conduct current and, hence, that V_1 is substantially non-conducting in the quiescent condition.

This proves to be necessary because Smith had placed an additional bias resistance in the cathode circuit of V_2. Without this resistance, the diodes become unnecessary.

Positive pulses are applied to the control terminals, at irregular intervals if desired, and each pulse causes one sweep of the time base potential. Since the time base condenser C_3 is held discharged by V_2, which normally conducts, no time is wasted in discharging the condenser before a new sweep can begin.

CHAPTER V

TRIGGER CIRCUITS

ALTHOUGH every self-operated saw-tooth time base incorporates a trigger device of one kind or another, this chapter will be confined to a few trigger circuits which appear to be especially closely related to one another. Some trigger circuits of a different type are discussed in Chapter IX. The circuits in this group are readily adaptable to a wide variety of problems, and they are frequently employed to provide a trigger action for bringing about the operation of a further circuit either automatically or upon the receipt of an initiating signal. The members of this family may be divided into three categories; those in which the trigger action is obtained in a single valve by the judicious selection of operating conditions so that amplification occurs between one electrode and another, without the usual reversal of phase, those in which phase reversal occurs between each of two pairs of electrodes, usually with amplification in the case of one pair only, and those in which a back-coupled pair of valves is employed.

The occurrence of a trigger action may be explained by demonstrating the existence of a negative resistance in the circuit, as indicated by a negative slope over a region of the voltage-current characteristic, obtained by direct measurement or by calculation.* Alternatively, it may be regarded as a consequence of positive feed-back in an amplifier. Thus, a two-valve amplifier provides amplification without phase reversal and, if the output is fed back to the input, the circuit will generally oscillate because the feed-back is positive. In a single-valve amplifier the output voltage is normally in phase opposition to the input so that back-coupling generally increases the stability of the circuit and does not tend to produce oscillation, unless a large phase change is introduced in the feed-back network. In order to construct a single-valve trigger circuit one may nevertheless employ the same principles as in a two-valve circuit, provided that the valve is used in such a way that amplification is obtained without phase reversal. Under certain conditions a pentode may be used for this purpose by applying a controlling potential to the suppressor grid and obtaining an amplified potential change at the screen grid. Feed-back from the screen to the suppressor then results in the production of oscillations

* H. J. Reich: "Trigger Circuits," *Electronics*, August 1939, p. 14; E. W. Herold: "Negative Resistance and Devices for obtaining it," *Proc. I.R.E.*, 1935, **23**, p. 1200; P. le Corbeiller: "The Non-linear Theory of the Maintenance of Oscillations," *Journ. I.E.E.*, 1936, **79**, p. 361; S. P. Chakravarti: "On the Nature of Negative Resistance and Negative Resistance Sections," *Phil. Mag.*, 1940, **30**, p. 294.

of various forms, which are comparable with the oscillations obtainable with the back-coupled two-valve amplifier.

In most cases the trigger circuit is arranged to come into operation when the charge upon the time base condenser reaches a predetermined potential and to function in the opposite sense when the charge has been brought to another predetermined value. This usually means that the first trigger action is equivalent to the closing of a switch, and the second action is equivalent to opening the switch, but, to make the analogy more complete, the switch must be of the snap-action toggle type.

These circuits have *two unstable limiting conditions* when they are employed in a self-running time base. The existence of *two* limiting conditions is basically due to the fact that a valve may be limited in two ways: by driving the control electrode sufficiently positive or sufficiently negative. The two limiting conditions are both unstable because the time base condenser is always either in the process of being charged or of being discharged. If the circuit is arranged so that a stable condition can be reached, the charge on the condenser becoming constant, it forms a single-stroke relaxation oscillator, and only one of the limiting conditions is unstable. Upon the arrival of the initiating signal the trigger circuit "flips" over from the stable limiting condition to the unstable limiting condition and "flops" back after a definite predetermined time interval. The term Flip-Flop is applied to circuits of this type, and they are generally employed to actuate single-stroke time bases and similar devices. Any relaxation oscillator may be over-biased so that only a single operation results from each initiating pulse. In the case of the flip-flop this is a "go and return" operation, but there is another type of circuit having two stable limiting conditions in which alternate initiating pulses flip and flop the circuit. This circuit will be described later.

The Transitron Relaxation Oscillator

One of the earliest forms of single-valve trigger circuit was described by van der Pol* in 1926. This circuit employs a tetrode in which the screen and grid have a resistance-capacitance coupling, the grid being fed from the high potential source via a high resistance, which forms part of the coupling network. Van der Pol postulates that it is essential to have an inductance, no matter how small, in series with the screen coupling circuit, as shown in Fig. 35, but later investigators appear to be of the opinion that this inductance is not necessary.

The term "transitron" has recently come into use to denote any

* B. van der Pol: "On Relaxation Oscillations," *Phil. Mag.*, 1926, **2**, p. 978; "The Non-linear Theory of Electric Oscillations," *Proc. I.R.E.*, 1934, **22**, p. 1051.

circuit which employs a single pentode valve in such a way that amplification is possible without phase reversal. The name was originally coined by Brunetti, who defined it as "a retarding-field negative-transconductance device." Generally, these circuits* are extremely versatile, and one may produce a sinusoidal, saw-tooth or square wave output from one oscillator by means of very simple switching. It is equally easy to convert the continuous oscillator into a flip-flop by changing the bias potential. When the circuit is arranged as a relaxation oscillator or as a flip-flop it is very valuable as a switching device, and has many applications to time bases and control circuits.

