4.3. Johnson, R. H., "Hard-valve modulators for experimental use in the laboratory," *J. Instn Elect. Engrs*, Part IIIA, **93**, p. 1043 (1946).
4.4. Fay, C. E., "High vacuum oxide-cathode pulse modulator valves," *Bell Syst. Tech. J.*, **26**, p. 818, No. 4 (Oct., 1947).
4.5. Melville, W. S., "The use of saturable reactors as discharge devices for pulse generators," *Proc. Instn Elect. Engrs*, **98**, p. 185 (1951).
4.6. Hussey, L. W., "Non-Linear coil generators of short pulses," *Proc. Instn Radio Engrs*, **38**, p. 40 (Jan., 1950).

CHAPTER 5

TRIGGER CIRCUITS: SOFT-VALVE, BLOCKING-OSCILLATOR AND MULTIVIBRATOR TYPES

Circuits which can exist in one or the other of two stable or quasi-stable states are known as "trigger circuits." When both states are quasi-stable the circuit exists alternately in one or the other state and is then known as a "relaxation oscillator." Trigger circuits which possess one stable and one quasi-stable state, pass from the stable to the quasi-stable state upon application of a trigger pulse. These circuits return to the stable state after a time determined by the circuit parameters. Such circuits are said to be "unistable" and are known as "flip-flops." This chapter and the next are devoted to relaxation oscillators and flip-flops. Bistable trigger circuits are considered in Chapter 3.

Trigger circuits which produce a waveform which rises with time at an approximately constant rate are known as "linear" time-base generators. The flip-flop form is known as a "triggered" time-base and the relaxation-oscillator form is known as a "free-running" time-base. The waveforms produced by the majority of so-called linear time-bases are portions of the exponential law $E(1-e^{-t/\tau})$. This law reduces to Et/τ when $t \ll \tau$.

Soft-valve trigger circuits operate by virtue of the fact that, over a certain range of electrode potentials, the current through a soft valve may be either of two values for any given set of electrode potentials. The current passed by a hard valve is, however, uniquely determined by the electrode potentials. Hard-valve trigger circuits operate by virtue of the fact that, over a certain range of electrode potentials, positive feedback exists in the circuit to a sufficient extent to cause the voltage-current characteristic to exhibit a negative resistance at some point in the circuit. The general characteristic is shown in Fig. 5.1. The circuit is unstable in the region of the negative resistance; it can exist in either of the two stable states corresponding to potentials above or below those which create the negative resistance.

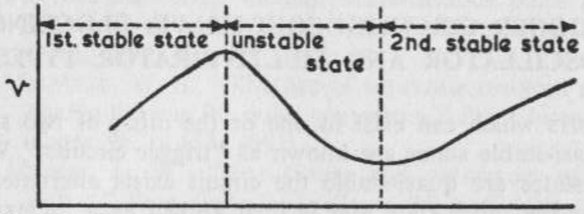

FIG. 5.1. CHARACTERISTIC OF A HARD-VALVE TRIGGER CIRCUIT

Hard-valve trigger circuits can be divided into three distinct types: (*a*) transformer-coupled circuits such as a single-valve amplifier in which the output is coupled back to the input through a transformer; (*b*) two-stage inphase-amplifiers in which the output is coupled back directly to the input; and (*c*) single-cathode multi-electrode valve-circuits in which amplification is obtained without phase-reversal in a single stage. Types (*a*) and (*b*) are considered in Articles 5.2 and 5.3 respectively. Type (*c*) is considered in the next chapter.

There are so many variations of trigger circuits in existence that only basic types can be dealt with in this book. In particular, many variations comprise the addition of diode clamps or cathode-followers to the basic circuit configurations. Supply decoupling-components and parasitic grid-stopper resistors have been purposely omitted from the given circuits in order to avoid possible confusion.

5.1. Soft-valve Trigger Circuits

A gas-filled cold-cathode diode only passes current when the potential applied between the electrodes is sufficient to ionize the gas. The striking potential depends upon the gas pressure, the electrode configuration, the material of the electrodes and their surface condition, so that it is fixed in the design of the valve. Many diodes with neon fillings are now available commercially. After striking, conduction in the diode

can be maintained at lower potentials than the striking potential. The striking potential of a typical valve, the S130, is about 130 V, and the extinction potential is about 100 V. The dynamic resistance of this valve is about 300 Ω when conducting.

5.1.1. Chance's Trigger Circuit

Chance (5.1) has used a gas-filled diode in a bistable trigger circuit, shown in Fig. 5.2. A positive potential E_m mid-way between the striking and the extinction potentials is applied to the diode. Negative trigger signals initiate the conduction state; positive trigger signals initiate the extinction state.

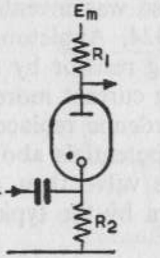

FIG. 5.2. CHANCE'S CIRCUIT

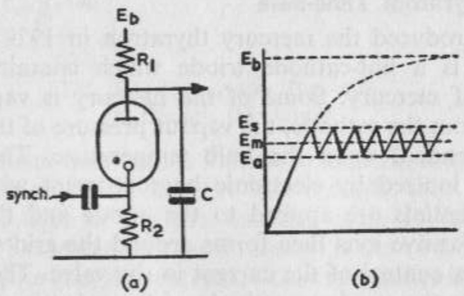

FIG. 5.3. NEON TIME-BASE
(*a*) Circuit; (*b*) Output.

5.1.2. Gas-diode Time-base

The neon time-base shown in Fig. 5.3 consists of a capacitor C which is charged from a constant potential E_b through a resistor R_1. The capacitor discharges through the neon when the voltage on the capacitor reaches the striking potential of the tube. The discharge ceases when the voltage falls to the extinction potential of the tube. The charging-curve is thus a small portion of an exponential curve of time-constant CR_1 so that the time-base is approximately linear when E_b is much greater than the striking potential of the tube. The resistor R_2 limits the peak current passed by the tube during the discharge. Synchronizing signals may conveniently be inserted across R_2. The major disadvantage of the neon time-base is that the output is limited to only about 30 V for typical gas-diodes.

The neon time-base was invented by Pearson and Anson in 1922 (5.2). In 1924, Appleton, Herd and Watson Watt replaced the charging resistor by a saturated diode in order to keep the charging current more nearly constant. In 1933, Bedford and von Ardenne replaced the diode by a pentode operating at anode potentials above the knee of the characteristic. The pentode valve then acts as a constant-current regulator as is shown by the typical characteristic curves of Fig. 2.30.

5.1.3. Thyratron Time-base

Hull introduced the mercury thyratron in 1929 (5.3). The thyratron is a hot-cathode triode which contains a small quantity of mercury. Some of the mercury is vaporized by the heat from the cathode, the vapour pressure of the mercury being dependent upon the bulb temperature. The mercury vapour is ionized by electronic bombardment when appropriate potentials are applied to the anode and the grid. A cloud of positive ions then forms around the grid so that the grid has no control of the current in the valve. The potential drop across the anode-to-cathode of the valve is about 15 to 18 V when ionized. Deionization can only be produced by reducing the anode potential. If the grid and anode potentials are initially chosen so that insufficient anode current flows to cause ionization, the valve behaves like a hard valve biased almost to cut-off. For each anode voltage there is a corresponding critical grid-voltage at which the anode-current flow is just insufficient to cause ionization. The ratio of striking-potential to critical grid-voltage is about 30 for a typical valve.

The basic thyratron time-base circuit is shown in Fig. 5.4. The striking potential of the valve is determined by the bias voltage on the grid so that variation of this voltage forms a convenient amplitude control. The resistors R_2 and R_3 limit the peak anode and grid currents which flow through the thyratron. Synchronizing signals may be superimposed on the bias voltage as shown. It should be noted that synchronizing signals initiate the flyback of the time-base whereas for many radar applications it is essential to initiate the start of the time-base.

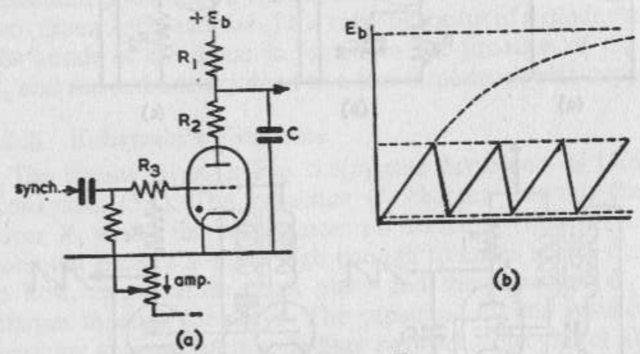

FIG. 5.4. THYRATRON TIME-BASE
(a) Circuit; (b) Output.

The thyratron time-base is limited to a maximum repetition frequency of about 40 kc/s. It was thought that the finite deionization time of the gas was the cause of failure, but Puckle (1.2) has stated that the limitation is due to the necessity for reducing the charging current as the capacitance is reduced.

5.2. Blocking and Squegging Oscillators

Both the blocking and squegging oscillator circuits described in Section 4.2.3 may be used as triggered or free-running time-base generators. The basic circuits of these time-bases are shown in Fig. 5.5. The transformer is generally iron-cored in blocking oscillators, whereas it is often air-cored in squegging oscillators.

