height control R_1 must be readjusted whenever R_5 is adjusted until the best compromise between a perfectly linear sweep and the desired picture height is secured.

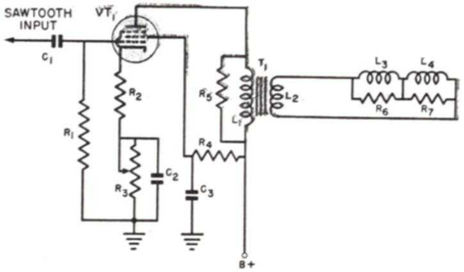


FIG. 25. Pentode vertical sweep amplifier.

During the sweep portion of the cycle, the current through the deflection coils L_3 and L_4 steadily increases in a linear manner, just as it should. When the end of the sweep period is reached, however, and the voltage suddenly changes to produce the retrace portion of the cycle, we do not get the normal retrace shape, because the deflection coils have a tendency to self-oscillate under the shock of the sudden voltage change. (There is considerable distributed capacity in the circuit and in the deflection coils; this capacity forms a resonant circuit with the inductance of the deflection coils and the transformer secondary.)

Instead of going to great trouble to avoid this oscillation, it is permitted to exist during the retrace, so the retrace may be half a sine wave in shape rather than linear with respect to time. As shown in Fig. 24B, the retrace may follow the dotted line instead of the straight line from the end of one scanning sweep to the beginning of the next.

This doesn't matter, because we must have linearity only during the actual sweep. It is perfectly all right for there to be distortions in the shape of the retrace as long as the distortions repeat themselves exactly (so that each line will be of the same length) and are completely wiped out before the beginning of the next sweep.

To meet these requirements, the coils are made with inductance and capacity values such that a half cycle of the oscillation will be completed within the desired retrace time. The oscillation is then forced to die out before the next sweep by the resistive loading in the circuit. There are three forms of loading here: 1, the resistance within the coils provides a low Q; 2, the coils are shunted by resistors R_6 and R_7, which further load them and control oscillations; and 3, the low plate resistance of the tube appears across the coils through transformer T_1 and also tends to load them.

Thus, although we use the proper trapezoidal voltage, the current is not exactly a saw-tooth; however, it is linear during the sweep, and the retrace variations are controlled so that they do no harm.

The circuit in Fig. 24 is the basis for most electromagnetic vertical sweeps. There is one important exception, however, which we shall now describe.

PENTODE VERTICAL OUTPUT

In a few instances, a true pentode connection has been used for the output in the vertical sweep chain of an electromagnetic set. The basic circuit is shown in Fig. 25. The most important difference between this circuit and that in Fig. 24 is the fact that here the screen grid is brought back to a separate voltage supply so that a true pentode action is obtained.

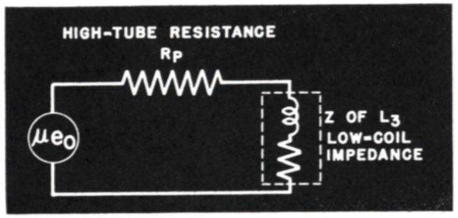


FIG. 26. Equivalent circuit of the pentode vertical sweep amplifier.

This connection leads to several basic differences in operation. To begin with, we now have the extremely high plate resistance of the pentode tube in series with the relatively small load reflected into the primary circuit by transformer T_1. This makes the effective inductance in the plate circuit of VT_1 so small that the circuit is basically resistive, as shown in Fig. 26. Since the circuit appears to be resistive, it is possible to produce a saw-tooth current in the plate circuit by feeding the grid of VT_1 with a saw-tooth voltage, just as we would in an electrostatic system.

Since the plate resistance of the tube no longer acts to damp oscillations, the resistor R_5 (see Fig. 25) is connected across the primary of T_1 to serve this purpose. To stabilize the circuit further, the screen-grid voltage is supplied through resistor R_4. Condenser C_3 is a by-pass for the screen.

Horizontal Electromagnetic Sweep Circuits

Although the horizontal deflection system may seem at first glance to be quite similar to the vertical deflection system in electromagnetic units, there is quite a difference in the actual design of the circuits used.