The fundamental basis on which these circuits are constructed is that when a change of potential is applied to the suppressor grid it appears in amplified form, without phase reversal, on the screen grid. The reason for this is as follows:

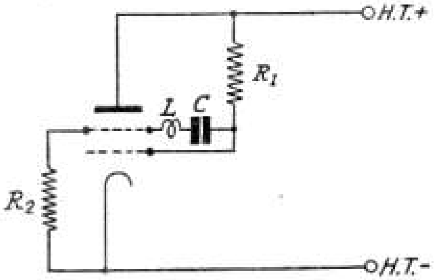

FIG. 35. Van der Pol's transitron circuit

If the anode current of a pentode is interrupted, electrons continue to pass between the wires of the screen grid, but they are no longer collected by the anode and must therefore return towards the screen (possibly passing back and forth several times before finally reaching the screen wires) and therefore the total cathode current in a pentode is constant provided the screen and control grid potentials remain unaltered. As a result of this the screen current is increased when the anode current is reduced. If, however, the screen is connected to a high-potential source of supply through a high resistance, the change in screen current will be much smaller than the change in anode current, but, on the other hand, there will be a considerable change in the screen potential.

By varying the potential of the suppressor grid the anode current is controlled and this, in turn, controls the screen current and, hence, its potential, so that when the suppressor potential is made more negative the screen potential becomes less positive. A pentode which is provided with a high resistance in series with the screen may therefore be used as an amplifier, the input being applied to the suppressor (suitably biased) and the output, in the same phase as the input, being taken from the screen. An amplifier of this type becomes an

* C. Brunetti: "The Clarification of Average Negative Resistance with Extensions of its Use," *Proc. I.R.E.*, 1937, **25**, p. 1595; "The Transitron Oscillator," *Proc. I.R.E.*, 1939, **27**, p. 88; C. Brunetti and E. Weiss: "Theory and Application of Resistance Tuning," *Proc. I.R.E.*, 1941, **29**, p. 333.

oscillator if a positive feed-back circuit is arranged between the input and output terminals; i.e. between suppressor and screen. For example, with a resistance-capacitance coupling between the suppressor and screen the device becomes a relaxation oscillator and is almost equivalent to a multivibrator. It is, however, essential that, in the absence of the coupling condenser, the amplification shall be greater than unity. If the standing bias on the suppressor is such that the amplification is less than unity, the device becomes a flip-flop. It is, of course, assumed that the amplification will exceed unity at some smaller value of bias potential. This application will be described later.

The Transitron Sinusoidal Oscillator

The transitron sinusoidal oscillator is shown in Fig. 36. It is included here for the sake of completeness although, of course, it is not a time

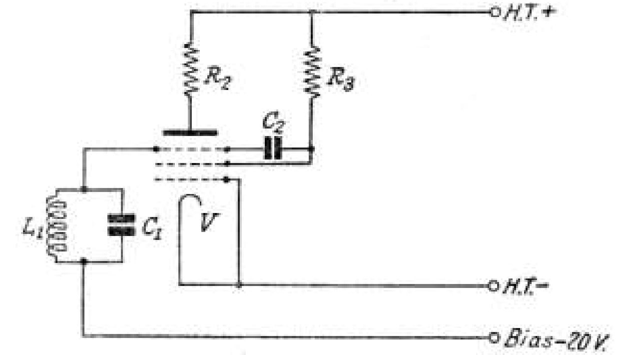

FIG. 36. The transitron sinusoidal oscillator

base. As in all oscillators, this circuit provides a negative resistance and it is only when the negative resistance is equal to or less than the (positive) resonant impedance of the oscillatory circuit that oscillation will be maintained, since only under the above conditions are the circuit losses made good and the oscillation prevented from decaying. The value of the negative resistance which appears in shunt across the oscillatory circuit is found as follows:

Let μ' denote the amplification factor (considered as positive) between suppressor and screen and R_s the internal impedance between screen and cathode, both values being measured under the operating conditions with the anode circuit complete. Then the screen current

$$i_s = \frac{E - \mu' e_{g3}}{R_3 + R_s}, \qquad \ldots (1)$$

where E is the H.T. potential, e_{g3} the applied suppressor potential and R_3 the screen feed resistance. This equation is similar to that employed in calculating the anode current of a triode, which is

$$i_a = \frac{E + \mu e_{g1}}{R_2 + R_a},$$

where e_{g1} is the grid potential, μ is the amplification factor between grid and anode (not the same as in equation (1)), R_2 the anode load and R_a the internal anode-cathode impedance. The reason for the different sign in the two numerators is that in the former case no phase-reversal takes place.

When the screen and suppressor are connected together by means of a condenser whose impedance is negligible at the frequency of oscillation, the alternating potential on the suppressor is equal to the alternating potential on the screen, or

$$e_{g3} = E - i_s R_3 \qquad \ldots (2)$$

then, by eliminating e_{g3} from equations (1) and (2)

$$i_s = \frac{E - \mu'(E - i_s R_3)}{R_3 + R_s}$$

$$= \frac{E(1-\mu')}{R_3(1-\mu') + R_s}.$$

Hence, it will be seen that the impedance offered to the H.T. supply rail by the screen circuit is

$$\frac{E}{i_s} = R_3 + \frac{R_s}{1-\mu'},$$

$$= R_3 + \frac{1}{\frac{1}{R_s} - \frac{\mu'}{R_s}}.$$

The effect of the screen-suppressor coupling is, therefore, to place a negative resistance equal to $-\frac{R_s}{\mu'}$, in parallel with the internal resistance R_s. The impedance which shunts the tuned circuit LC therefore consists of R_3, R_s and $-\frac{R_s}{\mu'}$, all in parallel. R_3 appears in parallel because the positive and negative supply rails are at the same potential in the A.C. sense due to the presence of the final condenser in the rectifier smoothing system which is of negligible impedance at the operating frequency. The value of the negative resistance may be controlled by inserting a variable bias resistance in the cathode circuit. This resistance will also control the purity of the output wave-form.