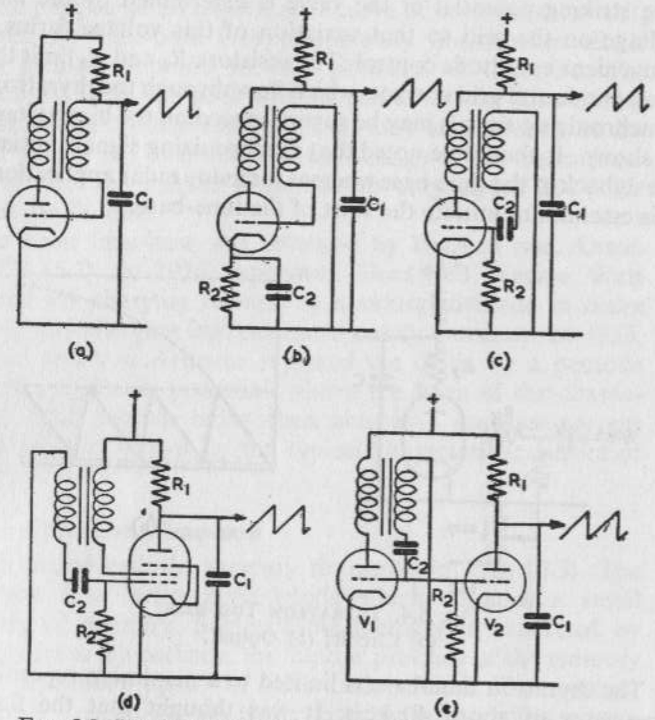

FIG. 5.5. BLOCKING AND SQUEGGING OSCILLATOR TIME-BASES

5.2.1. Appleton, Herd and Watson Watt's Time-base

The circuit of Fig. 5.5(*a*) is due to Appleton, Herd and Watson Watt (5.4), who used it in the first hard-valve time-base in 1923. In the original squegging version, R_1 was replaced by a saturated temperature-limited diode to improve the linearity. The capacitor C_1 is charged negatively whilst the circuit squeggs or blocks, the actual charge acquired by the capacitor during this time being dependent upon many factors as described by Benjamin (5.5). The capacitor charges positively through R_1 between pulses until the cut-off potential of the valve is passed, whereupon anode current flows and the circuit again squeggs or blocks. The resistor R_1 is returned to the h.t. supply in preference to earth in order to improve the linearity of the time-base waveform across C_1. Synchronization may be achieved by coupling negative pulses to the anode of the valve, or positive pulses to the grid of the valve, through a small capacitor. Synchronizing signals may alternatively be coupled through a third winding on the transformer. The circuit may be made unistable by clamping the maximum potential on the capacitor at a value more negative than the cut-off potential of the valve by means of a diode clamp. The anode of the diode is joined to the junction of C_1 and R_1 and the cathode is joined to a low-impedance bias-supply.

5.2.2. Kobayashi's Time-base

The circuit given in Fig. 5.5(*b*) was developed in 1929 by Kobayashi (5.6). The capacitor C_1 charges through the resistor R_1 whilst the valve passes no current. When the anode potential reaches a value high enough to cause anode current to flow, regeneration takes place and the capacitor C_1 discharges through the valve. The capacitor C_2 and resistor R_2 form an automatic cathode-bias network. Fig. 5.5(*c*) shows a variation of Kobayashi's circuit in which automatic grid-leak biasing is used.

5.2.3. Miscellaneous Blocking Oscillators

In Fig. 5.5(*d*) the blocking action takes place between the grid and the screen of a pentode valve. The anode current flows to discharge the capacitor C_1 during the blocking period. The circuit given in Fig. 5.5(*e*) uses a separate triode valve to discharge the capacitor C_1.

It is seen that synchronizing signals initiate the flyback of the blocking and squegging time-bases in a similar manner to the soft-valve time-bases. The blocking-oscillator time-base is a very economical circuit which is widely used in modern television receivers. In radar, the blocking-oscillator time-base circuit is often used as a frequency divider for calibration markers as shown in Fig. 5.6, but radar displays generally use precision time-base circuits for which the trace is initiated by a trigger signal. The circuit given in Fig. 5.6 divides calibration pulses at 2 nautical mile intervals (24·6 μs) by 5 to give pulses at 10 nautical mile intervals. The diode prevents the circuit from operating in the absence of trigger signals.

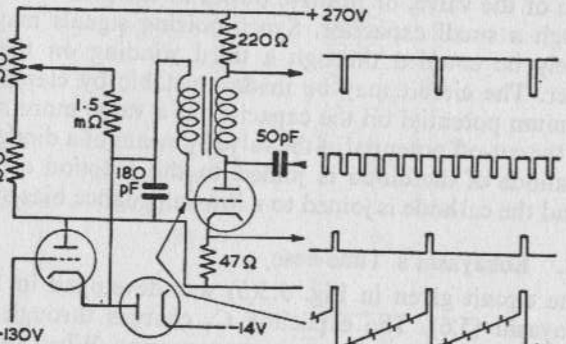

FIG. 5.6. BLOCKING OSCILLATOR FREQUENCY DIVIDER

5.3. Multivibrators and Two-valve Flip-flops

The multivibrator is a relaxation oscillator in which two amplifier-stages are employed in cascade, the output of the second being connected back in phase to the input of the first in order to provide an unstable region in which the input characteristic exhibits a negative resistance. Multivibrators may have one or both valves biased in such a way that the circuit can exist in one or two stable states. The terms unistable and bistable multivibrators have arisen to describe such circuits but, since the word multivibrator essentially implies a relaxation oscillator, the use of such terms is to be deprecated.

5.3.1. Abraham and Bloch's Multivibrator

The multivibrator was developed by Abraham and Bloch in 1918. The basic circuit is given in Fig. 5.7(*a*), which shows

two triode valves each having its anode coupled to the grid of the other valve through a capacitor and grid resistor.

Consider an incremental increase in anode current to occur in valve V_1, then a fall of potential will occur at the anode of V_1 owing to the increased potential drop across the anode-load resistor R_3. The fall of potential is coupled to the grid of valve V_2 through capacitor C_1 and resistor R_2. The anode current of V_2 is thereby reduced so that a rise of potential occurs at the anode of V_2. The rise is coupled to the grid of V_1 thereby further increasing the current in V_1. The effect is

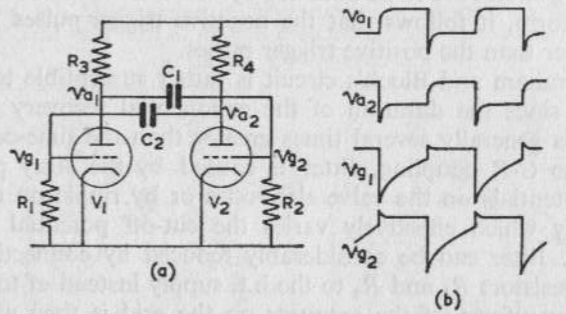

FIG. 5.7. ABRAHAM AND BLOCH'S MULTIVIBRATOR
(*a*) Circuit; (*b*) Waveforms.

cumulative when the loop gain of the amplifier exceeds unity so that eventually the anode current in V_1 reaches a maximum and the anode current in V_2 is cut off. This condition remains whilst the charge of C_1 leaks away through R_2, R_3, and V_1 until anode current is again permitted to flow in V_2. A cumulative action then takes place in the reverse direction until anode current in V_1 is cut off and anode current in V_2 is at a maximum. Thus the circuit oscillates between two quasi-stable states in which one valve is cut off and the other is on.

A symmetrical multivibrator has valves of identical characteristics in a circuit in which $R_1 = R_2$, $R_3 = R_4$ and $C_1 = C_2$. The periods during which the circuit remains in each state are then identical and the waveforms given in Fig. 5.7(*b*) apply to the circuit. It will be noticed that the grid of a valve is driven slightly positive at the start of each "on" period. It is during this time that the coupling capacitor is recharged through the associated anode load resistor and the grid-cathode circuit of the valve. The recharging process is shown to occur much quicker than the discharge on the assumption that the anode load resistors are much less than the grid resistors. The negative recharging "pips" on the anode waveforms are also present on the corresponding grid waveforms. Recharging also causes the leading edges of each anode potential-rise to be rounded. Thus if trigger pulses for a following circuit are to be obtained by differentiation of an anode waveform, it follows that the negative trigger pulses will be sharper than the positive trigger pulses.

Abraham and Bloch's circuit is rather susceptible to time-jitter since the duration of the exponential recovery on the grid is generally several times greater than the time-constant of the *C-R* coupling. Jitter is caused by the stray pick-up of potentials on the valve electrodes or by ripple on the h.t. supply which effectively varies the cut-off potential of the valve. Jitter can be considerably reduced by connecting the grid resistors R_1 and R_2 to the h.t. supply instead of to earth. The waveform of the recovery on the grid is then approximately linear so that less time-change occurs for a change of the cut-off potential.

Unsymmetrical multivibrators produce waveforms of mark-space ratios other than unity. Such circuits are often used in radar, a typical application being as a master timing-pulse generator such as that shown in Fig. 5.8. This circuit produces pulses of width 82 μs at repetition-frequencies which can be set between 250 pulses/sec. and 500 pulses/sec.

Synchronizing signals may be coupled into the multivibrator on either anode or grid. There are, however, preferred arrangements which may advantageously be used with a symmetrical multivibrator which is acting as a frequency divider. The circuit favours even division-ratios when equal synchronizing signals are fed in phase to both grids whereas the circuit favours odd division-ratios when equal but anti-phase synchronizing signals are fed to both grids as shown in Fig. 5.9.

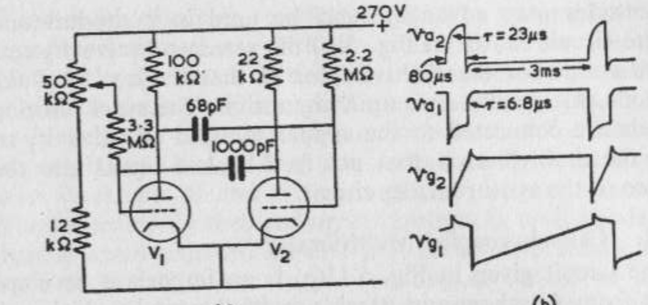

Fig. 5.8. Unsymmetrical Multivibrator which Produces Pulses of Width 82 μs at a Repetition Rate 250/500 p.p.s.
(*a*) Circuit; (*b*) Waveforms.

