5

EIT Decade Counting Circuits

The principle of operation of the Mullard/Philips E1T decade counter tube is fundamentally different from that of all other types of counting tube. The E1T is a high vacuum tube which has been especially designed for counting purposes; it has an indirectly heated cathode. The E1T is basically a small cathode ray tube of special design without any vertical deflecting plates and of about the same size as an octal based radio receiving tube. It has the advantage of being a self indicating device, but it cannot easily be used to control digital indicator tubes because the same electrodes are always being employed in the E1T whatever the state of the count. The method of readout is unique. An H.T. supply of 300 V is adequate for most E1T circuits.

The E1T is not a gas filled device and, therefore, its maximum operating speed is not limited by ionisation and deionisation times. All E1T tubes can operate at counting speeds up to at least 30,000 pulses per second, but about 75% of all the tubes can be used in slightly more complicated circuits for counting at frequencies up to 100,000 pulses per second[(1)]. Operation at frequencies of the order of one million pulses per second has been reported[(2)].

The form and the dimensions of the E1T are shown in Fig. 5.1.

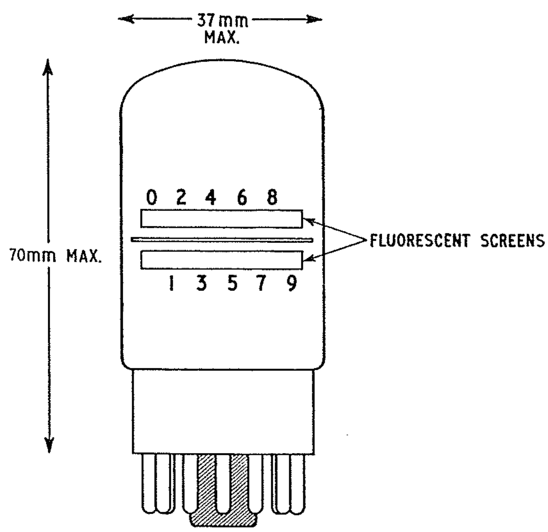


Fig. 5.1 The E1T decade counting tube

5.1 READOUT

The E1T tube employs a ribbon shaped electron beam of rectangular cross section which has ten stable positions in the tube. A small portion of the beam passes through one of the ten holes in the anode and strikes a fluorescent coating on the inside of the tube envelope so that a vertical green luminescent mark is formed in a position near to the digit which is to be indicated. The ten digits themselves are marked on a paper mask which is fixed to the outside of the tube. The beam advances at one step per input pulse until the digit 'nine' is reached, after which a further input pulse will reset the beam to zero.

Even digits are indicated as a mark on the upper strip of fluorescent material and odd digits on the lower strip (see Fig. 5.1); this enables a clearer indication to be obtained than would be possible if only one fluorescent strip were used to indicate all ten digits. The beam itself is not deflected vertically in order to enable it to strike the appropriate fluorescent strip, but is merely deflected horizontally across the tube. There are holes placed alternately in the upper and lower parts of the anode; when the beam passes through one of the upper holes an even digit is indicated, but at the next step it will pass through one of the lower holes to indicate an odd digit. Only a small portion of the beam passes through a hole, the remainder of the beam being intercepted by the anode.

5.1.1 The Electrodes of the E1T

In order to show that the tube has ten stable positions, the somewhat complicated electrode structure of the tube (shown in cross section in Fig. 5.2) must be studied. The conventional symbol for the tube, as used in circuits, is shown in Fig. 5.3 with the connections to the B12A base. Some of the less

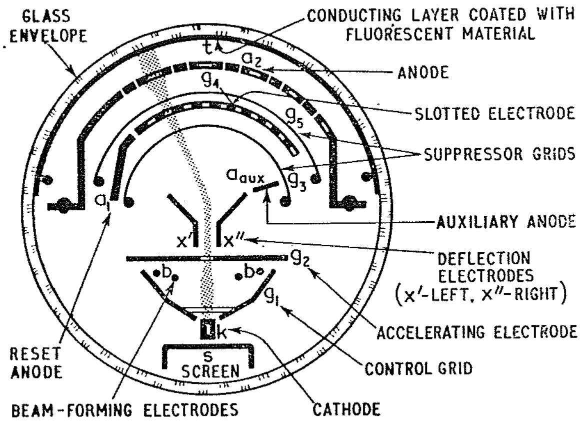
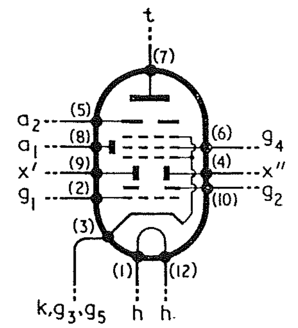


Fig. 5.2 The electrode structure of the E1T

important electrodes which have no external connection are not shown in this symbol. Sometimes g_3 and g_5 are also omitted from the symbol.

The electron beam is formed at the rectangular shaped cathode, k, the front of which is covered with an electron emissive oxide coating. The beam flows through the control grid, g_1, past the beam forming electrodes, b, and is then accelerated through the electrode g_2. These electrodes focus the beam and also give it the desired rectangular cross section which resembles a piece of thick ribbon placed in a vertical plane.

The beam is then deflected by the deflector plates, x' and x'', into one of the ten stable positions. The electrodes g_3 and g_5 are suppressor grids which are internally connected to the cathode to prevent any



BASE SOCKET:—DUODECAL TYPE 5912/20

Fig. 5.3 The symbol for the E1T; the numbers indicate the base connections

unwanted effects which might be caused by secondary electron emission from g_4 or from the anode, a_2.

The electrode g_4 has slots of the shape shown in Fig. 5.4. As will be shown later, it can be arranged that the electron beam will be stable only when a certain fraction of it is passing through one of the vertical rectangular slots in g_4. The purpose of the horizontal slot will be discussed later.

The beam then travels to the anode, a_2. A portion of it passes through the anode to the fluorescent target, t. This target is covered with a conductive coating which is connected to the positive H.T. supply line so as to prevent the accumulation of negative charge from the electron beam which might disturb the operation of the tube.

The electrode a_1 is the reset anode. When the tube is indicating the digit 'nine' and a further pulse is received, the beam is deflected by the plates x' and x'' so that it strikes the reset anode; the mecha-

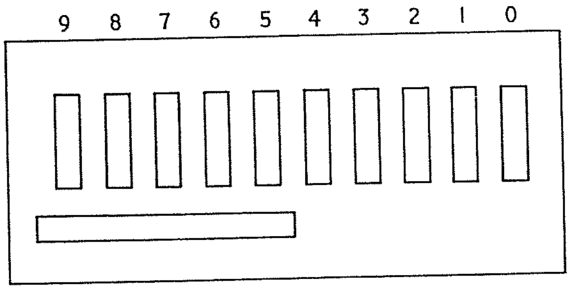


Fig. 5.4 The g_4 electrode showing the one horizontal and ten vertical slots

nism by which the tube is reset is then initiated by the fall of the reset anode potential.

The auxiliary anode, a_{aux}, is internally connected to the accelerating electrode, g_2, and is employed to capture undesired stray electrons. The screen s is internally connected to the cathode.

5.1.2 Ribbon Shaped Electron Beams[3, 4]

In tubes such as the E1T in which the beam is deflected only in one plane, a ribbon shaped electron beam of relatively large cross sectional area can be used (since the resolution in one plane is unimportant), but in normal cathode ray tubes a very small circular beam must be used to obtain good resolution in two dimensions. For a given charge density in the beam and a given applied voltage, a larger current will flow in a ribbon shaped beam than in a small circular beam owing to the larger cross sectional area of the former. A large current is desirable in the E1T so that the stray electrode capacitances can be quickly charged. The ribbon shaped beam enables the tube to operate from fairly small voltages. This favours high operating speeds because the change in the electrode potentials (and hence the change in the charge of the stray capacitances) is kept small.

The use of a ribbon shaped beam also has the additional advantages that the dimensions of the tube (and hence the inter-electrode capacitances) can be small and that the alignment of the tube need be carried out accurately only in one dimension.

In the E1T a beam current of about 1 mA is used at an applied potential of about 300 V.