When using an EF50 valve under the operating conditions shown below, R_s is about 25,000 ohms and μ is of the order of 4, so that the negative resistance, after allowing for R_3 (50,000 ohms) is about 10,000 ohms.

The existence of negative resistance is essential to any oscillator or trigger circuit, and the principles involved in the method of calculation described above are generally applicable.

The output may be taken from the anode of the valve or from the screen or suppressor. In practice, however, it is advisable to draw the output from the anode since, in this case, the impedance of the load has less effect upon the operation of the circuit.

Suitable values for the components of Fig. 36 are as follows:

R_2 10,000 ohms
R_3 50,000 ohms
L_1, C_1 } to provide the required frequency f
C_2 say 0·005 μF. (impedance to be negligible at frequency f)
H.T. 350 volts.

The Transitron Saw-Tooth Oscillator

Fleming-Williams* and Reich† have independently developed almost identical time base circuits in which a single valve is used to charge or discharge a condenser connected between the anode and one of the supply rails. Fleming-Williams' version of the circuit is shown in Fig. 37.

The mechanism of the complete circuit may be understood by commencing at the period when the suppressor is positive and the anode is taking current. The anode current is then considerably larger than the charging current through R_2, and therefore the condenser C_1 is discharged rapidly. As the anode voltage falls the anode current remains approximately constant until the knee of the characteristic is reached, when the value of the current commences to fall. This results in a rising screen current, a falling screen potential, and a falling suppressor potential. This, in turn, reduces the anode current still more and the process becomes increasingly rapid until the velocity is limited by the stray capacitances of the circuit. Thus, the anode current is suddenly cut off, while the suppressor is driven negative. This condition remains while the condenser C_1 is being charged through R_2. As the condenser charges the anode potential increases and a point is reached at which the anode commences to draw current which would otherwise pass to the screen. The suppressor-grid potential therefore rises once more, since the suppressor and screen are coupled, until the anode suddenly takes a large current, thus discharging the condenser C_1.

* B. C. Fleming-Williams: "A Single-Valve Time Base Circuit," *Wireless Engineer*, 1940, **17**, p. 161.

† H. J. Reich: "Trigger Circuits," *Electronics*, August 1939, p. 14. See also A. J. Young: British Patent 435816; E. L. C. White: British Patent 455497; and H. M. Lewis: British Patent 530227.

The discharge action introduced by the increase of suppressor potential and the resultant increase of anode current is obviously also a cumulative one, since the anode and screen currents are out of phase, and the initiation of the discharge is therefore rapid.

If the suppressor grid takes a large forward current when it is driven positive, and if C_2 is sufficiently small by comparison with C_1, then the suppressor grid will become negative before the completion of the discharge due to the condenser C_2 becoming charged by suppressor-grid current. This action has the effect of cutting off the anode current and increasing the screen current so that the screen finally takes all the current and the main condenser proceeds to recharge. On the other

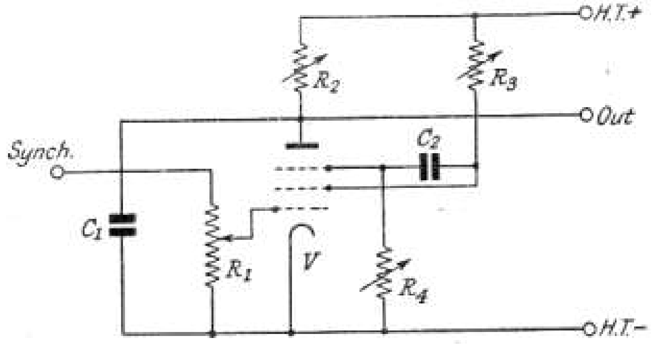

FIG. 37. The Fleming-Williams time base

hand, if C_2 is relatively large, the fall in anode current during discharge eventually produces a fall in screen potential, and the trigger action is again brought into play, though somewhat later. It is thus possible to obtain a saw-tooth wave-form across the condenser C_1. The rapidity of change-over from the charging to the discharging condition is determined by the amount of amplification existing between the suppressor and screen, together with the values of the stray capacitances.

The circuit works best with a valve having a high ratio of anode to screen current so that, during discharge, the screen potential rises to a high value and accelerates the discharge since the higher the screen potential the greater is the anode current. With such a valve the cathode current increases considerably during the discharge, and square pulses will appear across a small resistance inserted in the cathode circuit.

Figs. 38 and 39 show the wave-forms appearing between earth and the anode and screen of the valve. These wave-forms refer to the circuit of Fig. 37, for which representative circuit components are given on the next page.

R_1	10,000 ohms	H.T.	300 to 700 volts
R_2	0·2 to 2·0 megohms	V	Cossor MS/PEN.
R_3	0·05 to 0·5 megohm		
R_4	0 to 0·25 megohm		
C_1	0·1 μF.		
C_2	1·0 μF.		

By adjustment of R_2 and R_4 the charging time, and hence the time duration of the saw-tooth, is made controllable. The adjustment of R_3 controls the ratio of the charge to the discharge time, and hence determines the mark-space ratio for the square wave-form of screen voltage. The voltage on the screen grid when the charging and discharging times are equal is shown in Fig. 39.

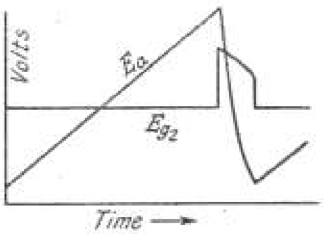

Fig. 38.