Since the picture is wider than it is high, the horizontal lines are longer than the height of the picture. The horizontal deflection field must therefore be stronger than the vertical one. However, the horizontal deflection coil cannot be as large as the vertical deflection coil, because the inductance and distributed capacity in the normal coil and output transformer would cause the retrace oscillation to be at too low a frequency. We want a half cycle of the oscillation to be over within the retrace time, which is about 6 micro-seconds; since the line rate is 15,750 lines per second, this oscillatory cycle must be about 71 kc. (The field rate is only 60 cycles, so the half-cycle oscillation need not be completed for about 800 microseconds; hence, the frequency of the vertical retrace oscillation need be only about 600 cycles.)

As a further handicap, a large inductance will have a reactance (at 15,750 cycles) that will be high compared to the resistance. This makes damping more difficult.

We cannot use too small a horizontal deflection coil, because then an excessively high current would be required to produce the magnetic field needed, which would mean that the driving tube would have to deliver extremely high amounts of power. As it is, a small transmitting tube is commonly used for the horizontal deflection output, and in some receivers a pair of these tubes are used in parallel.

Since it is practically impossible to prevent oscillation completely, designers have compromised on reasonably small coils that can produce a frequency high enough for a half cycle to be over in the retrace time, but not so small that the current requirement is unreasonable. Values around 8 millihenrys are used.

This oscillation must be damped out during the retrace time (about 6 microseconds). To provide this high-speed action, the circuit is arranged so that there is no damping except the internal resistance of the deflection coils during the first surge of the oscillation. Then, when a half cycle has been completed, a "damping" or "reaction scanning" tube closes a low-resistance path across the horizontal deflection coils, killing the oscillation very rapidly. Let's see how this damping circuit works.

HORIZONTAL DAMPING

A basic horizontal deflection output is shown in Fig. 27A. The power output tube VT_1 is connected to the primary of transformer T_1. The secondary coil L_2 is connected to the horizontal deflecting coils L_3 and L_4. A diode damping tube VT_2 and a loading resistor R_1 are connected across the deflecting coils.

Let's start our study with the action shown in Fig. 27B. Let's assume that the scanning current is progressing from M to N. At the time it reaches N, the output tube (VT_1) current is suddenly cut off because its grid is driven sharply negative by the trapezoidal voltage applied to it. This produces a sudden and sharp voltage change across the deflection coils L_3 and L_4, with the result that oscillation develops. With no damping other than the coil resistance, the oscillatory cycle would go through the points N-O-P-Q-R. We want only the half cycle from N to O of this oscillation (which gives us the retrace that we want), so we have to find some way to get rid of the energy that would continue the oscillation beyond O.

When the current through the coils reaches its negative peak O, it reverses in its direction. Since the voltage across an inductance is 90° ahead of the current, the voltage across the deflection coil goes through zero at this instant and starts to make the plate of the damping tube VT_2 positive with respect to its cathode. Hence, when the current has reached point O, tube VT_2 begins to conduct, permitting current to flow through R_1. The value of resistor R_1 is chosen so that the circuit is critically damped; the oscillations therefore cease at once, and the current flow through the coil