5.2 ANODE CHARACTERISTICS

The anode characteristics of the E1T must be examined in order to ascertain why the ten holes in g_4 enable the electron beam to exist in ten stable states. If the horizontal slot in g_4 (shown in Fig. 5.4) were not present, the main anode current, i_{a_2}, plotted against the deflector voltage of plate x'' ($V_{x''}$) would be as shown in Fig. 5.5(a) provided that the potential of the other deflector plate, $V_{x'}$, were kept constant. When the potential of x'' is altered, the beam is deflected and passes through a series of

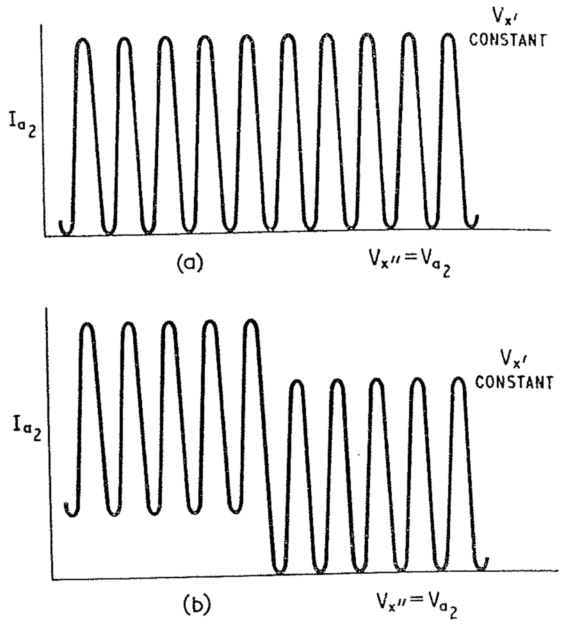


Fig. 5.5 Theoretical characteristics of the E1T, (a) when g_4 has no horizontal slot and (b) when the horizontal slot is present in g_4

maxima and minima as it passes across the holes in g_4. The anode current will be a maximum when the beam is centred on one of the holes in g_4 and will be zero when it is entirely intercepted by g_4.

In normal operation the main anode, a_2, is connected directly to the deflector plate x''. The potentials of x'' and of a_2 are therefore identical and Fig.

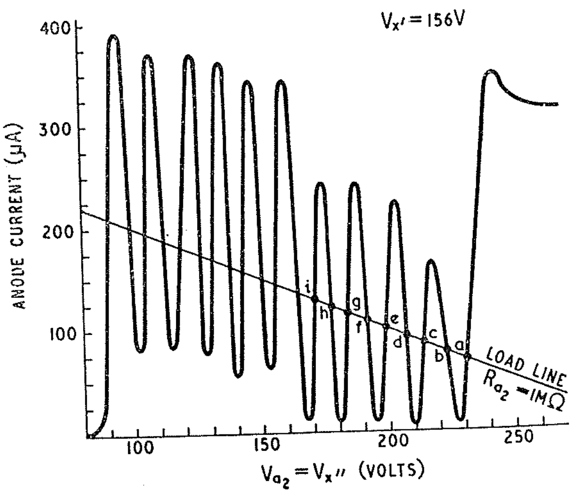


Fig. 5.6 The E1T anode characteristic for $V_{x'}$ = 156 volts

5.5(a) is the dynamic anode current/anode voltage characteristic for this method of connection when the potential of x' is constant.

The presence of the horizontal slot in Fig. 5.4 changes the anode characteristic from that shown in Fig. 5.5(a) to that shown in Fig. 5.5(b). When the beam is in a position to the left of the fifth vertical slot in Fig. 5.4, a constant current passes through the horizontal slot and this current is superimposed on any current which may pass through one of the vertical slots. Hence the shape of the Fig. 5.5(b) characteristic.

In practice the characteristic is further modified by the fact that the slots in g_4 are not of constant width. The actual E1T anode characteristic is shown in Fig. 5.6 for the case when the x' deflector electrode has a potential of 156 V (1, 5, 6). It may be noted that when both of the deflector electrodes have the same potential ($V_{x'} = V_{x''} = V_{a_2} = 156$ V), the beam is not deflected and the tube indicates a number in about the middle of the decade.

5.3 BEAM STABILITY

The basic type of circuit used to supply voltages to the tube is shown in Fig. 5.7. The anode resistor, R_{a_2}, normally has a value of 1 MΩ. The straight line in Fig. 5.6 is the load line for this value of resistor.

If the beam is initially at the position a of Fig. 5.6 (indicating the digit zero) and the potential of the deflector electrode x' is increased relatively slowly (so slowly that the effect of the stray capacitance, C, shown in Fig. 5.7 is negligible), the beam will tend to be deflected towards the electrode x'. As the beam moves, however, it can be seen from the anode characteristic of Fig. 5.6 that it begins to pass out of the slot in g_4 and less of it strikes the anode. The resulting reduction in anode current leads to a reduction in the voltage dropped across the resistor R_{a_2} and hence to an increase in the common potential of the anode and of the deflector electrode x''. The slope of the E1T characteristic is very steep at the points where it is crossed by the load line shown and therefore this increase in the potential of x'' is almost equal to the initial increase in the potential of x' which caused it. As both deflector electrodes

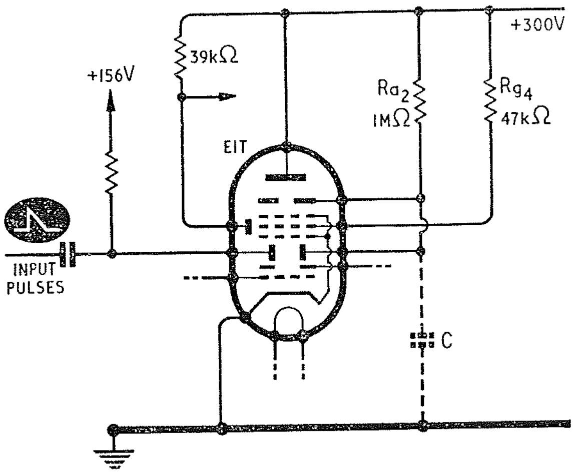


Fig. 5.7 The basic circuit for the E1T

are increased in potential by almost equal amounts, the amount by which the beam is deflected is virtually unchanged.

Similarly if the beam is at a and x' becomes slowly more negative, the anode current is increased (see Fig. 5.6) and this in turn causes a reduction in the potential of x''. Thus the position a in Fig. 5.6 is a very stable one. The intersections of the load line with the rising parts of the E1T characteristic are the ten stable beam positions which are required for storing the information about the state of the count.

The anode a_2 and the x'' deflector plate are connected in a feedback system. The slope of the E1T characteristic is very much greater than the slope of the 1 MΩ load line at the operating point and this results in the feedback factor—and hence the stability of the operating point — being very high. The positions a, c, e, g, i, etc. in Fig. 5.6 are all very stable.

If the beam is at any moment at b or d, any slight increase in the potential of x' will cause the beam to be deflected towards this electrode and it can be seen from Fig. 5.6 that the anode current will then increase as more of the beam passes through the slot in g_4. The potential of the anode and of x'' therefore decreases causing the beam to swing farther away from the x'' electrode. Eventually the beam will come to rest at one of the stable points c or e. Similarly if the beam is momentarily at b or d and the potential of x' is decreased slightly, the beam will move so that the voltage of x'' becomes higher until a stable operating point is reached. The positions b, d, f, etc. are therefore unstable and the beam does not stay in a position represented by one of these points for more than a minute fraction of a second. At these unstable points the anode current decreases with increasing anode voltage, thus giving

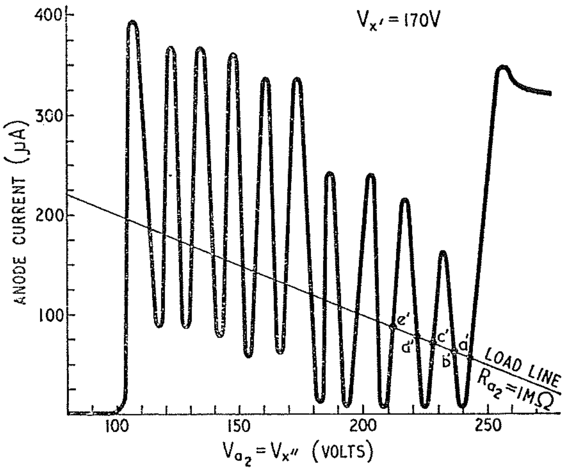


Fig. 5.8 The E1T anode characteristic for $V_{x'}$ = 170 volts

a negative resistance effect over this portion of the curve.

The criterion of stability for any operating point in Fig. 5.6 is that the anode current of the E1T must increase as the anode voltage increases. That is, the point at which the load line cuts the characteristic of the tube is stable if the characteristic at that point slopes upwards from left to right.

If for any reason (such as a change in the supply voltage) the potential of x' alters fairly slowly, the anode current/anode voltage characteristic will maintain the same general form as shown in Fig. 5.6, but will be moved horizontally along the x axis (anode voltage axis) of the graph. This is because the stabilising effect discussed above alters the voltage of the anode and x'' electrodes to maintain the beam deflection almost constant.