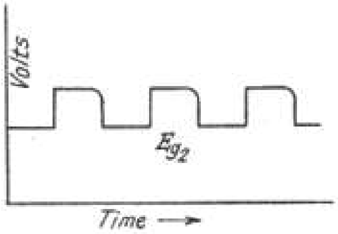

Fig. 39.

Voltage wave-forms pertaining to the circuit of Fig. 37

Fig. 40 shows a method of explaining the behaviour of the time base, when using an EF50 valve, by means of a family of static characteristic curves taken with a potential of 350 volts fed to the screen through a load resistance of 50,000 ohms and with zero grid volts. These are not ordinary valve characteristics, since they are obtained by varying the potential applied to the suppressor grid and measuring its effect on the potential of the screen, which is connected through a resistance to a fixed H.T. supply, the condensers C_1 and C_2 being omitted. It will be seen that, where the curves are rising steeply, a small change in the suppressor potential produces a larger change in the screen potential.

In the time base circuit the screen and suppressor are linked through the condenser C_2 and, so long as the charge on this condenser remains constant, there must be a constant difference between the screen and suppressor potentials. This condition is represented by drawing a straight line such as BGFC at a slope corresponding to $\frac{dE_{g2}}{dE_{g3}}=1$ (i.e. at 45° if the scales are equal). Since the screen and suppressor potentials must satisfy the two equations represented by the static curve and the dynamic straight line, the stable potentials must be as indicated by

the points of intersection. When the line cuts a curve at three points it would appear that there are three possible values for the screen potential, but the middle one is a point of unstable equilibrium and only the other two need be considered.

Assume now that the condenser C_1 is charged to 180 volts. In this condition the suppressor and screen potentials are indicated by the point B on the curve, the screen potential being a minimum because the current in R_3 is a maximum. The anode then commences to take current and the screen current falls, thus causing the screen potential to rise to the point C: this occurs very rapidly due to the cumulative

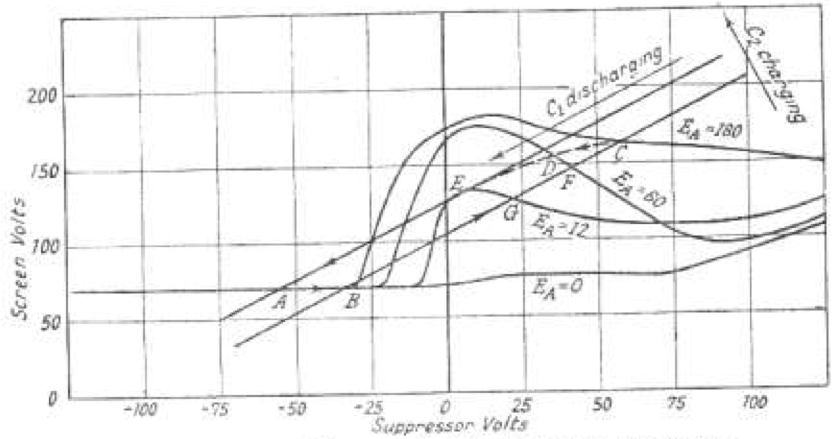

Fig. 40. Characteristic curves for Fleming-Williams' time base (EF50 pentode with zero grid volts)

action. The locus then follows a curve such as CDE, reaching the point A when the condenser C_1 is discharged. The locus follows the dotted portion of the curve as the coupling condenser C_2 charges, while the suppressor is positive. During the period when C_1 is charging, the screen potential remains constant while the suppressor potential slowly changes to the value B due to the condenser C_2 discharging through R_4 and through the screen and cathode.

This time base can be synchronized with either positive or negative signals. When it is desired to synchronize the time base from a negative signal the latter should be applied to the grid. While the condenser C_1 is being charged there is no anode current and the application of a negative pulse to the control grid reduces the screen current so that the screen potential rises. The suppressor potential is therefore caused to rise and anode current commences to flow, thus introducing the cumulative change of régime and discharging the condenser. When the synchronizing potential is positive it should be applied to the suppressor grid. In this case, the suppressor potential is increased and the change of régime is introduced as before. In either case, the amplitude of the synchronizing potential should be kept to the lowest possible value consistent with effective control. This is especially necessary when the synchronizing potential is applied to the grid, since, if the signal is too large, it will cut off the screen current entirely. Furthermore, the synchronizing potential should be applied for a period which is only just sufficient to ensure effective control of the commencement of discharge.

The Screen-coupled Transitron Flip-Flop

A flip-flop,* as already stated, is a circuit having *one stable and one unstable limiting condition.* The movement from the stable state is

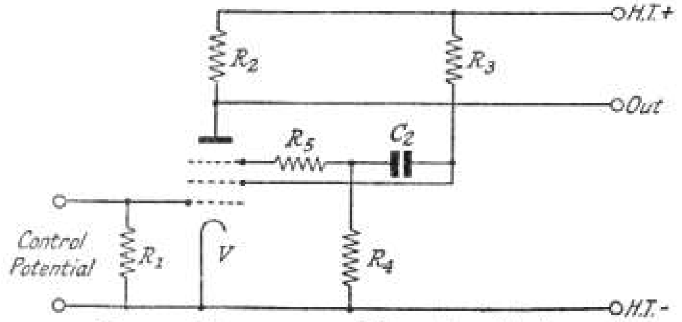

FIG. 41. The screen-coupled transitron flip-flop

effected by the application of a short-duration signal which releases a cumulative trigger action. This drives the circuit condition to the opposite extremity; i.e. to the unstable limiting condition. After a period, which is determined by the time constant of the circuit, the trigger action operates in the reverse direction and resets the circuit. The difference between a flip-flop and a continuously operating relaxation oscillator is that, in the case of the flip-flop, the fixed supply and bias potentials are so proportioned that oscillation is inhibited after each cycle, a new cycle being commenced by the application of a further initiating signal which momentarily brings the potentials to a point which, if maintained, would permit oscillation to continue indefinitely. Thus, a flip-flop is, in general, a relaxation oscillator which is over-biased (to or beyond cut-off).