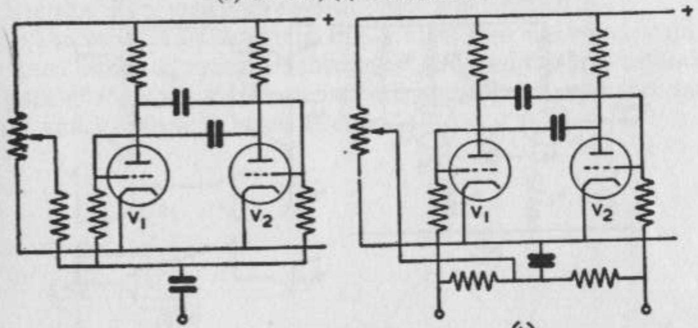

Fig. 5.9. Connexions for Symmetrical Multivibrators as Frequency Dividers
(*a*) Favours Even Integers; (*b*) Favours Odd Integers (balanced synchronization in antiphase).

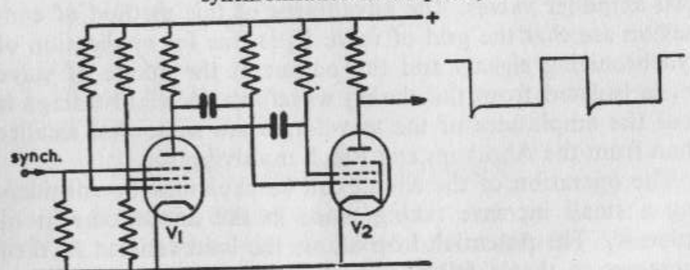

Fig. 5.10. Pentode Multivibrator

Pentodes may advantageously be used in multivibrators. In the circuit shown in Fig. 5.10 the screen of valve V_2 acts as an anode for the multivibrator so that the anode of the pentode solely feeds an output connexion. The synchronizing signals are connected to the suppressor grid of valve V_1 so that the multivibrator does not feed back a signal into the source of the synchronizing circuit.

5.3.2. Cathode-coupled Multivibrator

The circuit given in Fig. 5.11(*a*) is an important development from Abraham and Bloch's multivibrator in which one

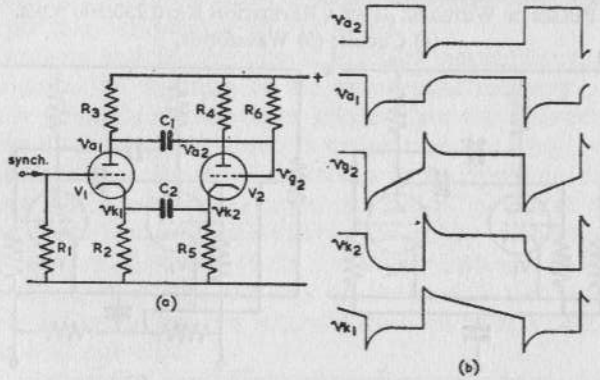

FIG. 5.11. CATHODE-COUPLED MULTIVIBRATOR
(*a*) Circuit; (*b*) Waveforms.

of the a.c. couplings is inserted between the cathodes of the two amplifier valves. The advantages of this method of connexion are that the grid of valve V_1 is free for application of synchronizing signals and the output at the anode of valve V_2 is isolated from the timing waveform. A disadvantage is that the amplitudes of the waveforms are somewhat smaller than from the Abraham and Bloch multivibrator.

The operation of the circuit can be explained by considering a small increase taking place in the anode current of valve V_1. The potential drop across the load resistor R_3 then increases so that a fall of potential is coupled to the grid of

V_2 through the a.c. coupling C_1R_6. The current in V_2 is thereby decreased so that the potential across the small cathode load resistor R_5 decreases. The cathode potential of V_1 is also decreased through the a.c. coupling C_2R_2, thereby causing further increase in the anode current of V_1. The action is cumulative when the loop-gain exceeds unity so that eventually V_2 is cut off and the current in V_1 is at a maximum. The capacitor C_1 then recharges through R_6 until anode current is again switched on in V_2. A cumulative action in the reverse direction then ensues resulting in cut-off of anode current in V_1 by the rise of potential across R_2. The capacitor C_2 then discharges through the resistors R_2 and R_5 and the valve V_2 until anode current is again switched on in V_1. Resistor R_2 is generally several times greater than R_5.

The waveforms shown in Fig. 5.11(*b*) also show recharging "pips" since C_1 recharges through R_3, R_5 and the grid-cathode path of V_2 when V_1 is switched off, and C_2 recharges through R_5 and V_1 when V_2 is switched off.

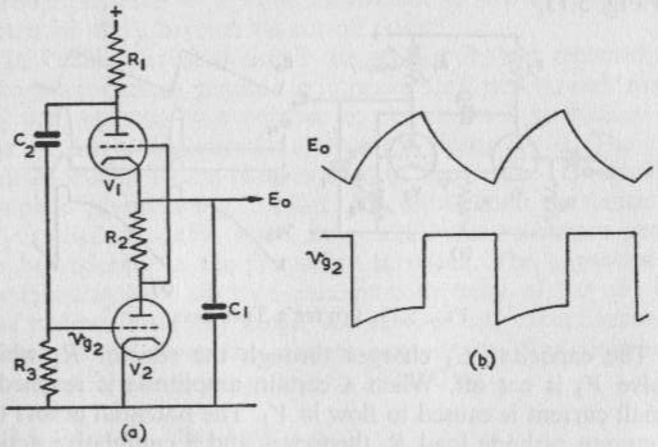

FIG. 5.12. FRÜHAUF'S TIME-BASE

5.3.3. Frühauf's Time-base

Fig. 5.12 shows the modern version of the time-base circuit developed by Frühauf in 1929 (5.26). It comprises a series-connected multivibrator which produces a substantially triangular waveform.

The capacitor C_1 charges through the anode resistor of valve V_1 and resistor R_1 in one state. The valve V_2 is then cut off by the potential drop across R_1 which is coupled to the grid of V_2 through the long time-constant coupling C_2R_3. When the anode potential of V_2 reaches a certain amplitude a small anode current is permitted to flow in V_2. The corresponding potential drop across R_2 reduces the anode current in valve V_1 and the potential drop across R_1 so that a cumulative action then ensues, resulting in complete cut-off of anode current in V_1. Capacitor C_1 then discharges through R_2 and the anode resistor of V_2 until anode current again flows in V_1.

5.3.4. Potter's Time-base

The cathode-coupled amplifier was adapted as a time-base generator by Potter in 1938 (5.27). The basic circuit is given in Fig. 5.13.

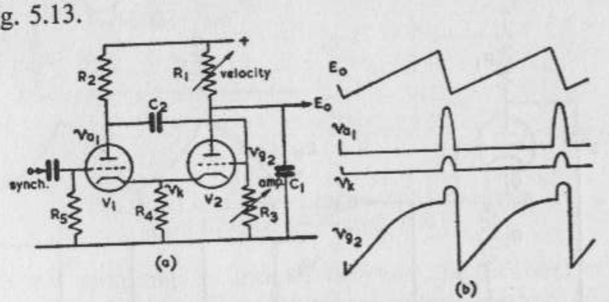

FIG. 5.13. POTTER'S TIME-BASE

The capacitor C_1 charges through the resistor R_1 whilst valve V_2 is cut off. When a certain amplitude is reached a small current is caused to flow in V_2. The potential across the common cathode load R_4 then rises and a cumulative action ensues resulting in anode current cut-off in V_1 whilst capacitor C_1 discharges through V_2 and capacitor C_2 charges through the grid-cathode path of V_2.

When the current through V_1 falls below a certain value, the voltage drop across R_4 becomes insufficient to cut off V_1. The flyback period is then terminated when V_2 is again cut off. The capacitor C_2 discharges through R_3, R_2 and V_1 during the trace until the grid voltage on V_2 becomes small enough to permit anode current to flow in V_2.

5.3.5. Puckle's Time-base

In 1933 Puckle (5.28) developed the time-base which is shown in basic form in Fig. 5.14(*a*). The capacitor C_1 charges through the resistor R_1 whilst valve V_1 is cut off by the potential drop across R_4 due to current flowing in valve V_2. When the cathode potential of valve V_1 falls to a certain value, anode current is permitted to flow in V_1. The potential drop across R_2 is then coupled to the grid of valve V_2 through the long time-constant coupling C_2R_3, so that the anode current in V_2 is reduced resulting in a cumulative action. The capacitor C_1 then discharges rapidly through the low anode resistor of valve V_1 and the low resistor R_2 until the current through R_2 falls to a value insufficient to maintain the grid potential of V_2 beyond the cut-off point.

In Puckle's original circuit the resistor R_1 was replaced by a constant-current pentode to improve the linearity, and triode V_2 was replaced by a pentode to permit the introduction of the synchronizing signal on the extra control-grid. The circuit of Puckle's time-base as used in the Cossor 339 oscillograph is given in Fig. 5.14(*c*). The anode load resistance of V_1 is made variable since, in general, this resistance needs to be reduced as the frequency is raised. The capacitor is switched in steps up to a maximum capacity of 1·0 μF. On the highest frequency range, the stray-circuit capacitances of about 50 pF form the storage capacitance. The time-base covers a frequency range of 6 to 250,000 c/s.