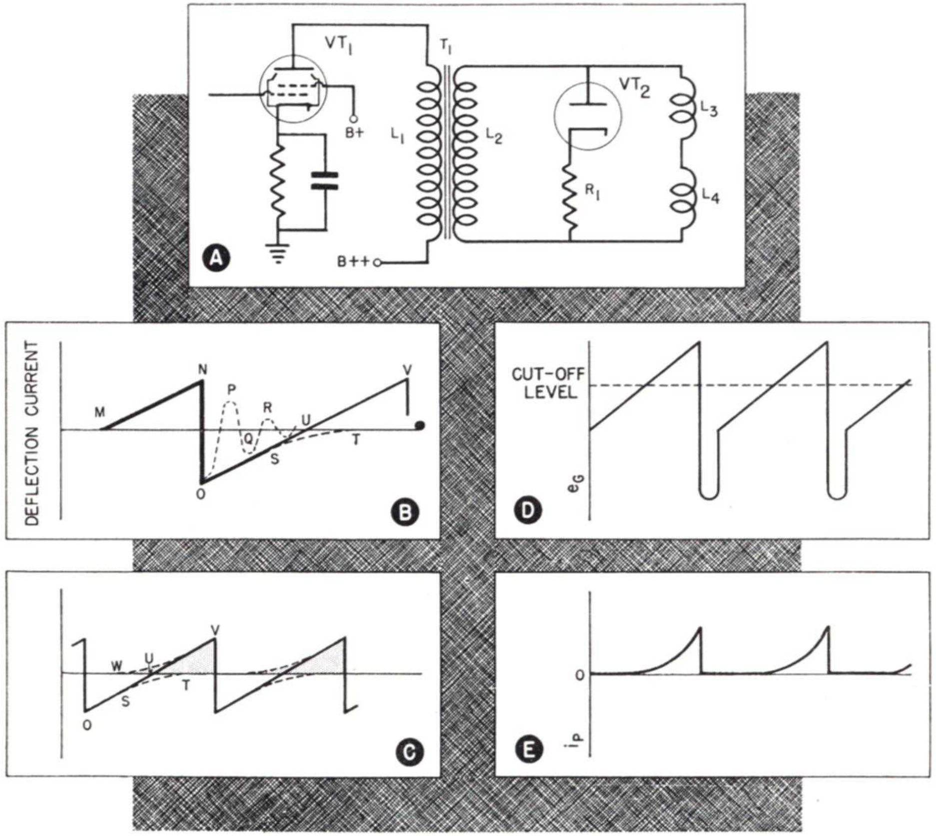


FIG. 27. How the horizontal sweep current for an electromagnetic sweep circuit is produced.

decreases toward zero along the line O-S-T.

To produce the proper deflection, the current through the deflecting coils must have the form shown by the line O-S-U-V. The energy stored in the coils that is released by the damping action supplies the first part of this current (from O to S). Beyond this point, however, the stored-energy current dies off along the line S-T, rather than moving from S to U.

Here the output tube begins to come into play, as shown in Fig. 27C. Just at the time the stored-energy current begins to die out, the tube begins to deliver current along the line W-V. These two currents added together produce the desired deflecting current O-S-U-V.

On succeeding cycles, the action is repeated. Tube VT_1 supplies power through transformer T_1 during the shaded portion of each cycle shown in Fig. 27C. When the tube is cut off suddenly (point V), an oscillatory action is started that produces the retrace and stores energy in the resonant circuit that is dissipated gradually to give the start of the next trace.

The grid voltage applied to output tube VT_1 is shown in Fig. 27D. This tube can pass current only when the grid voltage is above the cut-off value shown by the dotted line. (The rest of the input wave merely keeps the tube from conducting; the trapezoidal wave shape is needed so that the plate current can be cut off sharply.) Therefore, the plate current for this tube has the form shown in Fig. 27E. The curvature in this plate current is caused by the fact that we are operating over the knee of the characteristic curve of the tube. This plate current must be shaped very accurately so that the current flow produced in the secondary circuit will join smoothly with that flowing in the damping tube circuit to give the required deflection current. Therefore, we need some means of adjusting the characteristics of the output tube to make it deliver a plate current having the proper peak value and the proper shape. We'll show how this is done in a moment.

A TYPICAL DIODE DAMPER

Now that we have studied separately the various actions that occur in the output section of a horizontal electromagnetic sweep circuit, let's see how the whole section works. A typical practical circuit is shown in Fig. 28.

The oscillator and discharge circuits are not shown here. For our discussion, let's just say that they furnish a trapezoidal wave of accurate frequency to the grid of the power output tube VT_1.

This tube is usually a small transmitting tube, the plate connection of which is brought out to a top cap. A high-powered tube is needed to handle the current, and the unusual plate top-cap connection is needed because the inductive kick-back through the transformer from the oscillatory action of the deflection coils produces a momentary peak plate voltage of 5000 to 10,000 volts, which the ordinary tube socket and base cannot withstand. Putting the plate connection on top of the tube makes the envelope act as an insulator. Since such high peak voltages exist on the plate of the tube, you should never touch the plate circuit while the set is in operation.

Many receivers use this high peak pulse to supply the high voltage necessary for operating the picture tube. In such cases, the output transformer has the additional windings L_2 and L_3 (Fig. 28), which are connected to a rectifier-filter system that furnishes a d.c. output to the picture tube of from 7000 to 15,000 volts, depending on circuit design. We'll study such high-voltage supplies elsewhere in the Course.