Fig. 5.8 shows the anode characteristic for an E1T with a potential of 170 V applied to the x′ deflector electrode (1, 5, 6). It can be seen that the same system of stable and unstable operating points will be present and the general operation of the tube is unaffected by this voltage change.

5.4 THE COUNTING PROCESS

A very different process occurs when a positive going pulse with a very short rise time is fed to the x′ electrode. The beam will be deflected to the left and the potential of the anode and x'' electrode will again tend to rise by the process discussed previously. The capacitance C (shown dotted in Fig. 5.7) prevents any very rapid change in the potential of the anode and of the electrode x'', as time is taken for C to charge through R_{a_2}. The capacitance C is merely the inter-electrode and stray wiring capacitance of the tube circuit. The beam is therefore deflected to the left before the voltage of x'' has time to rise appreciably. If the pulse is rapid enough and of a suitable amplitude, the beam will therefore move to the next stable position to the left of the initial position in Fig. 5.6 and a count will have been registered.

The stabilising mechanism of the tube circuit cannot work more quickly than is permitted by the anode resistance R_{a_2} and the unavoidable stray parallel capacitance, C.

The pulse rise time and amplitude are quite critical. If the pulse is of too small an amplitude, the beam will not be deflected as far as the next stable position and no count will be registered, whilst if the amplitude is too large, the beam may pass through one stable position and register two counts for only one input to x'. The amplitude of the input pulse should be approximately equal to the difference of the tube anode voltage between two adjacent working points, e.g. a and c in Fig. 5.6. The geometry of the tube and the shape of the electrodes are carefully chosen so that the voltage difference between each of the stable working points (a to c, c to e, etc. in Fig. 5.6) is constant (about 13.6 V). The input voltage required to cause the tube to register one additional count is therefore independent of the digit being indicated.

It is most important that the input pulse amplitude to the x' plate of the tube should be 13.6 V ± 15% (that is, 11.5 to 15.5 V).

An additional requirement is that the trailing edge of the pulse must not be too sharp or it will deflect the electron beam back to its initial state and no count will be registered. If the slope of the trailing edge is not very great, the stabilising effect discussed previously will prevent the tube returning to its initial state when the trailing edge is applied to x′. If the time of fall of the pulse is too long, however, the maximum counting speed is reduced. It might be thought that if the stray capacitance, C, could be made very small, the maximum counting rate could be increased. In actual practice, however, the reset time is usually longer than the counting process itself and sets a limit to the maximum counting speed.

A suitable pulse for feeding into the x' electrode of the E1T is shown in Fig. 5.9. The slope of the leading edge of the pulse should not be less than 2×10^7 V/sec and that of the trailing edge should not be greater than 1.2×10^6 V/sec. If the average amplitude of the pulse is to be 13.6 V, the rise time should not therefore be greater than 0.7 μsec and the time of fall should not be less than 11 μsec.

The mechanism of the counting process can be considered to operate in the following way. If the operating point is at a in Fig. 5.6 corresponding to

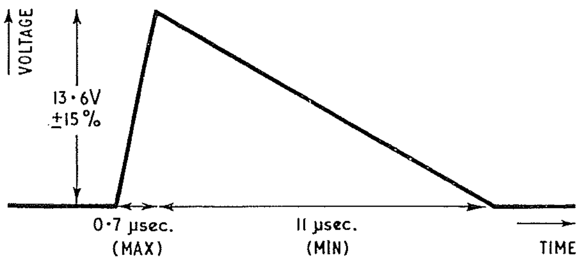


Fig. 5.9 An input pulse suitable for the operation of the E1T

an indication of zero, the anode and x'' potential is about 230 V whilst the x' deflector electrode potential is about 156 V. If a fast rising positive going pulse of 14 V is applied to the x' electrode (raising its potential to 170 V), the voltage of the x'' electrode remains constant for a very small fraction of a second owing to the stabilising effect of the capacitance C. The operating point is therefore momentarily moved to the point c' on the characteristic of Fig. 5.8. The pulse then decays slowly so that the potentials of x' and x'' decrease at about the same rate. Thus the operating point on the characteristic of Fig. 5.8 at c' is transformed relatively slowly into the characteristic of Fig. 5.6, but the operating point now has time to move along with the curve and finishes at c in Fig. 5.6.

It can be seen from Fig. 5.6 that the horizontal slot in g_4 (see Fig. 5.4) lifts up the low voltage part of the anode current/anode voltage characteristic so that the height of each peak above the load line is fairly constant. The rate at which the stray capacitance, C, can be discharged by the E1T anode current during counting operations is dependent on the height of each peak of the characteristic above the load line. A reasonable height for each peak is essential in high speed counting circuits. This subject is more fully discussed in the section of this chapter which deals with the design of an input circuit for 100 kc/s operation.

The stabilising effect of C on the anode potential should not be confused with the stabilising effect that R_{a_2} has on the position of the beam. Advantage is taken of the latter effect (which is suppressed during the steep front of the input pulse by the presence of C) for maintaining the beam at the correct position after it has been displaced.

5.5 FLYBACK CIRCUITS

When the tenth input pulse is received, the E1T tube must be reset from 'nine' to 'zero'. Normally this resetting process is initiated by a pulse from the reset anode, a_1, which is connected to the H.T. positive line via a 39 kΩ resistor (as in Fig. 5.7). If the tube is initially indicating the digit 'nine' and an additional input pulse is received, the beam will be deflected to strike the reset anode. The current passing to this anode will cause a voltage drop across the 39 kΩ resistor and a negative pulse can therefore be obtained from the reset anode. The pulse may be used to trigger a monostable multivibrator which is designed to provide suitable pulses to reset the tube and also to trigger the next decade.

Another method of obtaining a pulse to reset the E1T circuit does not depend on the use of a reset anode. When the beam is deflected from position 'nine' onto the reset anode, it leaves the g_4 electrode. This electrode is fed from the H.T. line via the resistor R_{g_4} and its potential therefore rises as the current through the resistor falls. This rise in potential can be used to render a triode conducting and the triode in turn provides a pulse to cut off the E1T. An example of this type of circuit will be given in Fig. 5.16.

The E1T itself may be reset by two basic methods. In the first method a negative pulse is applied to the control grid, g_1, or a positive pulse to the cathode, k. This pulse should have an amplitude of at least 24 V so that it is large enough to completely cut off the electron beam. The main anode current falls and therefore the main anode and x'' electrode potential rises. The change of the x'' electrode potential causes the beam to be deflected towards it so that 'zero' is indicated. This method of resetting the tube takes a comparitively long time and cannot therefore be used in high speed circuits. The circuitry required is, however, simpler than that used in the higher speed resetting circuits. Examples of practical circuits involving beam cut off will be given in the circuits of Figs. 5.10, 5.13 and 5.16.

In the second method of resetting the tube, a positive pulse is applied to the x′ electrode and deflects the beam to the zero position. This method is suitable for high speed circuits operating at up to one million pulses per second[2]. An example of this type of circuit will be given in Fig. 5.15.

5.5.1 Reset Involving Beam Cut Off

When an E1T tube is cut off, its anode voltage will rise exponentially as the stray capacitance C (shown dotted in Fig. 5.7) charges through the resistor R_{a_2} The time taken for this capacitance to charge limits the maximum frequency of operation of the tube. The minimum reset time may be estimated by the method discussed below.

It is important to ensure that the duration of the cut off pulse fed to the tube is great enough (with an adequate safety margin) to allow the stray capacitance, C, to charge to a potential which is enough to cause the beam to return at least as far as the zero position. Otherwise the beam may come to rest at any intermediate position. If the cut off time is too long, however, the reset time will be increased and the maximum counting rate will be reduced. If the beam is deflected too far, it will be in an unstable state and will quickly return to the zero position at the end of the cut off pulse.

It can be estimated from Fig. 5.6 (allowing adequate safety margins for normal tolerances, etc.) that the maximum voltage swing of the anode a_2 ever likely to occur in practice is from $V_{a_2}(9) = 95$ V in position 'nine' to $V_{a_2}(0) = 240$ V at the 'zero' position[1]. The maximum stray capacitance, C, in parallel with R_{a_2} can be taken as 16.5 pF. If a close tolerance 1% high stability resistor is used for R_{a_2}, the maximum possible value of this resistor will be 1.01 MΩ. In addition a 10 kΩ resistor is normally placed in series with R_{a_2} for test purposes (as shown in Figs. 5.13 and 5.15). The maximum value of R_{a_2} is therefore 1.02 MΩ.