5.3.6. Keen's Time-base

Keen (5.29) realized that the functions of the constant-current pentode and the amplifier pentode of Puckle's time-base can be performed by one pentode valve as shown in Fig. 5.15. During the trace, the pentode V_2 passes approximately constant anode and screen currents provided the anode potential is above the "knee" of the pentode characteristic. When the cathode potential of the triode V_1 falls below a

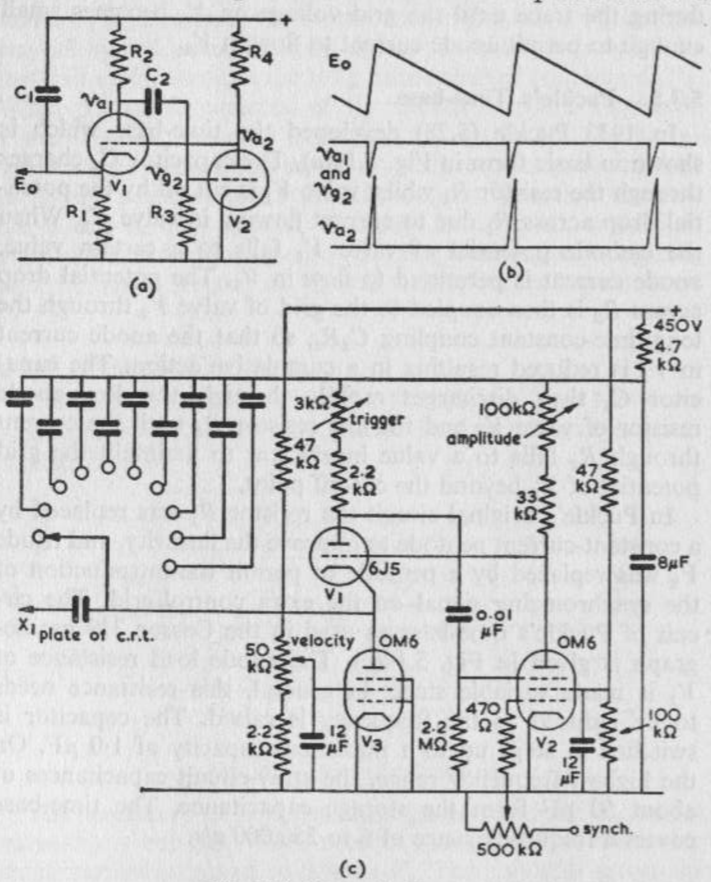

FIG. 5.14. PUCKLE'S TIME-BASE
(*a*) Basic Circuit; (*b*) Waveforms; (*c*) Typical Oscilloscope Circuit (Cossor 339).

certain value, anode current flows in V_1 so that V_2 is cut off and the screen potential of V_2 rises.

It is a disadvantage of Keen's time-base that synchronizing signals cannot be introduced on an isolated electrode as in Puckle's time-base. The synchronizing signal is preferably introduced on the screen of V_2, but the amplitude of the synchronizing potential must be limited to prevent modulation

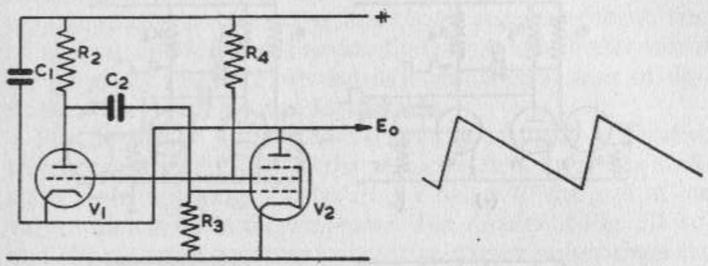

FIG. 5.15. KEEN'S TIME-BASE

of the current through V_2 and one must tolerate feedback of pulses into the synchronizing-signal source.

5.3.7. Two-stage Flip-flops

A representative group of basic circuits of two-stage flip-flops is shown in Fig. 5.16. There are many variations of flip-flops in existence; often circuits use one or two pentode valves instead of the triodes shown in the basic circuits. In general, a relaxation oscillator may be converted into a flip-flop by biasing the grid of one valve at a potential beyond cut-off.

Figs. 5.16(*a*) and (*b*) show flip-flops formed from Abraham and Bloch's multivibrator. These circuits normally wait in the stable state in which valve V_1 passes maximum current and valve V_2 is cut off. Application of a negative trigger pulse to the grid of V_1 initiates the changeover of anode current from V_1 to V_2. The grid of V_1 is then taken negative and thereafter recovers at a rate determined by C_1, R_1 and the h.t. supply potential. When the grid potential of V_1 passes through the grid cut-off potential, the valve again passes current and a cumulative action rapidly reverts the circuit to the again falls until eventually the anode current is completely cut off as shown in Fig. 6.1(*b*). In Fig. 6.2(*a*) the suppressor grid is returned to a constant potential of about +30 V. A resistor is inserted in the cathode lead so that the cathode potential increases as the grid potential is raised. When the cathode potential rises above the suppressor-grid potential, the anode current is reduced and the screen current rises. The characteristic is shown in Fig. 6.2(*b*). Circuits which obtain a negative resistance in this way are known as "transitrons." The negative resistance obtained with a transitron is

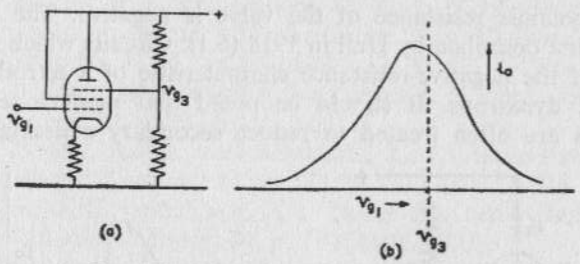

Fig. 6.2. Cathode-coupled Transitron

generally more stable and of lower value than that obtained with a dynatron.

A number of circuits have been developed in which a pentode valve is used as a negative-feedback integrator which operates between limits which are controlled by a transitron action. These circuits are known as "transitron-Miller time-bases" or "phantastrons." The term phantastron arose from the fact that the performance of these transitron circuits was so good as to be considered fantastic at the time of their development in 1942. One distinct advantage of the phantastron is that the trace is initiated by the synchronizing or triggering pulses, whereas the flyback is initiated in nearly all the time-bases developed prior to the phantastron.

During the war, F. C. Williams, N. F. Moody and others developed a number of circuits in which an extra pentode valve is used to provide the switching action for a Miller integrator. These circuits are less susceptible to variations of supply voltages and valve characteristics than those circuits which rely upon a transitron action. For this reason these were called sanatrons and sanaphants; the term "sana" being an abbreviation for "sanitary" meaning "satisfactory." The author developed several similar circuits in 1950 in which a double-triode valve provides the switching action for a Miller integrator. These circuits have been called pulsaphants since their main use is as precision-timed pulse generators.

6.1. Dynatrons, Transitrons and Phantastrons

6.1.1. Dynatron Time-base

Black (6.2) has developed a time-base which uses a dynatron as shown in Fig. 6.3. The time-base storage-capacitor C_1 is

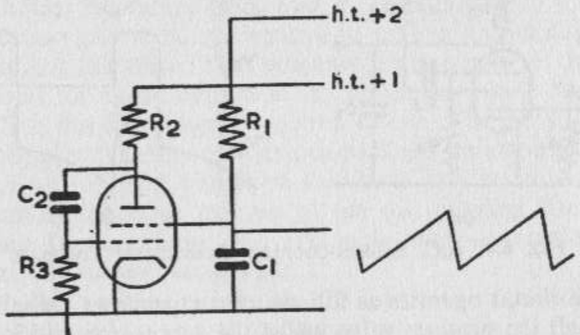

Fig. 6.3. Black's Dynatron Time-base

connected to the screen of the tetrode valve. The anode is coupled to the control grid through a further capacitor C_2 and a resistor R_3. The supply voltage to the anode is about one-half the supply voltage to the screen grid.

The circuit operates as follows: the capacitor C_1 charges through R_1 whilst the valve anode and screen currents are very small but progressively increasing. At a certain screen potential, the corresponding anode potential becomes low enough to enter the negative-resistance region of the characteristic. The anode current then decreases and the screen current increases. The fall of potential across the anode load resistor R_2 is then coupled to the grid of the valve through C_2 causing a further increase in the screen current. The capacitor C_2 then rapidly discharges through the screen of the valve until the screen potential is low enough to take the anode out of the negative-resistance region of the characteristic. The grid potential then falls and the cycle recommences.

6.1.2. Transitron Time-bases

The circuit given in Fig. 6.4(*a*) was developed by B. C. Fleming-Williams in 1939 (6.3). Similar circuits were also developed independently by Reich at about the same time (6.4).

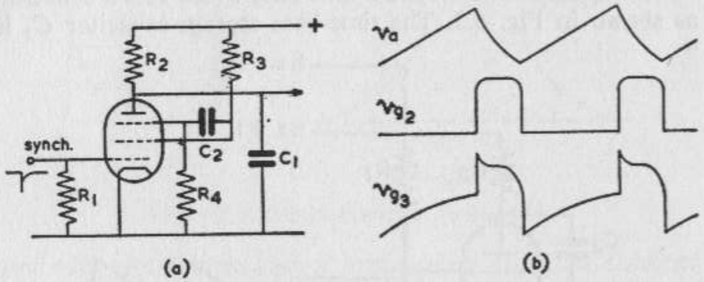

FIG. 6.4. A.C. SCREEN-COUPLED TRANSITRON TIME-BASE

The circuit operates as follows: the capacitor C_1 discharges through the pentode valve whilst the suppressor grid is positive. As the anode voltage falls, the anode and screen currents remain approximately constant until the knee of the anode characteristic is reached. The anode current then commences to fall and the screen current rises. The corresponding fall of screen potential is then coupled to the suppressor grid through the a.c. coupling C_2R_4. The anode current is then further reduced and a cumulative action ensues which results in complete cut-off of the anode current. The capacitor C_1 then recharges through R_2 until anode current again flows in the valve. The time at which the anode current is again switched on is determined by the amplitude of the fall of the screen potential, the time-constant C_2R_4, and the length of the

suppressor-grid-base. The suppressor-grid potential recovers exponentially whilst C_2 discharges during the trace. It is arranged that anode current is switched on again before the capacitor C_1 recharges to the full h.t. supply potential. The suppressor grid is taken positive during the flyback and C_2 recharges by drawing current through the suppressor grid. It should be noted that some valves (EF50 and CV138) pass reverse suppressor-grid currents at potentials about 40-50 V positive which may upset the operation of the circuit. This defect can be avoided by connecting a low-impedance diode between the suppressor and earth. Other valves are available which incorporate a diode and have a short suppressor-grid base (VR116, CV329).

In the d.c. screen-coupled transitron time-base, shown in Fig. 6.5(*a*), the values of R_4 and R_5 are adjusted so that the suppressor grid is taken negative to a certain critical potential during the trace. This potential corresponds to the cut-off point for anode current at the maximum anode potential to which the time-base is required to run. The capacitor C_2 compensates for stray capacitance on the suppressor grid.