The plate supply path for VT_1 is somewhat involved. Moving from the plate of the tube, it goes through L_1, through coil L_6, and then either through resistor R_4 or through the damping tube VT_2. From here, there is a parallel path through the deflection coils L_8 or through the secondary of the transformer L_4 to the B+ terminal (+280 volts). Since the cathode of the power tube is returned to a point that is at –100 volts with respect to ground, the total plate voltage applied to the tube is 380 volts (280 + 100).

The deflection circuit is somewhat more involved than the one we described earlier. The deflection coils are lumped together here as L_8. An additional condenser C_6 is connected across a part of the winding to supply additional capacity to get resonance at the proper point. Resistor R_5 is a centering control; it can be adjusted to change the d.c. current through the L_4-L_8 path and thus to center the picture on the face of the tube.

Coil L_7 is known as the width control. By varying the inductance of this coil, we can control the amount of signal applied to the deflection coils, thus controlling the width of the picture.

Adjusting this control to vary the width of the picture may make the lines non-linear. This lack of linearity can be corrected by changing the input voltage fed to VT_1 and by adjusting L_6, which is in the plate supply of this tube.

The control that varies the input voltage on the VT_1 grid is known as

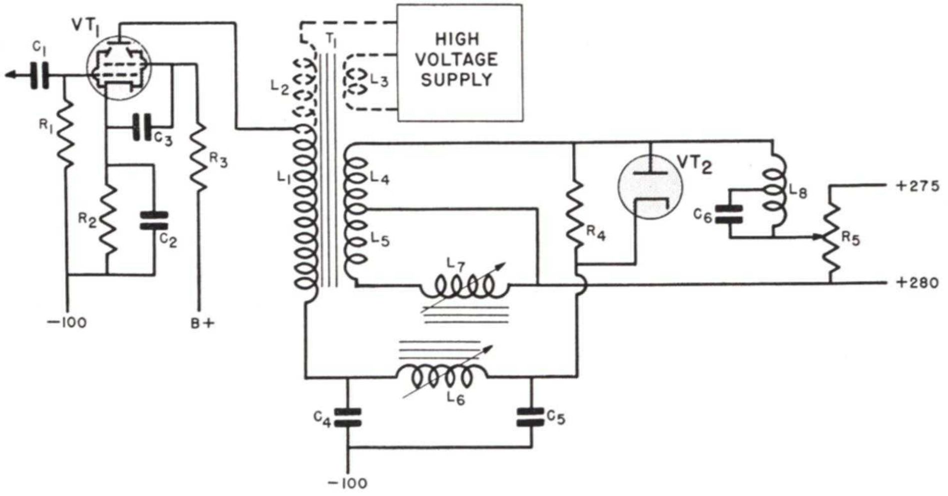


FIG. 28. The output section of a typical horizontal electromagnetic sweep circuit in which a diode damper is used.

the "drive" control because it changes the peak value reached by the grid voltage and hence controls the peak of the plate current.

Coil L_6 is used to adjust the plate voltage applied to VT_1 and hence affects the shape of the plate current pulse. For this reason, it is known as the "linearity" control. Let's run through the operation to see how L_6 works.

The plate supply circuit of VT_1 must be completed all the time, so resistor R_4 is included to complete the path from L_6 back through the deflection network to B+. Since R_4 is a fairly high resistance, it does not act as a load on the resonant circuit, which includes the deflection coils L_8, the condenser C_6, the inductive effects of the transformer secondary, and the width control L_7.

At the end of the oscillatory cycle, when damping is desired, tube VT_2 begins to conduct. The current that is passed by this tube is used to charge condenser C_5. As you can see from Fig. 28, the full B supply voltage (380 volts) is always applied across this condenser. When VT_2 is passing current, the voltage across C_5 rises to about 430 volts; when VT_2 cuts off, and tube VT_1 starts drawing current, C_5 discharges back to the 380-volt B-supply level. Effectively, therefore, there is a pulsating or a.c. voltage having the sweep frequency across this condenser. (This voltage is supplied by the energy stored in L_8 that is released when VT_2 conducts.) As you can see, this a.c. voltage is applied to the plate of VT_1.