The capacitance C charges from the H.T. supply voltage V_b from the initial anode voltge of $V_{a_2}(9)$ volts to $V_{a_2}(0)$ volts during the cut off pulse.

It is shown in many elementary text books on electricity that if a capacitor C is charged from a source of voltage V_b via a resistor R, the voltage V across the capacitor after a time t is given by the reation:

$$V = V_b(1 - e^{-t/RC})$$

where e is the base of natural logarithms.

The above equation may be altered to:

$$\frac{V_b - V}{V_b} = e^{-t/RC}$$

This equation applies only if $V=0$ when $t=0$. In the case of the stray capacitance C charging through the resistor R_{a_2}, however, $V = V_{a_2}(9)$ initially.

If C had charged to a potential of $V_{a_2}(9)$ from an initial potential of zero through R_{a_2}, the time taken, t_1, would be given by:

$$\frac{V_b - V_{a_2}(9)}{V_b} = e^{-t_1/R_{a2}C} \tag{1}$$

If t_2 is the total time taken for the potential across the capacitance C to reach the value $V_{a_2}(0)$ from an initial value of zero,

$$\frac{V_b - V_{a_2}(0)}{V_b} = e^{-t_2/R_{a2}C} \tag{2}$$

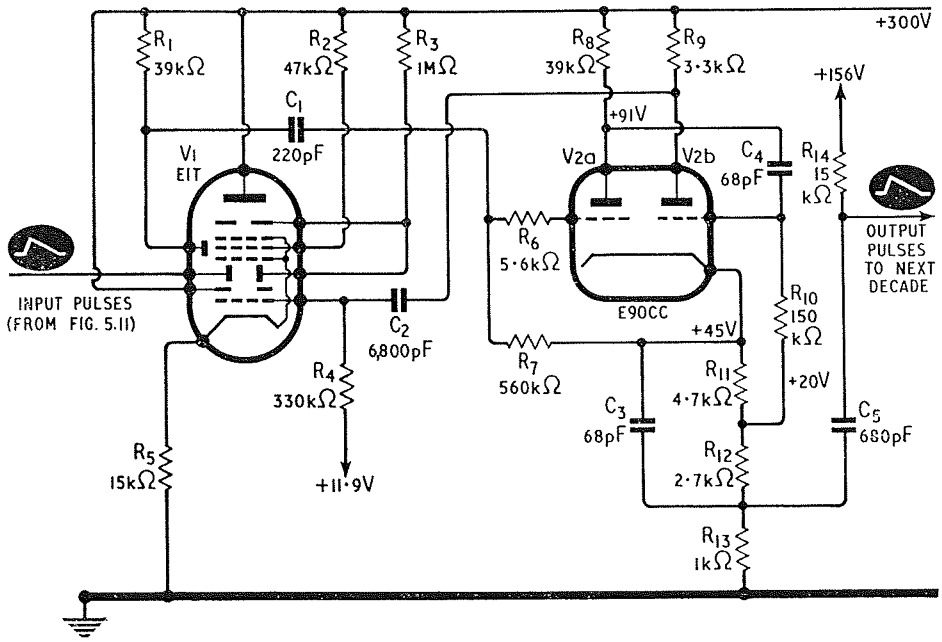


Fig. 5.10 An E1T counting and reset circuit for operation at frequencies of up to 30 kc/s

Dividing (2) by (1):

$$\frac{V_b - V_{a_2}(0)}{V_b - V_{a_2}(9)} = e^{-(t_2-t_1)/R_{a2}C}$$

In this equation $(t_2 - t_1)$ is equal to the time taken for the beam to move from position 'nine' to the 'zero' position.

Let $\quad (t_2 - t_1) = T$

$$\frac{V_b - V_{a_2}(0)}{V_b - V_{a_2}(9)} = e^{-T/R_{a2}C}$$

Putting the values quoted above into this equation:-

$$\frac{300-240}{300-95} = e^{\left(\frac{-T}{1.02\times10^{6}\times16.5\times10^{-12}}\right)}$$

When this equation is solved for T, it is found to be about 20.68 μsec. This is the minimum possible resetting time. In actual practice the resetting pulse should be somewhat longer than this in order to allow an adequate margin of safety. If an allowance of 33 μsec is made for the resetting time, the maximum counting rate which can be attained is about 30,000 per second[1].

It is found in actual practice that E1T circuits can operate reliably at up to 30,000 pulses per second when the resetting operation is carried out by cutting off the electron beam in the tube in the type of circuit shown in Fig. 5.10. In practical circuits the stray capacitance C should be kept as low as possible. The anode resistor R_{a_2} should be soldered directly to the a_2 or x'' contact of the E1T tube base.

5.6 30 KC/S COUPLING CIRCUIT

A circuit [1, 5, 6] which will reset E1T tubes and provide a suitable pulse for triggering the next tube is shown in Fig. 5.10. The E90CC ($V2$) acts as a monostable multivibrator. The grid of $V2$a is returned to the cathode of this valve via R_7 and no bias is provided. $V2$a is therefore normally fully conducting when the circuit is in the stable state. The anode current of $V2$a flowing through the 4.7 kΩ cathode resistor (R_{11}) produces a voltage drop of about 25 V across this resistor. The grid of $V2$b is returned to the lower end of this resistor and the 25 V across it therefore biases $V2$b to cut off.

If the electron beam is deflected onto the reset anode, a current flows through the reset anode resistor (R_1) of the E1T and the negative voltage pulse produced is applied to the grid of $V2$a via the capacitor C_1. The anode current of $V2$a is thereby reduced so that a positive pulse is produced at its anode. This pulse is fed to the grid of $V2$b via C_4 and causes this triode to conduct. A positive pulse is generated at the cathode of $V2$b and the common cathode voltage increases, thus cutting off $V2$a. The grid voltage of $V2$b is therefore raised further.

The negative pulse from the anode of $V2$b is fed to the grid g_1 of the E1T via the capacitor C_2. The E1T is thus cut off and therefore the main anode and x'' electrode of this tube rises in potential so that the beam is deflected to the zero position. The rise in total cathode current of $V2$ when $V2$b conducts is used to trigger the succeeding decade via C_5.

As C_4 discharges at the end of the pulse, the grid potential of $V2$b decreases exponentially. The common cathode voltage also decreases exponentially until the bias is reduced so much that $V2$a conducts. The resulting negative pulse at the anode of $V2$a passes to the grid of $V2$b via C_4 and quickly restores the circuit to its original stable state in which $V2$a is conducting and $V2$b is cut off.

If C_3 were omitted, a pulse with a steep leading edge could not be obtained from the cathode resistor of $V2$ for the purpose of triggering the next decade unless the value of R_8 were reduced. A lower value of R_8 would, however, result in a much greater continuous current being taken from the H.T. supply. If C_3 is used to shunt most of the cathode resistor, as shown, only the 1,000 Ω resistor is operative for abrupt changes of voltage and sharply rising output pulses can be obtained. The high value of the cathode resistor together with the fairly large value of R_8 render the circuit very stable. The pulse amplitude and duration are not affected very much by changes in the valve characteristics. The tapping on the cathode resistor at the junction of R_{12} and R_{13} has been chosen so that the output pulse to the next decade is of a suitable amplitude.

The negative going pulse which is used to cut off the E1T commences by a rapid fall of potential of about 60 V. The potential then rises to about −27 V in a period of about 27 μsec. The tube is completely cut off by a bias of −27 V and the duration is very suitable for ensuring that the beam is reset to zero without the reset time being much longer than is necessary.

The component tolerances for the coupling circuit of Fig. 5.10 are shown beneath Fig. 5.13.

5.7 INPUT CIRCUIT FOR FREQUENCIES UP TO 30 KC/S

An input circuit must be employed in front of the first E1T tube. This circuit converts the incoming pulses into pulses of an amplitude and duration which can be counted by the E1T. The input circuit described in this section (shown in Fig. 5.11.) is suitable for handling up to 30,000 pulses per second.

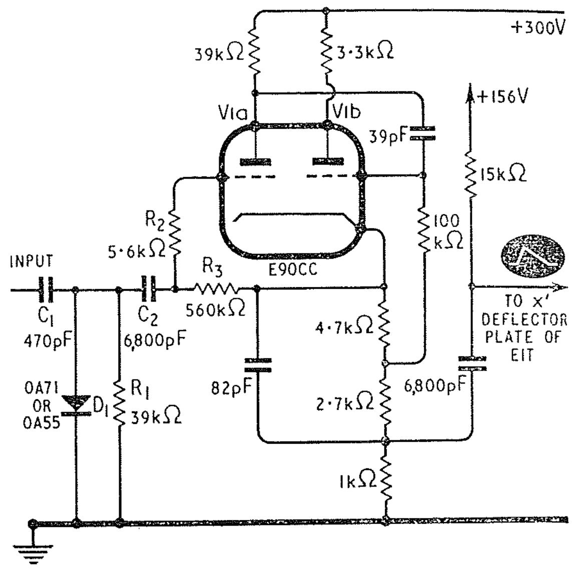


Fig. 5.11 An input pulse shaper circuit for use at frequencies of up to 30 kc/s

A faster but more complicated input circuit will be discussed later.