The a.c. coupled transitron time-base may be adjusted to operate in the same manner as the d.c. coupled circuit by making C_2 very large and arranging that d.c. restoration occurs on the suppressor grid.

The d.c. coupled circuit has the advantage that only one capacitor need be varied to change the velocity of the trace over a wide range whereas two capacitors must be varied in the short time-constant a.c. coupled circuit. The setting of the d.c. potentials is, however, more critical in the d.c. coupled circuit. When the suppressor-grid potential is too negative, the capacitor C_1 charges fully to the h.t. potential and then remains in this state. When the suppressor-grid potential is insufficiently negative, the anode current will be switched on at a low anode potential so that the amplitude of the time-base is reduced. The resistor R_5 may thus be varied as an amplitude control.

Synchronizing signals may be applied to either the control grid or the suppressor. Negative signals on the control grid cause the screen potential to rise. The suppressor grid is then also caused to rise so that the onset of the anode current occurs earlier at the end of the time-base trace. Similarly positive synchronizing signals applied to the suppressor also cause the initiation of the flyback of the time-base.

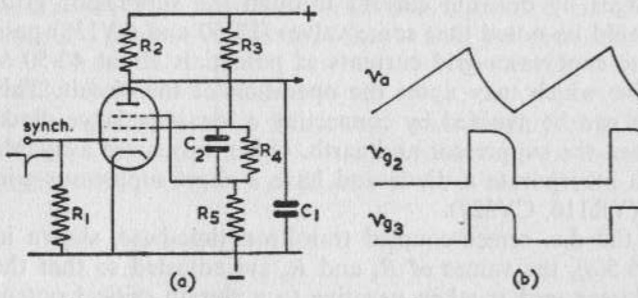

FIG. 6.5. D.C. SCREEN-COUPLED TRANSITRON TIME-BASE

6.1.3. Transitron Flip-flops

The screen-coupled transitron time-bases may be converted into flip-flops by choosing a low value of anode load resistance, or by applying negative bias to the suppressor grid, so that the anode potential cannot fall below the knee of the anode characteristic. By these means a stable state is obtained in which the anode passes current and a quasi-stable state is

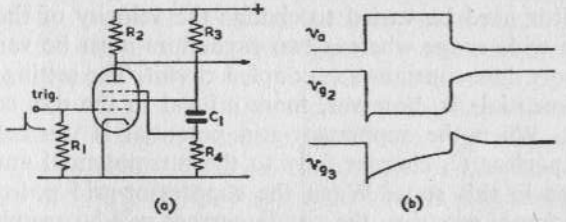

FIG. 6.6. A.C. SCREEN-COUPLED TRANSITRON FLIP-FLOP

obtained in which anode current is cut off for a period determined by a *C-R* network.

In Fig. 6.6, the application of a positive trigger pulse to the control grid causes a fall of the screen-grid potential which

then takes the suppressor grid negative. Anode current is cut off whilst the charge on C_1 decays exponentially through R_4 until the suppressor-grid potential reaches the cut-off point. Anode current then flows again and a cumulative action ensues which drives the suppressor grid into current whilst C_1 is recharged. It is advisable to use a valve which incorporates a diode between the suppressor grid and the cathode.

The d.c. screen-coupled flip-flop, shown in Fig. 6.7, is triggered by positive signals applied to the control grid. The

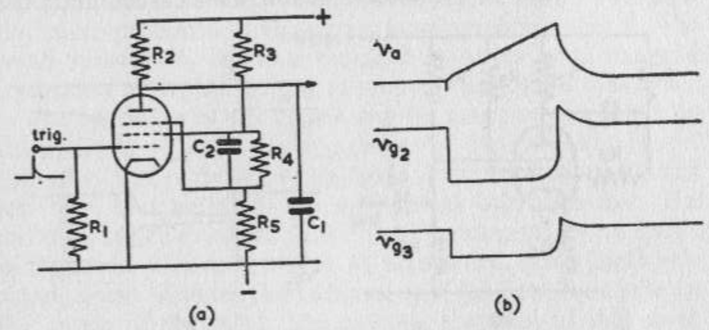

FIG. 6.7. D.C. SCREEN-COUPLED TRANSITRON FLIP-FLOP

anode current is cut off whilst C_1 charges through R_2. The d.c. coupling between the screen and the suppressor grid is such that the potential on the suppressor grid, in the quasi-stable state, just cuts off anode current at an anode potential less than the h.t. potential. The capacitor C_2 compensates for the stray capacitance on the suppressor grid.

6.1.4. Cathode-coupled Phantastron

The basic circuit given in Fig. 6.8 was developed by F. C. Williams in 1942 (6.6).

The cathode-coupled phantastron is a flip-flop which is particularly useful as an accurate delay circuit. The values of R_3, R_4, R_5 and R_6 are chosen so that the circuit rests in a stable state in which anode current is cut off by making the cathode potential sufficiently exceed the suppressor-grid potential. The valve passes grid current through the high resistor R_1 so that the grid potential is initially approximately equal to the cathode potential.

The application of a positive trigger pulse to the suppressor grid causes anode current to flow. The fall of anode potential is coupled to the grid through the capacitor C_1, thereby causing a reduction of the total current flowing through the valve. The potential drop across the cathode load resistor R_4 then decreases, reducing the potential between the cathode and the suppressor grid. A cumulative action then ensues until the

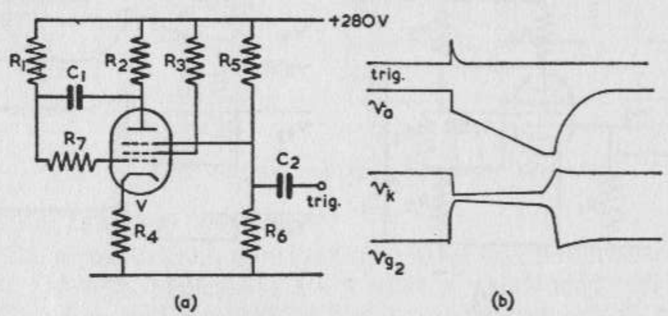

FIG. 6.8. CATHODE-COUPLED PHANTASTRON
$R_1, R_5 = 560k\Omega$; $R_2 = 220k\Omega$; $R_3 = 22k\Omega$; $R_4 = 3{\cdot}9k\Omega$; $R_6 = 27k\Omega$; $R_7 = 470\Omega$; $C_1 = 0{\cdot}005F$; $C_2 = 100pF$, $V = CV329$.

grid potential falls to an equilibrium value. The anode load resistor R_2 is of large value so that the cathode current falls to a small value. It is arranged that the corresponding cathode potential is less than the suppressor-grid potential. The capacitor C_1 then discharges through R_1, R_2 and the valve, causing the anode potential to fall with time. The fall of anode potential is very nearly linear since the grid potential rise is small compared with the fall of the anode potential during the anode run-down. The rate of fall of the anode potential is approximately,

$$dE_a/dt = -E/C_1R_1 \qquad (6.1)$$

where E is the potential of h.t. supply.

The anode potential falls linearly until the knee of the anode

characteristic is reached. The anode potential then remains constant allowing the grid potential to rise at a faster rate. The cathode potential also rises and eventually exceeds the suppressor-grid potential thereby causing reduction of the anode current. A cumulative action then ensues resulting in cut-off of the anode current whilst capacitor C_1 recharges through R_2, R_4 and the grid-cathode path of the valve.

The values of components given in Fig. 6.8 produce a run-duration of 2·0 ms. The circuit is triggered by a positive pulse of amplitude +20 V applied to the suppressor grid. The positive pulse produced at the screen is of amplitude 160 V. The small resistor R_7 is often required in series with the grid connexion of a phantastron to stop r.f. parasitic oscillations.

The operation of the circuit can be made more precise by the addition of a top-limiting diode on the grid electrode of the valve. The cathode of this diode is returned to a potential less than that at which the grid would otherwise rest. The duration of the quasi-stable state can be changed by variation of R_1 or the voltage to which R_1 is returned, but a preferable arrangement includes the addition of a top-limiting diode on the anode of the valve. The cathode potential of this diode is then varied over a range of values less than the h.t. supply potential. It is also possible to trigger the phantastron by applying negative pulses to the cathode of this diode.

The cathode-coupled phantastron is not very suitable as a time-base generator since the anode potential falls by a step of about 30 V prior to the linear run-down. The screen-coupled phantastron is more suitable as a time-base since the step is only about 6 V and the linearity is about five times better.

6.1.5. Screen-coupled Phantastron

The a.c. and d.c. screen-coupled transitron time-base circuits described in Section 6.1.2 may be converted into corresponding phantastron circuits by returning the storage capacitor to the grid of the valve as shown in Figs. 6.9(a) and 6.10(a). The method of operation of the phantastron differs from the corresponding transitron in that the discharge of the capacitor through the valve is controlled by negative feed-back. The current is kept at an approximately constant small value during the discharge so that the anode potential falls

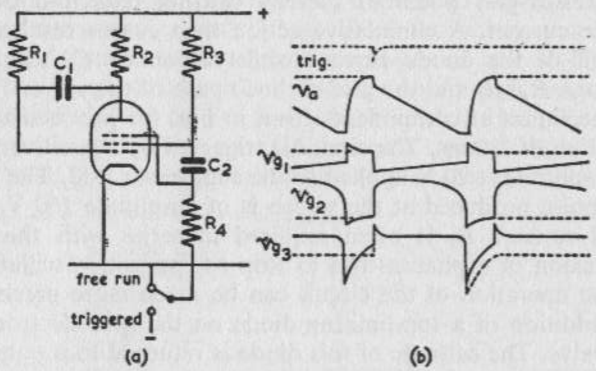

FIG. 6.9. A.C. SCREEN-COUPLED PHANTASTRON

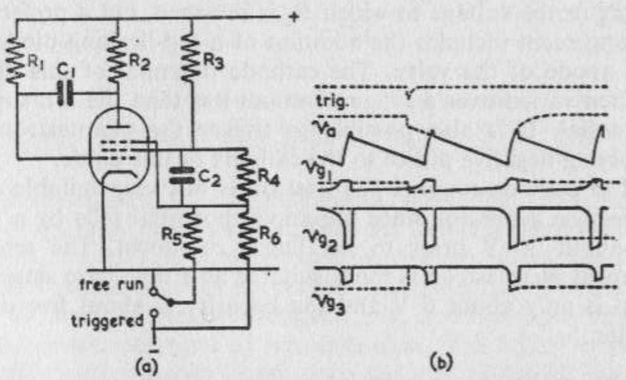

FIG. 6.10. D.C. SCREEN-COUPLED PHANTASTRON

linearly with time at a much slower rate than for the corre-sponding transitron.