The expression "flip-flop" provides an excellent name for the arrangement since it describes the action perfectly. The circuit may be said to reside in the stable condition, to flip to the unstable régime,

* A transitron flip-flop is also known as a "trant."

and then to flop back to the stable régime after a predetermined lapse of time. The words flip and flop thus indicate the *changes of régime* and not the régimes themselves.

The transitron relaxation oscillator shown in Fig. 37 may be converted into a flip-flop by applying a negative bias to the suppressor or by reducing the value of R_2. The condenser C_1 should also be removed if it is desired to obtain a steep-sided output pulse at the anode. The principle of the circuit is essentially the same as the two-valve multivibrator type of flip-flop which is described later, except that the necessary amplification without phase reversal is obtained in a single valve, one of the couplings being the electronic one between the suppressor and screen, and the other the resistance-capacitance coupling provided by the condenser C_2 and the resistance R_4, as shown in Fig. 41. Suitable values for the components are as follows:

H.T. 250 to 350 volts	R_4 200,000 ohms
R_1 To suit the input circuit, say, 1,000 to 5,000 ohms	R_5 normally zero (see page 68)
R_2 10,000 ohms	C_2 0·001 μF.
R_3 50,000 ohms	V EF50.

The behaviour of the circuit can best be explained graphically by means of the static relationship between the suppressor and screen potentials. These relationships are plotted in Fig. 42 for an EF50 valve operating under the conditions enumerated above, but with an H.T. supply potential of 340 volts.

Several values of control grid bias are taken in order to determine the effect of the input pulse. The curves are obtained by applying a variable potential to the suppressor and measuring the resulting screen potential and suppressor current. A correction is made to the screen potential curves to allow for the effect of the suppressor current since, in practice, a part of this also passes through the screen resistance.

The suppressor current is plotted in the lower family of curves, and it will be noted that the current is reversed above 40 volts. The effect of the current on the screen circuit is, therefore, to lower the screen potential in the region from 0 to 40 volts on the suppressor, and to raise it when the suppressor potential is above 40 volts. At still higher suppressor potentials, of the order of 100–120 volts, the suppressor current again becomes positive and rises rapidly with further increase of suppressor potential.

The dynamic relation between screen and suppressor potential may be indicated by a straight line such as ABC drawn at the proper angle, i.e. 45° when the scales are equal, to correspond with the external coupling between the screen and suppressor, so that a given change in screen potential results in a similar change in that of the suppressor. In the circuit of Fig. 41 the presence of the condenser C_2 makes the change in suppressor potential equal to the change in screen potential, neglecting for the moment variations in the D.C. charge on the condenser which can be represented by parallel movements of the line such as, for instance, to the dotted line DE (Fig. 42).

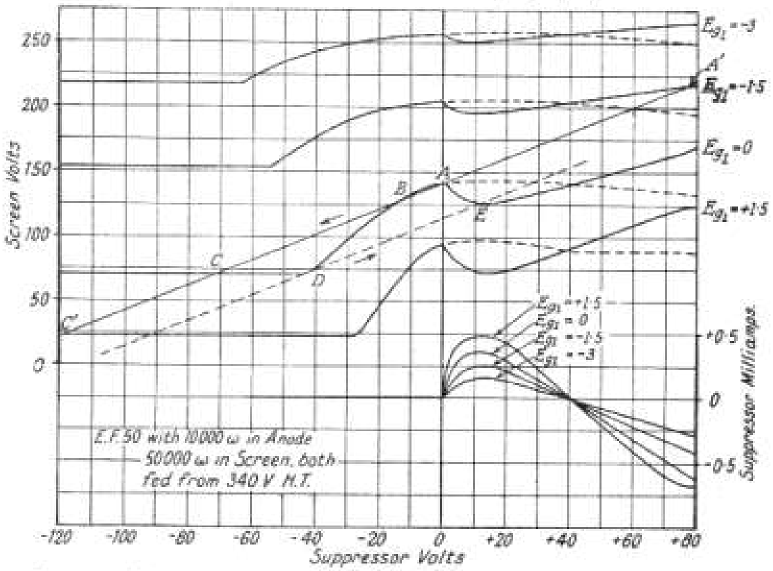

FIG. 42. Characteristic curves for the screen-coupled transitron flip-flop

As the suppressor and control grid are both normally at cathode potential, the point A indicates the starting-point and the line ABC determines the operations as long as the condenser charge remains constant. While the static curve gives the screen potential which would result from the screen and suppressor currents alone, the operating line gives the actual screen potential which is a result of the sum of the currents flowing into the screen and into the stray capacitances. When the operating point lies above the static curve, part of the screen current is being supplied from the stray capacitance so that the potential must fall rapidly and vice versa. In this way it can be shown that the points of intersection at A and C are both stable, apart from variations in the charge on C_2, while the intersection point at B is unstable.