The input circuit [1, 5, 6] of Fig. 5.11 consists of a differentiating circuit (470 pF plus 39 kΩ) followed by a monostable multivibrator which is very similar to that used in the resetting circuit of Fig. 5.10.

If the differentiating circuit were omitted, at a low rate of counting the length of the input pulses might exceed that of the natural period of the multivibrator. The multivibrator would then return to its initial state whilst the input pulse was still present and a spurious count would be registered. This difficulty is only encountered in the input circuit and not in the circuits of succeeding stages because the

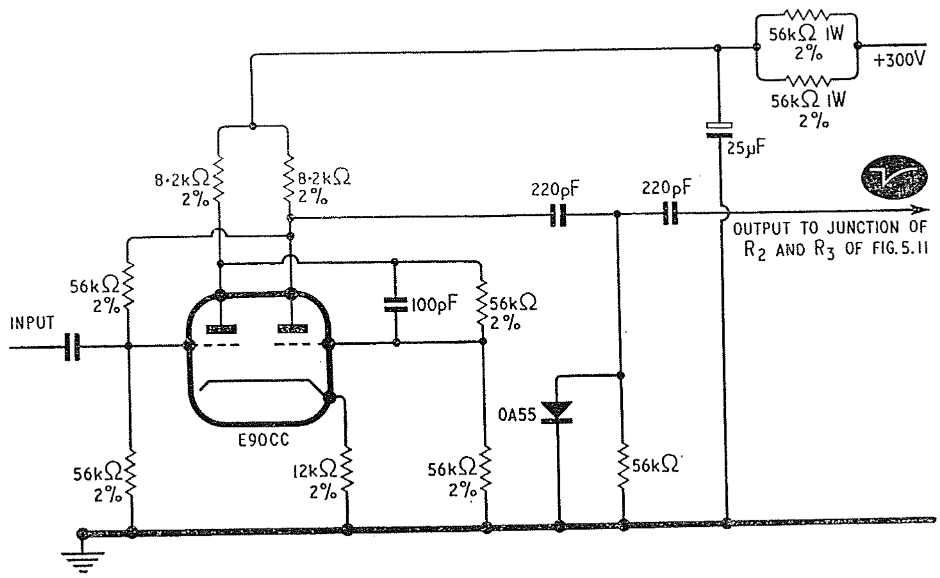


Fig. 5.12 An auxiliary pulse shaping circuit for feeding the circuit of Fig. 5.11 or 5.13

inputs to all stages after the first are derived from the multivibrator of the previous stage which gives a pulse length which is quite short.

The 0A71 germanium diode in parallel with the 39 kΩ input resistor prevents any positive pulses from reaching the grid of *V*1a. Such pulses arise from the trailing edge of a negative going input pulse or the leading edge of any stray positive going pulse; if they reached the grid of *V*1a they could cause faulty counting.

The coupling capacitor and the grid resistor of *V*2b have somewhat lower values than those recommended for the coupling circuit of Fig. 5.10 in order that the maximum counting rate can be attained. The output pulses will be somewhat shorter owing to the lower time constant, but this is no disadvantage, however, since the pulses from the multivibrator of Fig. 5.11 do not have to operate a resetting circuit.

The triode *V*1a is normally conducting and *V*1b is normally cut off. The input pulses to *V*1a should have an amplitude of between 20 and 50 V and should be negative going with a leading edge duration not exceeding 13.5 μsec or positive going with a trailing edge duration not exceeding this same value. The total pulse duration should equal one cycle of the pulse repetition frequency less at least 10 μsec. At 30,000 pulses per second this input pulse duration should not therefore exceed $33.3-10 = 23.3$ μsec.

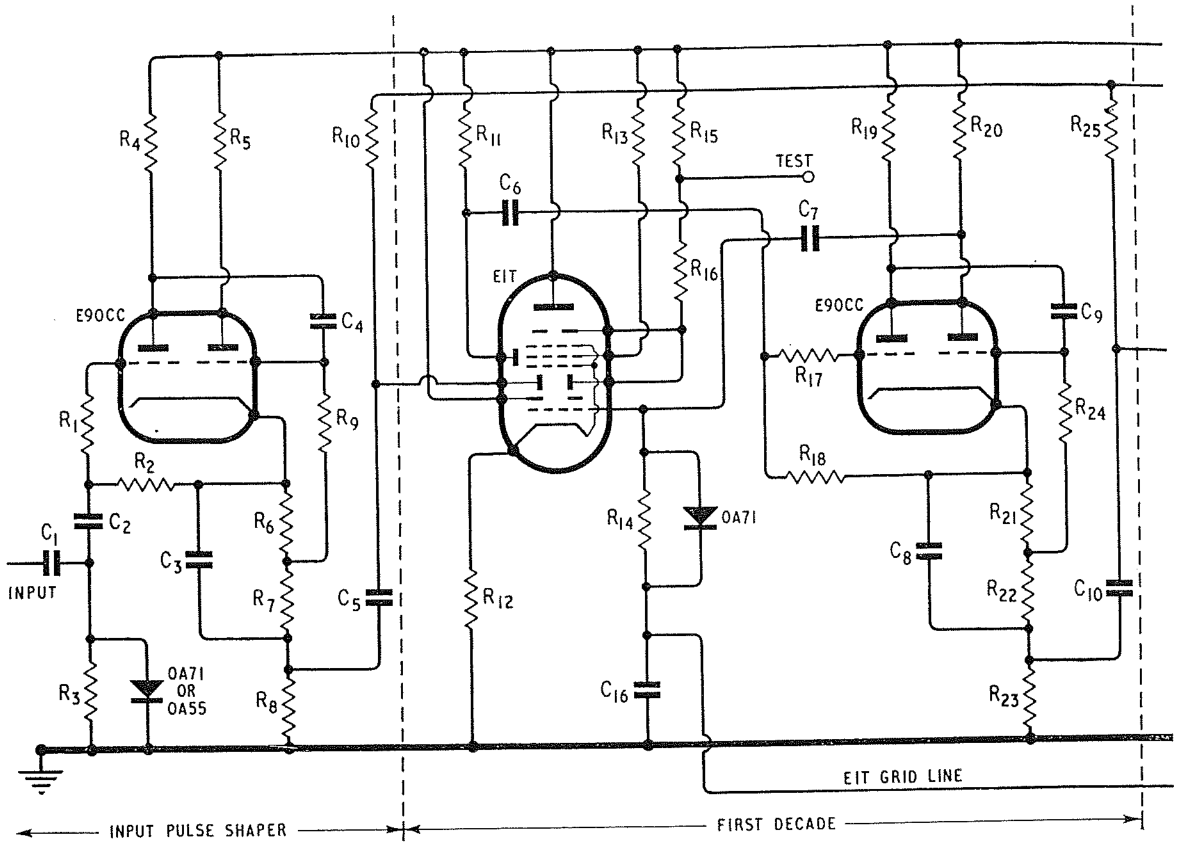
The component tolerances for the circuit of Fig. 5.11 are shown below that of Fig. 5.13.

If sinusoidal signals are to be counted, they may be passed through a double limiter which will clip both positive and negative going peaks. A square wave input signal is thus obtained which can be used to operate the circuit of Fig. 5.11.

5.7.1 Auxiliary Pulse Shaper

The circuit of Fig. 5.12 may be used to convert pulses of arbitrary waveform (including sine waves) into pulses which will operate the circuit of Fig. 5.11 [6,7]. When this additional pulse shaping circuit is used, the components marked C_1, C_2, D_1 and R_1 in Fig. 5.11 may be omitted.

The use of the circuit of Fig. 5.12 enables sine waves of a frequency as low as 10 c/s to be counted if the input voltage is at least 15 V. At still lower frequencies sinusoidal signals may be counted if the input amplitude is increased and if a clipper diode is incorporated in the input circuit to render the waveform suitable for triggering the auxiliary pulse shaping circuit by increasing the slope of the pulse edges. The value of the input capacitor used may also be increased at low frequencies.