The circuit constants are then preferably chosen so that the fall of anode potential becomes the trace, and the rise of anode potential becomes the flyback. These circuits become flip-flops

when the bias on the suppressor is made sufficiently negative. Such circuits are particularly suitable as triggered time-bases.

The a.c. screen-coupled phantastron was developed as a flip-flop circuit in 1943 by B. C. Fleming-Williams. The corre-sponding d.c. screen-coupled version of the flip-flop was described by F. C. Williams in 1946 (6.6) and the a.c. screen-coupled phantastron time-base was described by Cocking in 1946 (6.7). Satisfactory d.c. screen-coupled phantastron time-bases were developed in 1948.

The waveforms applying to the a.c. and d.c. screen-coupled phantastrons are given in Figs. 6.9(*b*) and 6.10(*b*) for both the free-running and triggered versions. Synchronizing or trigger signals may be applied to the anode, grid, or suppressor of the valve. In each case provision must be made to isolate the source of the synchronizing signals from the phantastron when the run-down commences or else velocity modulation of the trace occurs. It is usual to limit the amplitude of the synchronizing signal to something less than the amplitude of the initial change of potential which occurs in the phantastron circuit at the point where the trigger is applied through a uni-directional device. Suitable circuits are given in Fig. 6.11. In (*a*) the negative trigger signals are limited to about 10 V amplitude before application to the cathode of a top-clamping diode which is connected to the anode of the phantastron. In (*b*) the positive trigger pulses are applied to an "anode-follower anode clamp" which applies negative trigger pulses of the same amplitude to the anode of the phantastron. The advantage of the anode-follower over the diode is that the output impedance of the anode-follower is low ($2/g$) and virtually independent of the source impedance of the syn-chronizing signals. In both (*a*) and (*b*) the step-fall of poten-tial at the commencement of the run assists in isolating the trigger or synchronizing signals from the trace. Negative trigger signals may also be applied to the grid of the phantas-tron through an isolating diode; however, the triode circuit shown in (*c*) is preferable. The value of a small cathode-bias resistance on the phantastron may be chosen so that the triode anode is negative during the trace and positive during the flyback or wait-state. In (*d*) the phantastron is triggered by positive signals applied to the suppressor grid through a series diode. A shunt diode, as shown, prevents the trigger signals from rising positive during the trace.

The d.c. screen-coupled phantastron time-base is less susceptible to changes of the valve characteristic and the power-supply potentials than the corresponding transitron. This is because the recharging current for the storage capacitor causes

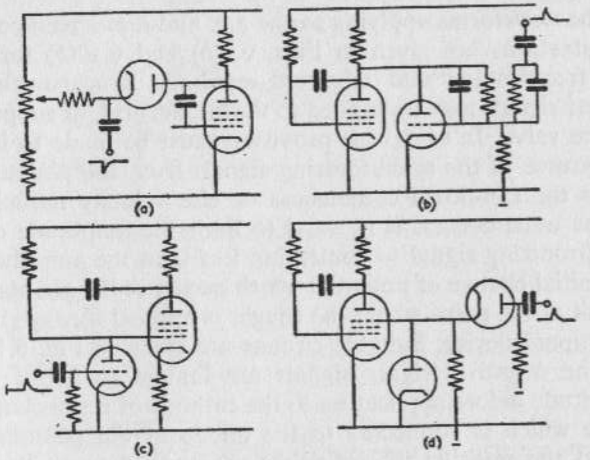

Fig. 6.11. Methods of Triggering or Synchronizing Phantastrons

the control-grid potential to be taken positive at the start of the flyback and thereafter to fall with time whilst the anode potential rises. The screen potential correspondingly rises with time causing the suppressor-grid potential to rise also during the flyback. This rise tends to offset changes in the topping potential of the anode owing to changes of the suppressor-grid d.c. potential. It should be noted that the topping potential of this time-base is necessarily less for free-running than for triggered operation although sweep amplitudes of about 70 per cent of the h.t. supply are obtainable. The rise of potential on the suppressor grid can be increased during the flyback

by increasing the charging current for the storage capacitor. This can be done by reducing the value of the anode load of the phantastron but a preferable method is to connect a cathode-follower valve between the anode of the phantastron and the storage capacitor. This is shown in the time-base circuit given in Fig. 6.12, which produces a trace of 150 V amplitude that can be varied between about 750 ms and 250 μs maximum duration by varying the size of capacitor C_1 between 0·5 μF and 150 pF. The flyback period is only about 1/150 of the trace period due to the rapid recharging of the

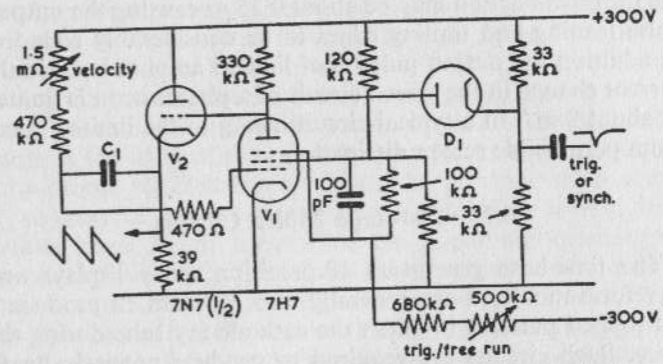

Fig. 6.12. D.C. Coupled Phantastron Time-base (Basic Cossor 1036/1037)

storage capacitor C_1 by the cathode-follower. The circuit may be adjusted for triggered or free-running operation by variation of the suppressor grid-bias control. This circuit was developed by the author in 1948 for use in the Cossor 1036 and 1037 oscillographs.

Phantastrons may be used to generate pulses of a precise width since, in a suitably designed circuit, the duration of the quasi-stable state is virtually independent of h.t. supply and valve-characteristic variations. When the anode of a phantastron is connected only to the feedback capacitor and the anode load resistor, it is possible to keep the stray capacitances on the anode as small as 10 pF in a typical layout. The feedback capacitor can then also be as small as 10 pF so that the total capacity to be discharged through the valve during the anode run-down is 20 pF. A typical small pentode valve of 0·8 W maximum screen dissipation rating will pass a maximum anode current of about 4 mA during the run-down so that a run-down rate of $dV/dt = i/C = 200$ V/μs can be obtained. Since the amplitude of the run-down may be about 200 V it follows from this consideration that it should be possible to produce pulses of width 1 μs from the phantastron. However, in practice phantastrons are rarely used to generate pulses of width less than 2·5 μs because the switching time of the transitron action may be about 0·25 μs causing the output-pulse leading and trailing edges to be considerably rounded. In addition the output pulse is of limited amplitude since the current change in the screen circuit of a phantastron is limited to about 8 mA in a typical circuit owing to the limited maximum permissible screen dissipation.

6.2. Two-stage Miller Circuits

The time-base generators of precision radar-displays and waveform-monitors are generally also required to produce a flat-topped pulse to brighten the cathode-ray tube during the trace. Such circuits are required to produce precisely linear time-base waveforms which are free from velocity modulation and which are negligibly affected by variations of valve characteristics.

The cathode-coupled phantastron is unsuitable as a precision time-base since the anode potential falls by a large step (about 30 V) prior to the linear run-down. The screen-coupled phantastron is more suitable since the step-fall of anode potential is tolerably small (about 6 V); in addition the gain of the amplifier is greater so that the linearity of the time-base is better. The pulse present at the screen of the phantastron falls in amplitude during the anode run-down, although this fall is relatively small when the gain of the amplifier is high. The main disadvantages of the screen-coupled phantastron are that the maximum run-down rate of the time-base waveform is limited by the screen dissipation of the valve, and a buffer

valve must generally be inserted between the trigger source and the phantastron.

The maximum run-down rate of the anode potential of the phantastron shown in Fig. 6.10 is limited by the stray circuit capacitances and the maximum anode current which the valve can pass during the trace. The minimum permissible value of the anode-grid capacitor C_1 is usually 50 pF when the circuit drives a cathode-ray tube, so if 4·0 mA is the maximum current that the grid leak R_1 can pass during the trace, the maximum run-down rate is $dV/dt = i/C_1 = 80$ V/μs. The anode current passed by the valve during the trace is equal to the sum of the currents flowing through R_1 and the anode load resistance R_2. The current through R_1 is nearly constant during the trace whilst the current through R_2 rises to a maximum value when the anode potential reaches the bottoming value at the knee of the pentode characteristic. The potential drop across R_2 then nearly equals the potential drop across R_1 so that, for fast run-down rates, R_2 should be several times greater than R_1 in order that the maximum discharging-current of the capacitor shall nearly equal the maximum anode-current which may be passed by the Miller valve. Since the flyback time of the anode waveform is determined by the time-constant of the anode load resistor and the capacitor C_1, it follows that the flyback will be at a slower rate than the run-down rate when $R_2 \gg R_1$. A cathode-follower on the anode of the Miller valve enables a more rapid flyback to be obtained when connected as shown in Fig. 6.12. The anode load resistor may then be made greater than the grid-leak resistor although the limit is then set by the stray capacitance present on the anode of the Miller valve. A more satisfactory arrangement is shown in Fig. 6.13 in which a pentode valve V_2 forms a low-resistance path to charge the capacitor C_1 whilst the anode current is cut off in the Miller valve. During the trace the potential drop across R_2 is sufficient to cut off the anode current in V_2 so that the anode current passed by V_1 is solely that passing through the capacitor.