When a small positive pulse is applied to the control grid the static curve is lowered so that it no longer intersects the operating line in the AB region and the operating point moves very rapidly to a point such as C′, returning to C at the end of the pulse. Reference to Fig. 43 (*a*),

which shows the appropriate wave-forms, will make it clear that the suppressor is now negative, and the condenser C_2 discharges through R_3 and R_4 while the operating line moves to the position DE. At D the operating point must leave the static curve and another rapid movement occurs, ending at E. The suppressor is now positive and C_2 charges while the operating point follows the static curve from E to A and remains there since the voltage drop across R_4 has then reached zero and A is a stable point.

The movement from D to E is extremely rapid and is the period during which the anode current changes from zero to a large value. The period from E to A is one in which the condenser C_2 settles down

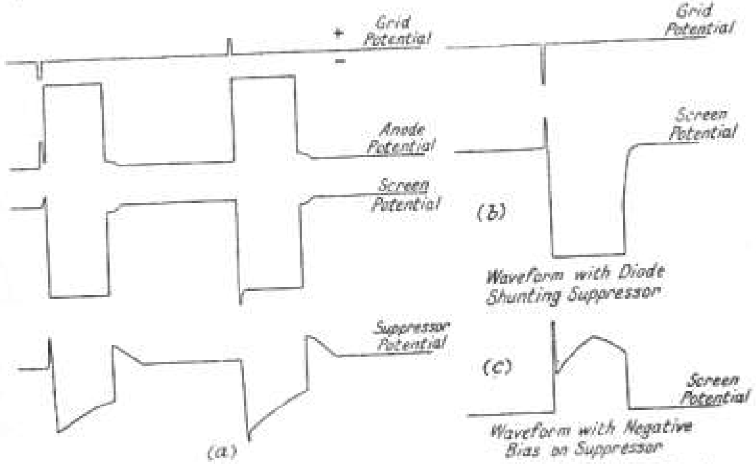

FIG. 43. Voltage wave-forms for the screen-coupled transitron flip-flop

to the stable condition, after which the circuit is ready to receive a further initiating pulse. If another pulse is applied before the point A is reached, the duration of the next unstable régime is somewhat reduced, depending upon the state of charge of C_2 at the moment of arrival of the pulse.

It will be seen that the condition which makes the circuit give a single stroke instead of a continuous oscillation is that the suppressor is not biased on the unstable part of the static curve (i.e. the part which is steeper than the operating line).

Referring to the wave-forms of Fig. 43 (*a*) for the positive input pulse, it will be seen that the flat-topped screen potential wave corresponds to the horizontal region CD on the static curve, which occurs during anode current cut-off. The hump at the end of the stroke is the depression at E, which is a result of the addition of the suppressor current to that of the screen. The static curve, without the modification for suppressor current, is shown (dashed) to the right of the point A. By introducing R_5 in series with the suppressor, the hump can be practically eliminated owing to the reduction in suppressor current but further complications are introduced.

When a negative impulse is applied to the control grid, the operating point moves to a point such as A′ and returns to A at the end of the input pulse, unless it lasts sufficiently long for the condenser charge to alter appreciably. If the input pulse is small so that A′ corresponds with a suppressor potential between zero and +40, the suppressor current is always in the same direction as the current through R_4 and thus it helps to alter the condenser charge. The operating line therefore moves to the left and, at the end of the pulse, it may be clear of the static curve in the AB region so that the operating point flies to the left of C. After this, the sequence is the same as for positive initiation.

An increase in the amplitude of the negative pulse applied to the grid drives the point A′ farther to the right and the suppressor current may neutralize the current through R_4 if the suppressor reaches the reversed current region. In this event the condenser cannot discharge and the circuit will not trigger, however long the pulse may last. If R_4 is too high the reversed suppressor current may exceed the forward current through R_4 so that the condenser discharges instead of charging. In an extreme case the condenser may be charged 40 or 50 volts in the period of the input pulse and, at the end of the pulse, the suppressor is left 40–50 volts positive, thus allowing the suppressor current to maintain the charge so that the circuit becomes "locked."

When R_5 is introduced the locking trouble is greatly increased. The negative suppressor current is then able to maintain the suppressor positive and prevent the circuit functioning whenever the suppressor is momentarily driven into reversed current.

Values of R_5 from 0·05 to 1·0 megohm are particularly apt to give this trouble with the EF50, but higher values such as 2·0 megohms give satisfactory results as the suppressor potential cannot then reach the locking-point. Although the hump is removed in this way, the return to the stable condition is appreciably slowed down and it seems preferable to use a valve which has no reverse suppressor current (e.g. MSPen.B) and which is therefore not liable to lock. If a diode is connected between the suppressor and cathode (diode anode to suppressor), the suppressor can be prevented from going positive and R_5 can be of the order of 0·1 megohm without any risk of locking. The end of the square wave is then followed by a tail, as shown in Fig. 43 (*b*).

At this point it is interesting to note what happens if the points A

and E are made to coincide, as they do with zero suppressor bias and approximately 1·5 volts negative bias on the control grid. The points C and D also coincide. With a positive pulse on the grid the circuit triggers, but the return to the stable condition occurs at or before the end of the pulse without any delay. With a negative input pulse the circuit gives a square-wave output whose duration depends on the amplitude and duration of the input pulse. This occurs because the condenser C_2 receives a charge while the suppressor is driven positive by the input and the amount of this charge determines the time period before the return stroke. The same factor is to some extent operative even with zero bias: the duration of the output square-wave is not

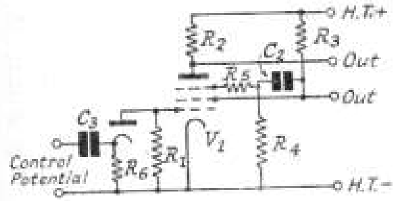

Fig. 44. Method of synchronizing a screen-coupled transitron flip-flop by means of negative synchronizing pulses

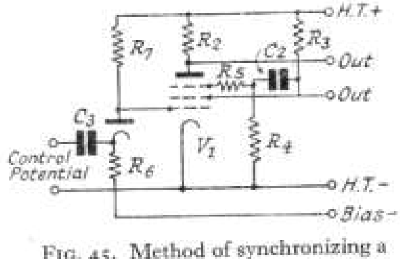

Fig. 45. Method of synchronizing a screen-coupled transitron flip-flop by means of positive synchronizing pulses

entirely independent of the input, being slightly greater for negative initiation than for positive.