Connected to C_5 is a phase-shifting network consisting of condenser C_4 and inductance L_6. By adjusting the inductance of L_6, we can shift the phase of the a.c. voltage across C_5 with respect to the time that it is applied to the plate of VT_1; this lets us control to some extent the shape of the plate current pulse.

All of the controls associated with this circuit are interlocking to a certain extent; in other words, adjusting one usually makes it necessary to adjust one or more of the others also. Adjusting the width control L_7 changes the width but also causes the right side of the picture to stretch slightly by effectively speeding up the scanning in this portion of the scanning cycle. Adjusting the drive control that varies the input to the tube VT_1 also increases the width somewhat but crowds the right side of the picture and stretches the left side. Thus, these two controls tend to off-set each other to some extent. Adjusting the linearity control L_6 does not appreciably effect the width but does correct to a small extent for other irregularities. Rotation of the control in one direction causes the second quarter of the picture to stretch and the first quarter to crowd, and vice versa. In other words, adjusting this control mostly affects the first half of the scanning sweep.

TRIODE DAMPING

The diode damping tube circuit that we have just described is used by a great many manufacturers. Some others use a triode tube connected as shown in Fig. 29. Here, tube VT_2 is a dual-triode power tube arranged with the sections in parallel. The parallel connection of the two triode sections gives them a very low plate resistance that loads the deflection coils during the damping portion of

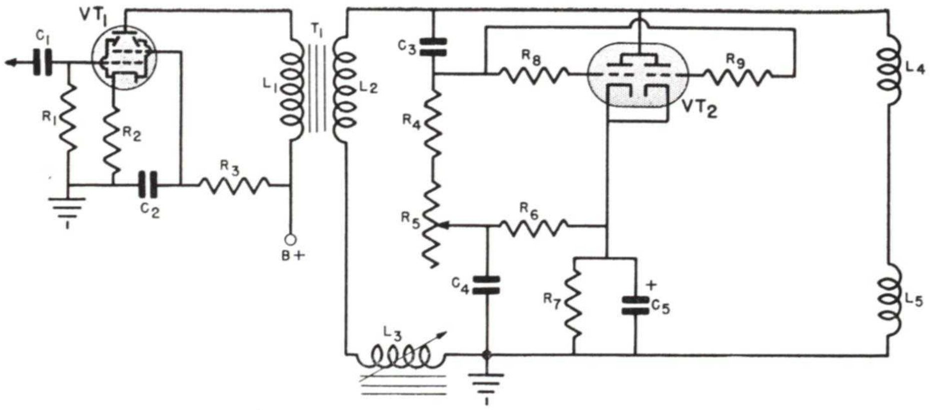


FIG. 29. How a triode damper is used in the output section of a horizontal electromagnetic sweep circuit.

the cycle. Since the tube is a power output tube, it is able to conduct a high current during the damping portion of the cycle.

In Fig. 29, the output tube VT_1 operates the deflection coils L_4 and L_5 through transformer T_1. Coil L_3 is a width control.

The same oscillatory action occurs during the retrace in this circuit as in the one previously described. When the oscillatory cycle reaches the point at which the current through the deflection coils is at its maximum negative value, the voltage across the coils reverses polarity, making VT_2 start to conduct. This coil voltage also passes through C_3 and appears across R_4, R_5, and R_6 as a positive voltage on the grids of VT_2. This makes the plate resistance so low that VT_2 acts practically as a short circuit. During the initial portion of the cycle, therefore, the tube passes a very high current into the damping resistor R_7.

The network C_3-R_4-R_5-R_6 is arranged to have a very short time constant with respect to the oscillatory cycle. Condenser C_3 charges rapidly, with the result that the voltage across the grid resistance network falls quickly from its highly positive value back towards zero bias. As a result, the plate resistance of VT_2 increases rapidly but smoothly as the retrace cycle progresses.

This arrangement tends to smooth out the sweep cycle. Furthermore, since the rate of change of the plate resistance of VT_2 depends on the R-C time constant of the grid circuit, it is possible to vary the damping by changing the setting of resistor R_5 in the grid network. Since the damping action controls the amount of current in the deflection coils during the first part of the sweep cycle, R_5 is a linearity control for the first part of the sweep.