The practical limitation to the maximum anode current for a given valve is set by the maximum screen potential at which the valve may operate during the trace. In phantastrons and some sanatrons, sanaphants and pulsatrons this limit is set by the maximum rated screen dissipation of the Miller valve since the screen passes all the current during the stable state. If the screen and control-grid potentials of a typical pentode valve are kept constant it is found that the anode passes about 75 per cent of the total valve current when the anode potential is above the knee of the characteristic. The application of a cut-off bias to the suppressor grid then leaves the total

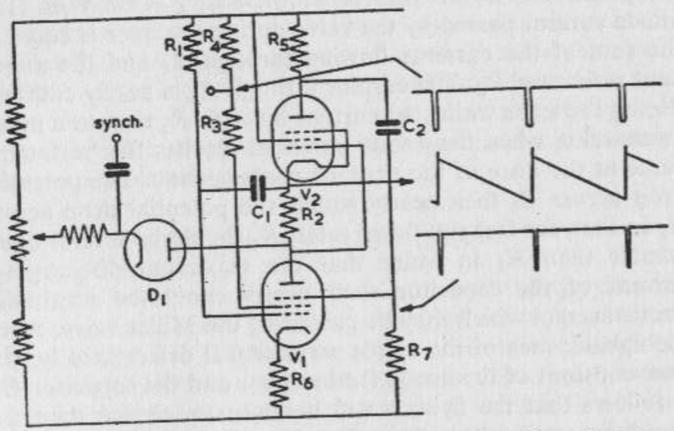

FIG. 6.13. SERIES-CONTROLLED SANATRON TIME-BASE (BASIC COSSOR 1035/1049)

valve-current approximately unchanged but transfers all the current to the screen. For a typical pentode the maximum screen-dissipation may be only 0·8 W and the screen impedance may be 8 kΩ at zero grid voltage when the anode current is cut off. Thus 80 V is then the maximum permissible screen potential in the stable state. The screen current is then 10 mA so that the maximum anode current is about 7·5 mA, and the screen current is about 2·5 mA when the suppressor-grid bias is zero. However, during the run-down the control-grid voltage must necessarily be taken negative so that the maximum operating anode current must be kept appreciably

less than 7·5 mA during the trace, a typical practical limit being 4·0 mA.

The screen of the Miller valve is preferably fed from a high voltage through a series unbypassed resistor; the screen potential then rises during the trace so that a higher anode current can then be passed. The gain of the Miller stage is then slightly reduced so that the linearity of the run-down is slightly reduced.

6.2.1. The Sanatron

The basic sanatron comprises two pentode valves, one being connected as a Miller integrator, the other being connected as a gated amplifier which is cut off during the run-down by coupling the anode potential of the Miller valve to the grid of the gate valve. The anode potential of the gate valve is at a maximum during the run-down. The flyback of the time-base occurs when the gate valve passes current since the output of this stage is coupled to the Miller valve in such a way that anode current is then cut off in the Miller valve.

In the suppressor-grid-controlled sanatron, shown in Fig. 6.14, the anode potential of the gate valve V_2 is d.c. coupled to the suppressor grid of the Miller valve V_1 so that anode current in V_1 is cut off when sufficient anode current flows in V_2. The capacitor C_1 then recharges through the resistor R_2 and the grid-cathode path of V_1 until the anode potential rises to the potential E_1 at which it is clamped by the diode D_1. The sanatron is triggered by the application of a negative pulse to the suppressor grid of the gate valve V_2. The anode potential of V_2 then rises and switches on anode current in V_1. The anode potential of V_1 then falls taking the grid of V_2 negative through the capacitor C_2 and the grid of V_1 negative through the capacitor C_1. The anode current of V_2 is thereby reduced so that a cumulative action ensues until anode current in V_2 is cut off. The grid potential of V_1 falls to a value near to cut-off at which the gain of the stage is unity. The resistor R_3 (about 2 kΩ) is inserted in order to ensure that the grid of V_2 is taken beyond the cut-off point. The diode D_2 prevents the grid of V_2 from being taken more

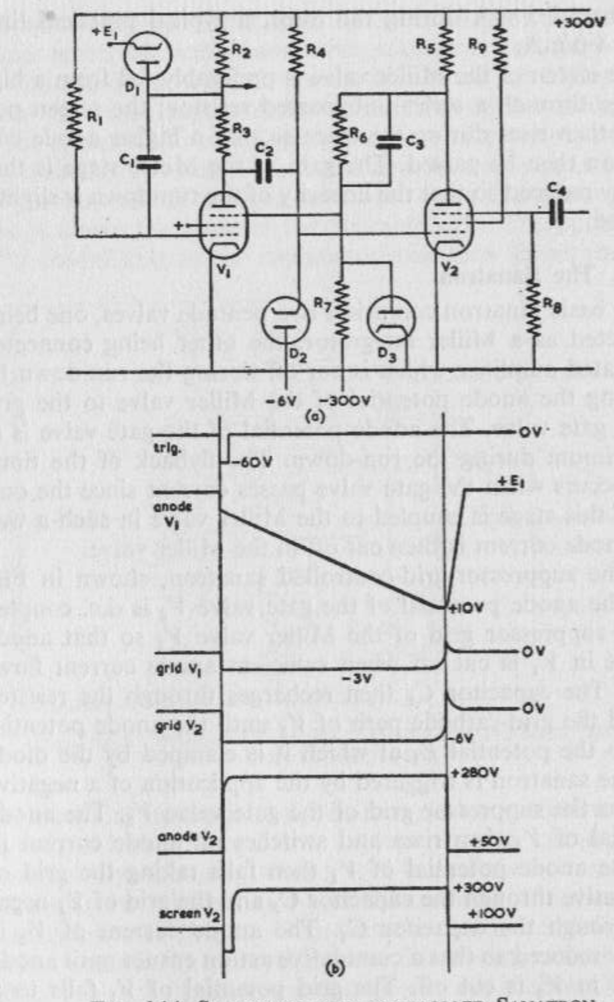

FIG. 6.14. SUPPRESSOR-GRID-CONTROLLED SANATRON

than a few volts beyond cut-off. The time-constants C_1R_1, C_2R_4, are approximately equal so that the grid of V_2 is maintained beyond cut-off whilst the anode potential of V_1 falls linearly with time. When the anode potential of V_1 bottoms, the grid potential of V_2 rises whilst C_2 charges through R_4. Anode current is then switched on in V_2 causing a cumulative action to ensue until the cycle is complete. It should be noted that the application of additional trigger pulses to the suppressor grid of V_2 cannot cause modulation of the trace since V_2 is cut off during the trace. The positive pulse present on the

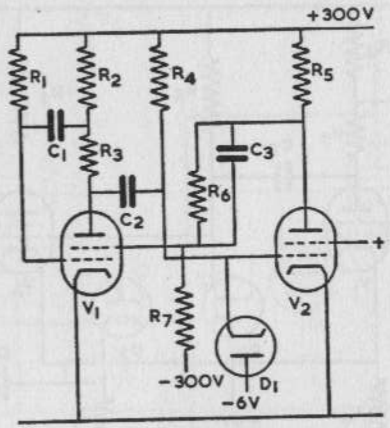

FIG. 6.15. SCREEN-GRID-CONTROLLED SANATRON

anode of V_2 is flat topped, its amplitude being limited by the rated anode dissipation of V_2. Stray capacitance on the anode of V_2 must be kept small to minimize the switching delay of the circuit. The small capacitor C_3 assists in minimizing the trigger delay by compensating for the stray capacitances on the suppressor grid of V_1 and the anode of V_2.

In the screen-grid-controlled sanatron of Fig. 6.15, the screen potential of the Miller valve is varied from about −30 V in the stable state to about +200 V during the run state. Thus screen current flows through V_1 only during the trace. Taking the same typical screen rating of 0·8 W as before, it follows that the screen current may be 4 mA during the trace so that the anode current may be 12 mA during the trace. This is three times greater than for the suppressor-grid-controlled sanatron: it allows a run-down rate of 240 V/μs to be obtained. Higher currents can be passed when the circuit is operated at a low duty ratio since the Miller valve only passes current during the trace. It is also possible to use tetrode valves in place of the pentodes. This is sometimes advantageous since these valves often have a higher power-handling capacity.

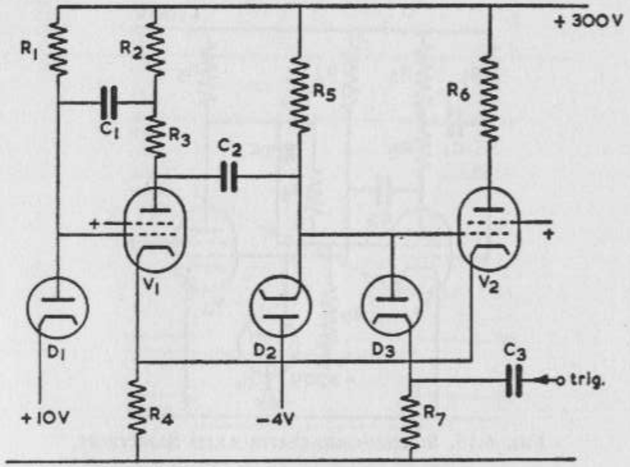

FIG. 6.16. CATHODE-CONTROLLED SANATRON

The cathode-controlled sanatron shown in Fig. 6.16 has the additional advantage that the initial step-fall of the time-base voltage is reduced. During the stable state the diode D_1 clamps the grid of the Miller valve at +10 V and diode D_3 with resistors R_5 and R_7 fix the grid of V_2 at +18 V. The valve V_2 passes sufficient current through the common-cathode load resistor R_4 to raise the cathode potential to about +20 V. Current is thereby cut off in V_1. A negative trigger pulse applied to the grid of V_2, through the diode D_3, causes a reduction of the current flowing in V_2. The potential across R_4

falls allowing current to flow in V_1. The potential drop across R_3 is then coupled to the grid of V_2 causing cut-off of V_2 whilst the linear run-down of V_1 anode potential takes place. When the anode potential of V_1 bottoms, the grid potential of V_2 rises, causing anode current to flow again in V_2. A cumulative action then ensues resulting in cut-off of V_1.