If operation on both positive and negative pulses is not desired, it is possible to bias the suppressor to a point on the flat portion of the characteristic between C and D, so that the return stroke is not followed by a tail, but the hump at EAB is then transferred to the top of the wave as in Fig. 43 (*c*). Initiation is by negative input only and the duration of the input pulse has little effect, since the circuit is triggered at the beginning of the pulse.

Two further methods of applying the initiating pulse are shown in Figs. 44 and 45. In Fig. 44 the valve is normally conducting and the initiating pulse must be in the negative direction. This results in a positive pulse at the anode and a negative one at the screen grid. Fig. 45 shows a circuit which operates with a positive input pulse and the output pulses are negative at the anode and positive at the screen grid.

The flip-flop circuits already discussed are known as screen-coupled circuits, but there is a further type in which the external coupling takes place between the suppressor grid and the cathode, the former being at a fixed potential and the latter changing in potential owing to the presence of a cathode load resistance.

The Cathode-coupled Transitron Flip-Flop

Whereas a screen-coupled transitron functions by providing amplification between the suppressor grid and the screen grid without phase reversal, the cathode-coupled transitron flip-flop provides amplification with phase-reversal between the suppressor grid and the anode and phase-reversal without amplification between the control grid and the suppressor grid. Of the phase-reversals mentioned above, that between the anode and the suppressor grid occurs only during the negative-slope portion of the characteristic.

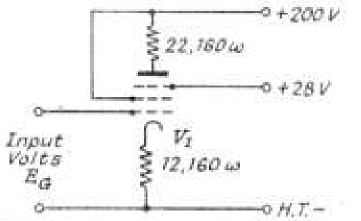

FIG. 46. Basic circuit of the cathode-coupled transitron flip-flop as used for making the measurements shown in Fig. 47

The basic circuit is shown in Fig. 46 and the static characteristic curve associated with the circuit is plotted in Fig. 47, from which it will be seen that for grid potentials above 27 volts positive with respect to the negative supply rail, the slope of the curve becomes negative.

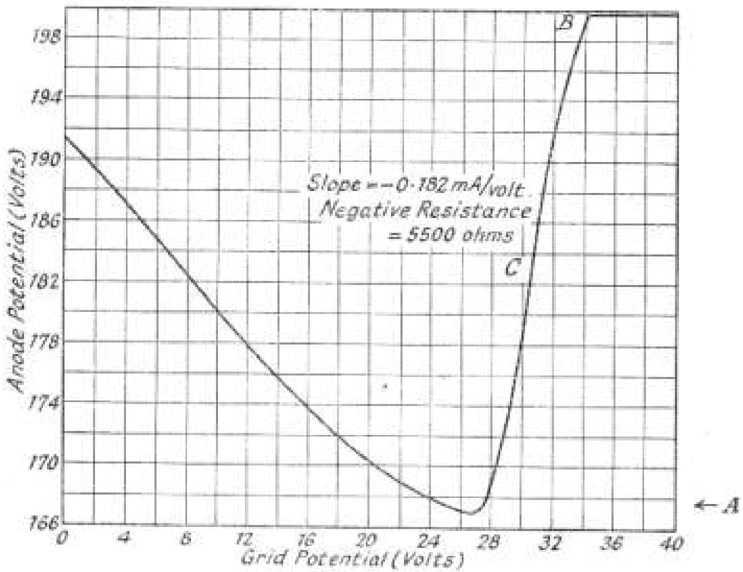

FIG. 47. Characteristic curve pertaining to the circuit of Fig. 46

Fig. 46 shows the actual potentials and resistance values employed when making the measurements embodied in the curve of Fig. 47. The valve is a type VR116 and, for the purposes of measurement, the feed-back arrangements which are necessary to form a practical circuit are omitted. These feed-back arrangements are described later.

Examination of Fig. 46 will show that the suppressor potential is determined by the value of the cathode load resistance and the current flowing through it and this is, in turn, determined by the grid potential with respect to the negative rail. A change in grid potential therefore produces a change in the opposite sense in the suppressor grid potential.

When the grid potential is increased to about 25 volts positive, the suppressor grid commences to reduce the anode current. When the grid potential is raised to 34 volts the suppressor grid has become sufficiently negative to cut off the anode current, and the cathode current passes entirely through the screen grid circuit and the valve then behaves as a triode. In this particular case, the value of the negative slope can be seen to be −0·182 milliamperes per volt, which corresponds to a negative resistance of 5,500 ohms. Obviously, therefore, if the anode is coupled to the grid, the circuit is capable of generating oscillations. Furthermore, examination of the curve of Fig. 47 will show that if the grid is biased to the points *A* or *B* on the curve, the circuit will have *one stable limiting* condition and will therefore function as a flip-flop; but, if it is biased to the point *C*, it will have *two unstable limiting conditions* and will operate as a square-wave generator (see Appendix VI).