Resistors

Resistor	Value	Tolerance	Rating
R_1	5.6 kΩ	10%	1/2 W
R_2	560 kΩ	10%	1/2 W
R_3	39 kΩ	5%	1/2 W
R_4	39 kΩ	2%	2 W
R_5	3.3 kΩ	2%	1/2 W
R_6	4.7 kΩ	2%	1 W
R_7	2.7 kΩ	2%	1/4 W
R_8	1 kΩ	1%	1/8 W
R_9	100 kΩ	1%	1/4 W
R_{10}	15 kΩ	2%	1/8 W
$R_{11}=R_{26}$	39 kΩ	10%	1/2 W
$R_{12}=R_{27}$	15 kΩ	1%	1/8 W
$R_{13}=R_{28}$	47 kΩ	5%	1/2 W
$R_{14}=R_{29}$	330 kΩ	10%	1/2 W
$R_{15}=R_{30}$	10 kΩ	10%	1/2 W
$R_{16}=R_{31}$	1 MΩ	1%	1/2 W
$R_{17}=R_{32}$	5.6 kΩ	10%	1/2 W
$R_{18}=R_{33}$	560 kΩ	10%	1/2 W
$R_{19}=R_{34}$	39 kΩ	2%	2 W
$R_{20}=R_{35}$	3.3 kΩ	2%	1/8 W
$R_{21}=R_{36}$	4.7 kΩ	2%	1/4 W

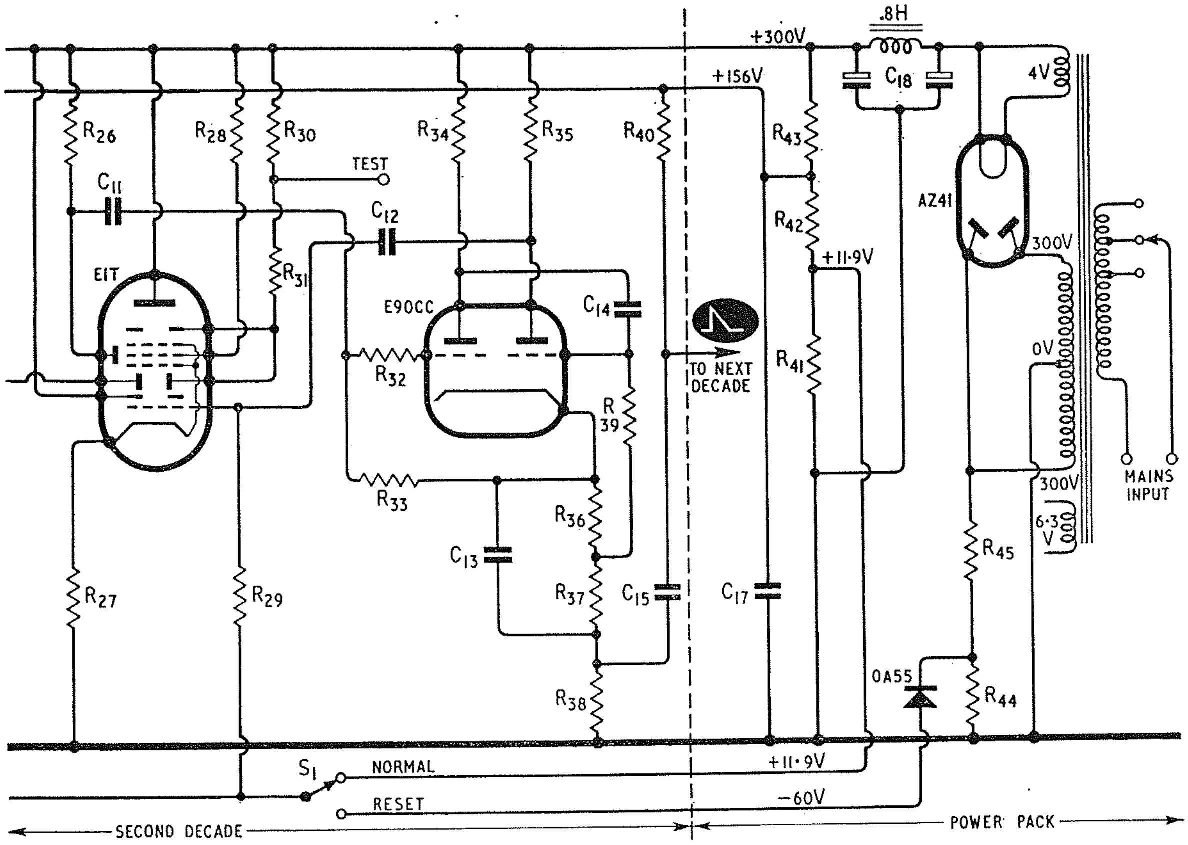
Fig. 5.13 A complete two decade counting

5.8 A COMPLETE 30 KC/S CIRCUIT

Fig. 5.13 shows the circuit of a two decade E1T counter[1 5, 6] which can count pulses at frequencies up to 30 kc/s. It is based entirely on the circuits which have just been discussed with the addition of a suitable power supply.

The first part of the circuit to the left of the first dotted line is a pulse shaping circuit which feeds the first E1T tube. If necessary the circuit may be preceded by the auxiliary pulse shaper of Fig. 5.12, in which case C_1, C_2, R_3 and the diode in parallel with R_3 in Fig. 5.13 may be omitted. The circuits between any two of the dotted vertical lines in Fig. 5.13 form one complete decade including the coupling and resetting circuits. Any number of similar decades could, of course, be added after the circuit of Fig. 5.13, but the values of the potential divider resistors and the power supply should be modified, however, if more than seven decades are to be used.

The switch S_1 normally connects the E1T grid line to the +11.9 V tapping on the potential divider. If S_1 is used to momentarily connect the E1T grid line to a supply of −60 V, the E1T tubes are cut off and the electron beam in each tube is



$R = R_{37}$	2.7 kΩ	2%	1/8 W
$R_{23} = R_{38}$	1 kΩ	1%	1/8 W
$R_{24} = R_{39}$	150 kΩ	2%	1/8 W
$R_{25} = R_{40}$	15 kΩ	2%	1/8 W
Capacitors			
C_1	470 pF	10%	
C_2	6800 pF	10%	

C_3	82 pF	2%
C_4	39 pF	5%
C_5	6,800 pF	10%
$C_6 = C_{11}$	220 pF	10%
$C_7 = C_{12}$	6,800 pF	10%
$C_8 = C_{13}$	68 pF	2%
$C_9 = C_{14}$	68 pF	2%
$C_{10} = C_{15}$	680 pF	5%

C_{16}	0.39 μF	20%	
C_{17}	0.15 μF	20%	
C_{18}	2×50 μF	400 V	
R_{41}	5.6 kΩ	1%	1/8 W
R_{42}	68 kΩ	1%	1 W
R_{43}	68 kΩ	1%	1 W
R_{44}	15 kΩ	10%	1 W
R_{45}	330 kΩ	10%	1 W

circuit for frequencies up to 30 kc/s

returned to the zero position by the same process as that discussed previously.

The power supplies need not be stabilised provided that the +156 and the +11.9 voltage lines are obtained from the +300 V supply by means of a potential divider such as that shown. Any fluctuations which occur in the mains voltage will then alter all of the supply voltages by the same percentage. This will have no noticeable effect on the operation of the tubes for normal variations of the mains voltage (±10%). Such circuits have been found to operate reliably at mains voltages between 140 and 270 V, but prolonged operation at such extremes might impair the life of the tubes[5, 6]. It is, however, most important to ensure that the resistors in the potential divider chain have tolerances not exceeding ±1%; wire wound resistors are especially suitable.

An 0A71 diode (or an 0A55 or 1N86) is placed in parallel with the resistor R_{14}. No diode need be placed across the corresponding resistor, R_{29}, in the second decade or across the corresponding resistor in any succeeding decade which may be added to the circuit. During the intervals between the negative going resetting pulses which are fed to the control grids of the E1T tubes, the potentials of these grids depend on the counting speed. This effect is only appreciable in the first stage where the counting speed may be high. A diode is therefore placed in parallel with R_{14} of the first decade so that the potential of the E1T control grid is kept constant (except during flyback) whatever the counting speed may be. Except for the presence of this diode in the first stage, all of the decades are identical.

In any decade except the first, 10% components may be used in the multivibrator circuits only provided that the values of coupling capacitors such as C_{14} and grid leaks such as R_{39} are increased to 82 pF and 180 kΩ respectively and provided that the output pulse amplitude to the next decade is adjusted to 13.6±2% by adjustment of the value of R_{38}. This adjustment may have to be repeated from time to time, since 10% resistors alter somewhat in value during life. It is therefore normally much more convenient to use the close tolerance resistors specified for the circuit. It is, in any case, essential to use close tolerance resistors in the cathode and anode circuits of the counter tubes.