The grid-controlled sanatron shown in Fig. 6.17 has the advantage that the initial step-fall of the time-base may be

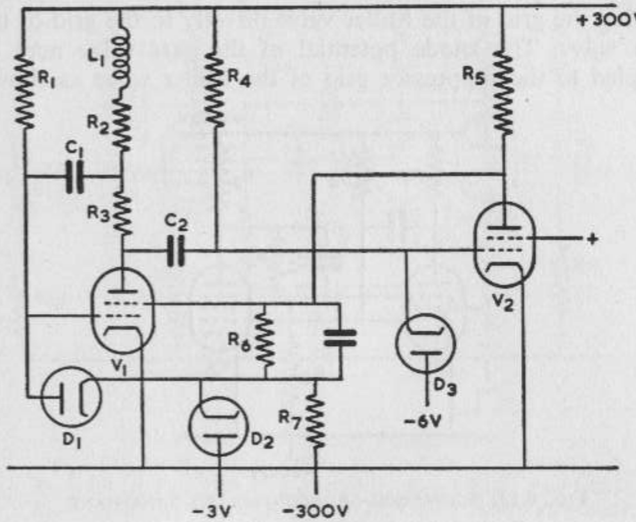

FIG. 6.17. GRID-CONTROLLED SANATRON

made very small. The grid potential of V_1 is clamped at −3 V during the stable state by the diodes D_1 and D_2. Upon application of a negative trigger pulse to the grid of V_2 through diode D_3, the current in V_2 is cut off allowing the potential on the cathode of diode D_1 to rise above earth. The capacitor C_1 then discharges through V_1 until V_1 bottoms. The valve V_1 passes anode current during the wait-state since a grid potential of −3 V does not cut off V_1. The anode load resistor R_2 is of low value, so that only a small potential drop occurs across it. The choke L_1 is of large value so that the current flowing through R_2 and L_1 changes only by a small amount during the run-down period.

6.2.2. The Sanaphant

The sanaphant circuit is intermediate in performance and complexity between the phantastron and the sanatron. The basic circuit comprises two pentode valves, one being connected as a Miller integrator, the other being connected as a gated amplifier which is cut off during the run-down by connecting the grid of the Miller valve directly to the grid of the gate valve. The anode potential of the gate valve may be coupled to the suppressor grid of the Miller valve as shown

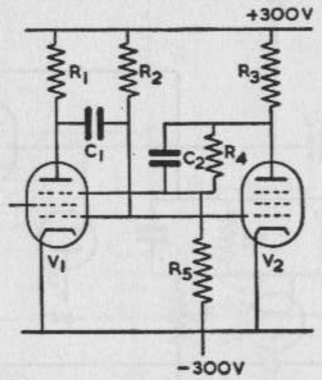

FIG. 6.18. SUPPRESSOR-GRID-CONTROLLED SANAPHANT

in Fig. 6.18. The operation of the circuit is similar to the screen-coupled phantastron already described. The circuit has the virtue that only one capacitor need be varied to alter the time-base velocity over a wide range. The anode of the gate valve may alternatively be coupled to the screen of the Miller valve in order to increase the maximum time-base velocity obtainable with a Miller valve of limited screen-dissipation rating.

6.2.3. The Pulsaphant

In 1950, the author (6.11) developed the basic pulsaphant circuit shown in Fig. 6.19. In response to a negative trigger pulse of amplitude 5 V, the circuit generates a positive pulse

of amplitude about 75 V at the cathode of V_2 and a negative pulse of amplitude about 75 V at the anode of V_{2a}. The pulse width may be varied between 0·7 μs and 10 μs by varying E_1 between 20 V and 280 V for the circuit component values shown in Fig. 6.19.

In the stable state, V_{2b} is conducting, and passes sufficient

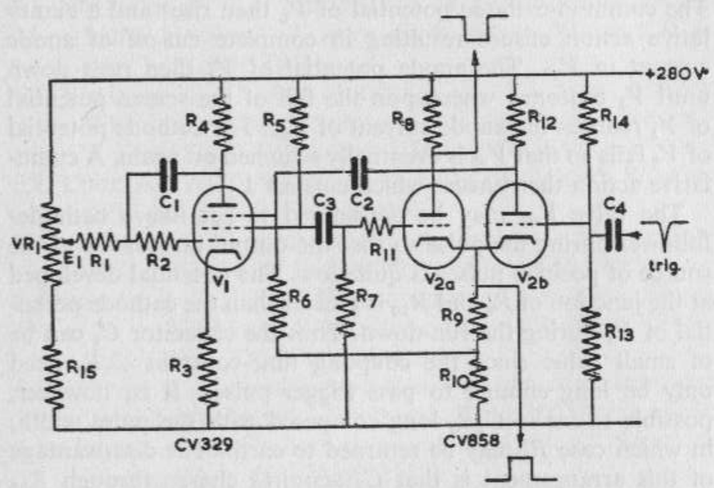

FIG. 6.19. LEVELL'S PULSAPHANT

R_1=91kΩ; R_2, R_{11}=470Ω; R_3=1·8kΩ; R_4=330kΩ; R_5, R_{12}=20kΩ; R_6=220kΩ; R_7=100kΩ; R_8=2·2kΩ; R_9=1·8kΩ; R_{10}=330Ω; R_{13}=18kΩ; R_{14}=470kΩ; R_{15}=3·9kΩ; VR_1=50kΩ; C_1=10pF; C_2, C_4=300pF; C_3=0·01μF.

current through R_9 and R_{10} to cut off, or reduce to a small value, the anode current of V_{2a}. V_1 is connected in a manner similar to the cathode-coupled phantastron, the main differences being that R_3 is lower than that required for a cathode-coupled phantastron and R_6 is returned to a potential which rises during the run-down. The potential drop across R_3, owing to the screen and grid currents flowing in V_1, is sufficiently greater than the potential drop across R_{10} to cut off the anode current in V_1.

The application of a negative trigger pulse to the grid of

V_{2b} reduces the current in this valve so that the anode potential rises. The rise is coupled to the suppressor grid of V_1 thereby causing anode current to flow in V_1. The grid potential of V_1 is then caused to fall so that the screen potential of V_1 then rises. The rise is coupled to the grid of V_{2a} through C_3 so that the current in V_{2a} is switched on or caused to rise. The common-cathode potential of V_2 then rises and a cumulative action ensues resulting in complete cut-off of anode current in V_{2b}. The anode potential of V_1 then runs down until V_1 bottoms, whereupon the fall of the screen potential of V_1 reduces the anode current of V_{2a}. The cathode potential of V_2 falls so that V_{2b} is eventually switched on again. A cumulative action then ensues which cuts off V_1.

The valve V_{2a} may be considered to act like a cathode-follower during the pulse so that the output impedance of the source of positive pulses is quite low. The potential developed at the junction of R_9 and R_{10} is greater than the cathode potential of V_1 during the run-down. Thus the capacitor C_2 can be of small value since the coupling time-constant C_2R_8 need only be long enough to pass trigger pulses. It is, however, possible to make C_2R_8 long compared with the pulse width, in which case R_8 may be returned to earth. The disadvantage of this arrangement is that C_2 acquires charge through R_{12} and the suppressor grid of V_1 during the pulse so that a d.c. restoring diode may then be needed across R_8 when the circuit is required to operate at a high rate.

The couplings C_2R_8 and C_3R_7 may be replaced by d.c. couplings when a negative supply is available. The cathode of V_1 may then be connected directly to earth thereby improving the linearity of the run down.

The pulsaphant can be made free running by returning R_8 to the positive h.t. supply. The time-constant C_2R_8 is then chosen to determine the pulse/space time.

6.3. Bibliography

6.1. HULL, A. W., "The dynatron, a vacuum tube possessing negative resistance," *Proc. Inst. Radio Engrs*, **6**, p. 5 (1918).

6.2. BLACK, D. H., "A new hard valve relaxation oscillator," *Elect. Commun.* (July, 1939).

6.3. FLEMING-WILLIAMS, B. C., "A single-valve time-base circuit," *Wireless Engr*, **17**, p. 161 (1940).

6.4. REICH, H. J., "Trigger-circuits," *Electronics*, **12**, p. 14 (August, 1939).

6.5. WILLIAMS, F. C., "Introduction to circuit techniques for radio location," *J. Instn Elect. Engrs*, **93**, Part IIIA, No. 1 (March, 1946).

6.6. WILLIAMS, F. C., and MOODY, N. F., "Ranging circuits, linear time-base generators and associated circuits," *J. Instn Elect. Engrs*, Part IIIA, No. 7 (1946).

6.7. COCKING, W. T., "Linear saw-tooth oscillator," *Wireless Wld*, **52**, p. 176 (June, 1946).

6.8. ATTREE, V., "Improving flyback time on a Miller time-base," *Electronic Engng*, **20**, p. 97 (March, 1948).

6.9. BRIGGS, B. H., "The Miller-integrator," *Electronic Engng*, **20**, p. 243 (Aug., 1948); ibid., **20**, p. 279 (Sept., 1948); ibid., **20**, p. 325 (Oct., 1948).

6.10. CLOSE, R. N., and LEBENBAUM, "Design of phantastron time-delay circuits," *Electronics*, **21**, p. 100 (April, 1948).

6.11. LEVELL, D. A., "A hard-valve pulse generator," *Electronic Engng*, **24**, p. 507 (Nov., 1952).

6.12. BRUNETTI, C., "The transitron oscillator," *Proc. Inst. Radio Engrs*, **27**, p. 88 (1939).

6.13. BRUNETTI, C., and GREENOUGH, L., "Some characteristics of a stable negative resistance," *Proc. Inst. Radio Engrs*, **30**, p. 542 (1942).

6.14. MCDADE, J. R., "The phantastron control circuit," *Elec. Engng*, **67**, p. 974 (1948).

6.15. SCROGGIE, M. G., "Applications of the Dynatron," *Wireless Engr*, **10**, p. 527 (1933).

6.16. WILLIAMS, F. C., *British Pats Nos.* 582,758 and 584,329.