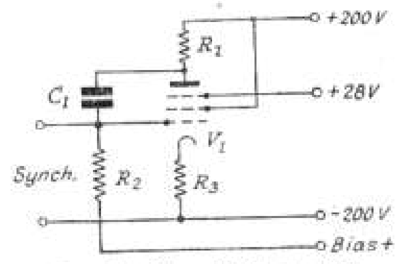

FIG. 48. The cathode-coupled transitron flip-flop

Fig. 48 shows the flip-flop form of the circuit, the condenser C_1 being inserted to provide the necessary feed-back from the anode to the grid of the valve. Suggested component values are:

R_1	20,000 ohms
R_2	100,000 ohms
R_3	10,000 ohms
C_1	dependent upon requirements
V_1	VR116.

The condenser C_1 provides positive feed-back from the anode to the grid during the negative slope portion of the characteristic and negative feed-back in the positive portions. Since there is phase reversal between the grid and the suppressor grid, the feed-back circuit causes the suppressor grid to become more negative when the anode goes positive during the negative slope portion of the characteristic curve.

It is now difficult to obtain valves of the VR116 type, but their special merit for use in this circuit lies in the fact that the suppressor grid is closely wound so that the potential required at the suppressor grid to cut off the anode current is small—some 5 to 10 volts dependent upon the potentials of the anode and screen grid.

The value of the bias potential with respect to the negative rail can be determined from an inspection of Fig. 47, viz. +24 volts approximately for a positive synchronizing signal or +36 volts approximately when the synchronizing signal is negative.

In order to understand the operation of the circuit, assume that the valve is biased at +24 volts. The anode potential will then be approximately 168 volts and the injection of a positive synchronizing potential will carry the grid potential beyond +27 volts, resulting in an increase in the anode potential which will rise to 200 volts due to the feed-back circuit causing the grid potential to rise with that of the anode. When the anode current becomes cut off at 200 volts, the time constant $(R_1+R_2)\ C_1$ commences to discharge and the grid potential therefore falls. When this potential falls below +34 volts, the anode potential commences to fall, thus reducing the grid potential still further until finally the grid potential reaches the point A once more and the circuit becomes stable.

This circuit is due to B. C. Fleming-Williams, of A. C. Cossor, Ltd.

TWO-VALVE TRIGGER CIRCUITS

The Two-Valve Flip-Flop

There are a number of variations of the two-valve flip-flop, and one form of the circuit is shown in Fig. 49. This circuit may be regarded as an over-biased multivibrator in which one of the condensers has been replaced by a direct connection. However, as will be explained later, the essential feature which makes the circuit a flip-flop is not the presence of the direct coupling, but the fact that sufficient bias is applied to prevent continuous oscillation.

The application of a negative potential to the grid of V_1 results in the grid of V_2 being driven positive and thus causes anode current to flow in V_2 which is normally biased to, or beyond, cut-off. The screen potential of V_1 is therefore depressed so that the grid of V_2 is held positive during and after the cessation of a short-duration exciting signal. The circuit is returned to the normal condition by the discharge of the coupling condenser. The duration of the unstable régime may be controlled by adjustment of the coupling time constant. The circuit, in essence, provides A.C. feed-back in a D.C. amplifier in the sense that the potential appearing at the grid of V_2 appears also at the anode of V_1 after amplification by the valves V_2 and V_1. This is followed by A.C. feed-back from the anode of V_1 to the grid of V_2. Since the complete amplifying chain is continuous, it is immaterial whether the

exciting signal is applied to the grid of V_1 or of V_2 provided that it is of the appropriate polarity and has sufficient amplitude. The output signal may be taken from the anode of either valve.

Appropriate values for the components of Fig. 49 are as follows:

R_2	50,000 ohms to 1 megohm (dependent upon the required time constant)
R_3, R_4	50,000 ohms.

The value of R_5+R_6 must be so arranged that the current I through the two resistances is sufficient to make IR_5 greater than the potential

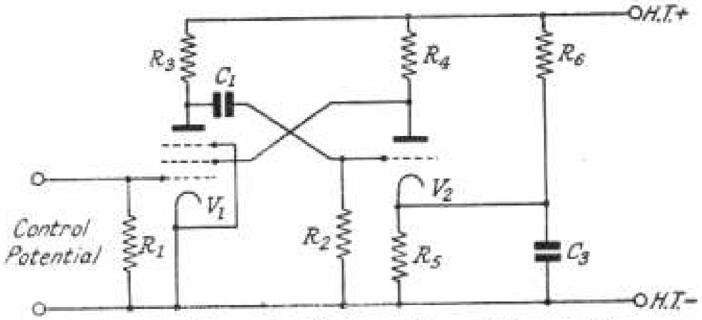

FIG. 49. Two-valve flip-flop with one A.C. coupling

required to cut off anode current in V_2. The time constant C_3R_5 must be at least ten times the value of the time constant C_1R_2.

It should be noted that an essential difference between the two-valve flip-flop and the multivibrator is that the flip-flop has one of the valves biased to cut-off. This bias is capable of keeping the circuit in its stable condition after one period of operation, even if two A.C. couplings are used between the valves.

An example of a flip-flop using two A.C. couplings is shown in Fig. 50. The interval between the flip and the flop, i.e. the duration of the unstable régime, depends upon the time constants of the two coupling circuits in very much the same way as in the multivibrator.

An important point to note is that if the synchronizing, or exciting pulse is applied to the grid of V_1 it must be in the negative direction with either form of two-valve flip-flop and must last for a shorter time than the unstable régime. If it is required to operate a flip-flop from a positive pulse it should be applied to the grid of V_2, although, in this case, a larger pulse amplitude is generally required. It should be noted that this arrangement is not the same as that of the transitron flip-flop which will operate, though in a somewhat different manner, with either a positive or a negative pulse applied to the *same electrode*.