In order to facilitate testing of the circuits, the anode load of each E1T tube may be split into two parts as shown in Fig. 5.13. An oscilloscope may be connected to the test point. If the stage is operating correctly, the oscillogram should show ten distinct steps. The effect of variations in the mains voltage on the tube may thus be investigated.

5.9 CIRCUIT FOR USE AT UP TO 100 KC/S

If the E1T tube is to be used to count at up to 100,000 pulses per second, it is essential that each counting operation should be completed within 10 μsec. This limitation is imposed on both the resetting operation and on the normal forward movement of the electron beam as it moves from the zero to the ninth positions. Carefully designed input and resetting circuits are therefore essential for high speed operation of E1T tubes.

5.9.1 Input Circuit Design

The leading edge of the pulse fed to the E1T should be very steep so as to occupy the minimum amount of time. The trailing edge cannot be very steep or it will immediately reset the E1T to its previous state. It must, however, be as steep as is consistent with reliable counting. In addition the trailing edge should decrease more or less linearly with time in order that the shortest trailing edge which will not reset the tube to its former state can be used.

The application of the leading edge of the pulse to the E1T deflector plate results in the electron beam being suddenly moved to the next stable position. The anode and x'' deflector plate voltage will not decrease immediately to their value at the new stable state because of the effect of the stray capacitance C (see Fig. 5.7). If the beam is to remain in its new position, it is important to ensure that the trailing edge of the input pulse does not decrease at a rate which is greater than that at which the anode voltage can decrease. The rate of change of the anode voltage is determined by the current which can be taken by the E1T tube to discharge the stray capacitance, C. This current, I_c, is the difference between the maximum tube current at the particular peak of the characteristic concerned and the current flowing through the load resistor at the existing instantaneous voltage. I_c is thus the height of the peak of the characteristic above the load line.

The charge of the stray capacitance, C, is equal to CV coulombs where V is the potential difference across the capacitor. If it is assumed that I_c and the slope of the trailing edges of the pulses are constant, the time, t, taken by the anode and x'' potential to decrease by an amount V volts as C discharges is given by the equation[1, 6, 8]:

$$t = \frac{CV}{I_c} \text{ sec}$$

The minimum possible duration of the trailing edge is equal to this time, t.

It should be noted that t is inversely proportional to I_c. The presence of the horizontal slot in g_4 (see Fig. 5.4) raises the value of I_c when the digit being indicated is five or more. This extra slot thus enables the duration of the trailing edge of the counting pulse to be kept as short as possible and the maximum counting speed to be attained.

In the 100 kc/s circuit to be described (Figs. 5.14 and 5.15), the total stray capacitance, C, by-passing the anode is about 23 pF. The smallest positive peak of the characteristic (see Fig. 5.6) is that situated between the stable points where the digits zero and one are indicated. For the average tube this peak is about 70 μA above the load line. If one substitutes these values of C and I_c in the above equation together with the value of about 14 V between the successive stable positions, one finds that the minimum duration of the trailing edge of the pulse, t, is 4.6 μsec[1, 6, 8]. In some E1T tubes this first peak is smaller, but the steps can be completed in 10 μsec provided that no peak has a value of I_c less than 35 μA.

5.10 A PRACTICAL 100 KC/S INPUT CIRCUIT

The circuit shown in Fig. 5.14 can be used to convert input pulses of arbitrary waveform into pulses of the correct amplitude and duration for feeding into an E1T tube[1, 6, 8]. The trailing edges of the output pulses from this circuit are linear. The total duration of each output pulse is slightly less than 10 μsec so that operation at 100 kc/s is possible. The pulse shape and amplitude are substantially independent of changes in the tube characteristics.

The E90CC (or E92CC) double triode acts as a pulse squarer. It is used in a monostable multivibrator circuit in which the triode $V1$a is normally conducting and $V1$b is normally cut off owing to the differences in their quiescent grid voltages. When a negative going input pulse is applied to the circuit, $V1$a is cut off and $V1$b conducts. The anode voltage of $V1$b drops from about 173 to 130 V until the circuit returns to its quiescent state at some point in the positive going trailing edge of the input signal. The current taken by $V1$b in the fraction of a second during which it conducts is made equal to the normal quiescent current of $V1$a. The supply voltage at the lower end of R_4 is, therefore, independent of the counting frequency.

The pulse squarer thus provides a negative going pulse of 43 V amplitude for the shaping circuit.

5.10.1 The Pulse Shaper

The capacitor C_4 and the resistor R_{12} of Fig. 5.14 differentiate the square wave so as to provide one negative going and one positive going peak. The negative going peak is removed by the diode $V2$a and the positive going peak is applied to the anode of $V2$b. The capacitor C_6 together with any associated stray capacitance is charged from the cathode of $V2$b. The output voltage rises quickly to about 170 V, thus giving the desired 14 V amplitude over the quiescent value of 156 V.

C_4 and R_{12} are chosen so that the anode potential of $V2$b, after reaching its peak, will decrease faster than the cathode voltage of the diode which therefore becomes non-conducting. C_6 and the associated stray capacitance therefore starts to discharge through R_{13} and R_{14} and the output potential tends towards +90 V. As soon as it drops to +156 V, however, the diodes conduct and the output potential then remains constant. Thus the trailing edge of the pulse is reasonably linear—as has been verified by oscillograms at 50 kc/s and 100 kc/s[6, 8].

It is important that the stray capacitance between the output of the circuit of Fig. 5.14 (including the E1T input circuit) and earth should be kept to a minimum, as variations in this capacitance will affect the amplitude and duration of the pulse fed into the E1T. The stray capacitance in the multivibrator circuit should also be kept to a minimum. The leading edge of the output pulse from Fig. 5.14 has a duration of about 1 μsec and the trailing edge a duration of about 8 μsec. The pulse duration will be somewhat smaller when the beam is near the x' electrode, since this electrode takes some current and effectively acts as a resistance in parallel with R_{13} and R_{14}. The reduction in pulse duration when the tube is indicating a large digit is not important, since the height of the peaks above the load line is greater in the case of the large digits (see Fig. 5.6).

The input pulses to the circuit of Fig. 5.14 should be of at least 15 V in amplitude and at least 2 μsec in duration. They may be sinusoidal, square or triangular in shape. If the circuit is to be fed with a sinusoidal voltage of a frequency which is less than about 20 c/s, either a fairly large input voltage should be used or alternatively the value of C_1 should be increased. If pulses of a duration less than 2 μsec are fed into the circuit, the multivibrator will be triggered, but the amplitude of the output pulse will be somewhat reduced.

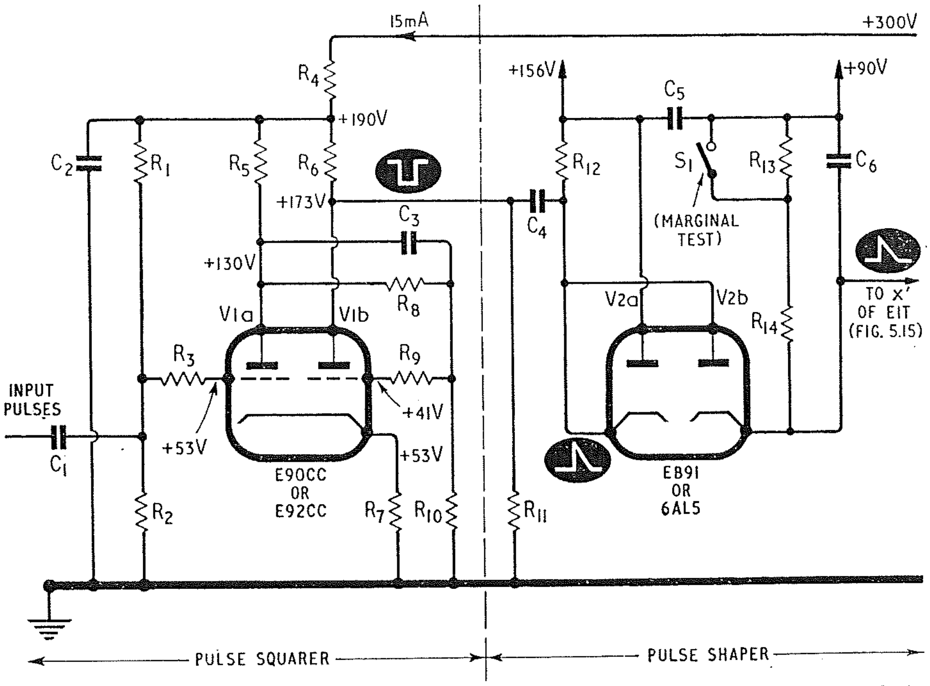


Fig. 5.14 An input circuit for the operation of the E1T at frequencies up to 100 kc/s