As you can see, there are no controls in the plate supply of tube VT_1. However, there is a drive control (not shown) at the input of tube VT_1.

Notice that the cathode resistor of VT_1 is not by-passed. This introduces degeneration, which improves the linearity of the sweep.

Although it is not shown here, there is an extra primary winding on T_1 from which the high voltage needed for the picture tube is secured. The circuit is like the one in Fig. 28 in this respect.

VARIATIONS

Most receivers in which electromagnetic deflection is used get the high voltage for the picture tube by the method just mentioned (that is, by using the high voltage peak that occurs across the primary of the output transformer). An added advantage of this system is that it protects the picture tube, because the high-voltage supply to the tube is automatically cut off if anything happens to the sweep circuit. However, a few receivers (particularly early ones) have been made that use other methods of getting the high-voltage supply.

In general, you will find that the deflection coils for the horizontal deflection system will have low inductance and that an output transformer will be used. However, there is even an exception to this—one manufacturer has made a circuit using horizontal deflection coils of high inductance, thus eliminating the need for an output transformer. This circuit is carefully designed to have very low distributed capacity so that it is still possible to get a fairly high frequency and thus obtain the retrace action in the same manner as in other receivers.

You can always expect to find variations of this sort where design engineers are trying to eliminate some particularly costly part or are trying to get around some patent restriction. In general, however, no matter how the circuit is changed, it must perform the functions we have described if it is to have the proper sweep characteristics.

In the next Lesson, we shall show how the sweep chain can be controlled either directly by the synchronizing pulses that come in with the television signal or indirectly by a "lock" arrangement that in turn operates from these sync pulses. Just remember that the sweep circuits we have described all have the important characteristic of providing a continuous sweep so that the raster will be produced whether a signal is tuned in or not. This protects the picture tube. Then, when the signal is tuned in, the hold controls can be adjusted to make the sweep circuits lock in frequency with the sync pulses and thus scan in synchronism with the transmitted image.

Lesson Questions

Be sure to number your Answer Sheet 55RH-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. Why is it necessary to have a sweep system that will keep the electron beam of the picture tube in motion whether we have a signal or not?
2. In which type of sweep is the deflection: (a) *voltage-operated;* (b) *current-operated?*
3. If one bright vertical or horizontal band is observed in a raster when no signal is being received, is the trouble caused by: (a) *poor screen;* (b) *insufficient high voltage;* (c) *a.c. hum;* or (d) *non-linear sweep?*
4. Is the frequency of a blocking oscillator adjusted to be *higher* or *lower* than the desired frequency?
5. If the second-anode voltage applied to an electrostatic picture tube is increased, will the amount of sweep voltage needed: (1) *increase;* (2) *decrease;* or (3) *remain the same?*
6. What voltage wave form must be applied to the input of the sweep amplifier to create a saw-tooth current through electromagnetic deflection coils?
7. Why does the use of a pentode as the vertical sweep amplifier make it possible to apply a saw-tooth voltage to the grid of the tube and yet produce a saw-tooth current through the vertical deflection coil?
8. When electrostatic scanning is used, why is it necessary to have more horizontal sweep voltage than vertical sweep voltage?
9. Is a damper tube needed in the vertical sweep circuit?
10. Why does the C-bias adjustment in a vertical sweep amplifier (Fig. 25) act as a linearity control?

Be sure to fill out a Lesson Label and send it along with your answers.

ASK WHY

The ability to observe *intelligently*— to learn—to gain information—depends greatly upon your willingness to ask WHY.

Don't simply take things for granted. Get in the habit of asking other people WHY. And most important of all, *ask yourself* WHY—then find out the answers!

Be a *student* for the rest of your life—be a person who seeks knowledge—be a person who *wants to know*—be a man who *asks* WHY!

Thomas Edison became rich and famous because he was curious about the *reasons* for this and the *reasons* for that. He asked himself and others WHY. Alexander Graham Bell was able to invent the telephone, because he asked WHY. Marconi discovered much about Radio because he had the habit of asking WHY.

And so I advise you—a man who wants to know more and more about Radio and TV—to develop the lifetime habit of asking WHY. This will contribute much to your eventual success.

J.E. Smith