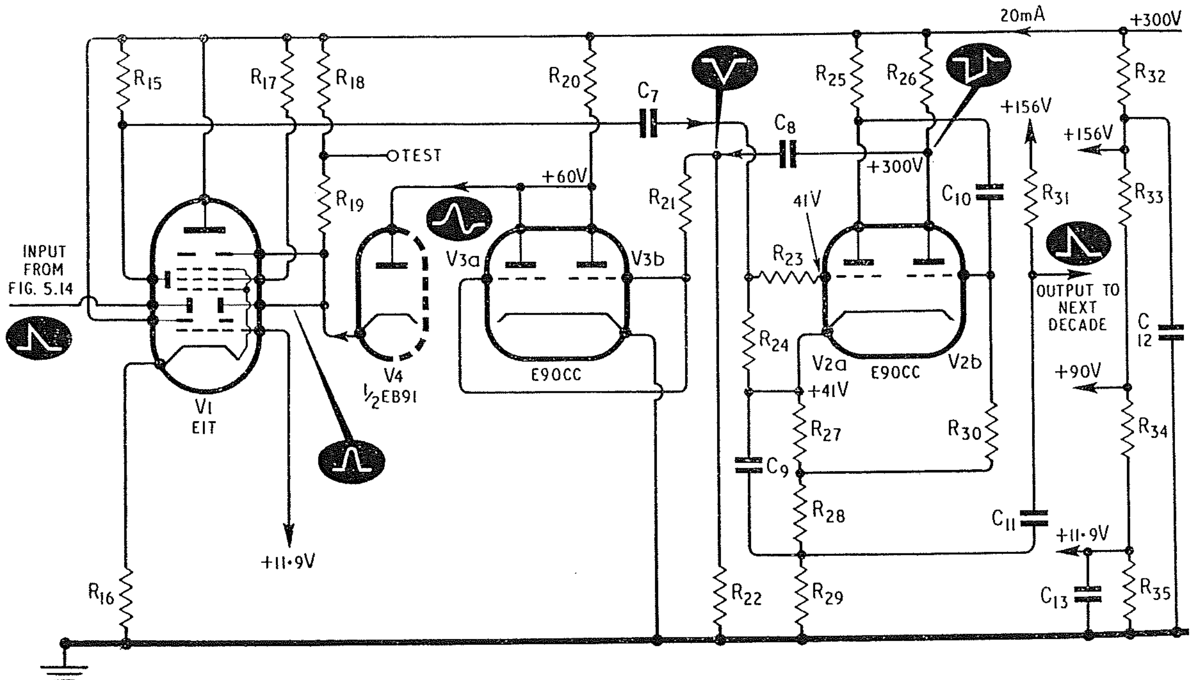


Fig. 5.15 A 100 kc/s E1T reset circuit with facilities for coupling to the next stage. The potential divider on the right-hand side can be used to supply both the above circuit and that of Fig. 5.14

istors

1	82 kΩ	1%	1/2 W
2	33 kΩ	1%	1/4 W
3	1 kΩ	10%	1/4 W
4	7.5 kΩ	5%	3 W
5	5.6 kΩ	1%	1 W
6	5.6 kΩ	1%	1 W
7	6.8 kΩ	1%	1 W
8	39 kΩ	1%	1 W
9	1 kΩ	10%	1/4 W
10	18 kΩ	1%	1/2 W
11	56 kΩ	2%	1 W
12	47 kΩ	2%	1/4 W
13	150 kΩ	2%	1/4 W
14	680 kΩ	1%	1/4 W
15	39 kΩ	10%	1/2 W
16	15 kΩ	1%	1/4 W
17	47 kΩ	5%	1/2 W

R_{18}	10 kΩ	10%	1/4 W
R_{19}	1 MΩ	1%	1/2 W
R_{20} (Wire wound)	18 kΩ	5%	5 W
R_{21}	1 kΩ	10%	1/4 W
R_{22}	6.8 kΩ	2%	1/4 W
R_{23}	5.6 kΩ	10%	1/4 W
R_{24}	560 kΩ	10%	1/4 W
R_{25}	39 kΩ	2%	2 W
R_{26}	3.3 kΩ	2%	1/2 W
R_{27}	4.7 kΩ	2%	1 W
R_{28}	2.7 kΩ	2%	1/2 W
R_{29}	1 kΩ	1%	1/4 W
R_{30}	150 kΩ	2%	1/4 W
R_{31}	15 kΩ	2%	1/4 W
R_{32}	33 kΩ	1%	1 W
R_{33}	15 kΩ	1%	1/2 W
R_{34}	18 kΩ	1%	1 W
R_{35}	2.7 kΩ	1%	1/4 W

Capacitors

C_1	2 μF	10%	paper
C_2	0.1 μF	10%	
C_3	22 pF	10%	
C_4	47 pF	2%	
C_5	0.01 μF	10%	
C_6	39 pF	2%	
C_7	220 pF	10%	
C_8	220 pF	2%	
C_9	68 pF	2%	
C_{10}	68 pF	2%	
C_{11}	680 pF	5%	
C_{12}	0.47 μF	paper	
C_{13}	0.47 μF	paper	

* R_4 may be replaced by two 15 kΩ 2% 2 watt resistors connected in parallel if desired.

10.2 Marginal Tests and Tube Selection

ıe switch S_1 in Fig. 5.14 enables a check to be ade as to whether any particular E1T tube will ›erate satisfactorily at high frequencies in the rcuit. If S_1 is used to short circuit R_{13}, the dur- ion of the trailing edges of the pulses will be duced by about 18%. If the circuit operates satis- ctorily under these conditions, it may be expected function satisfactorily when S_1 is open. These arginal tests should preferably be carried out at veral input frequencies, say 20 c/s, 1 kc/s and)0 kc/s.

This test enables E1T tubes which are suitable ›r high speed operation to be selected. Other tubes hich do not function satisfactorily at high frequen- es may be used in decades operating at frequencies p to 30,000 pulses per second.

.11 Flyback Circuit for 100 kc/s Stage

: has been shown previously that if the electron eam is cut off to cause flyback, the resetting oper- tion requires more than 20 μsec. If a circuit is to ɔunt at frequencies up to 100 kc/s, another method f resetting the electron beam must be employed ı which the operation is completed in not more ıan 10 μsec.

The circuit of Fig. 5.15 shows a suitable resetting nd coupling circuit[1, 6, 8] for high speed operation. 'he monostable multivibrator $V2$ is identical with ıat used in the circuits of Figs. 5.10 and 5.13. It is fed from the reset anode via C_7. The negative going pulse at the anode of $V2b$ (which was used for cutting off the E1T tube in the 30 kc/s circuits) is differentiated by C_8 and R_{22} and the resulting pulses are applied to both grids of the double triode $V3$. Both sections of this valve are cut off and the anode voltage increases rapidly. $V4$ conducts and passes the positive going pulse to the anode and x'' deflector plate of the E1T. The beam is therefore rapidly deflected to the zero position. When $V3$ returns to its normal conducting state, the resulting negative pulse cannot pass through the diode to the E1T anode. In actual practice the E1T anode does receive a small part of the negative going pulse owing to the anode to cathode capaci- tance of $V4$ which forms a capacitative voltage divider in conjunction with the anode by-pass capacitance of the E1T.

The anode and x'' potential of the E1T tube in the circuit of Fig. 5.15 can rise much more quickly than in the circuits in which flyback is effected by beam cut off. When the diode of Fig. 5.15 conducts, the 1 MΩ resistor R_{19} is effectively in parallel with the combined resistance of R_{20} (18 kΩ) and the forward resistance of the diode. The latter is small and the time constant which controls the rate of rise of the E1T anode potential is therefore approx- imately 18 kΩ multiplied by the stray anode to earth capacitance. In the 30 kc/s circuits the correspond- ing time constant is the slightly smaller stray E1T anode capacitance multiplied by 1 MΩ (the tube anode resistor). Thus the time constant has been reduced by a factor of nearly fifty in the 100 kc/s flyback circuit. It should be noted that the use of $V4$ in the 100 kc/s circuit increases the stray anode capacity of the E1T from about 16.5 pF to about 23 pF.

It is important that the E1T anode potential should be raised sufficiently during flyback for the beam to return to the zero position, but if it is raised too high, the beam will take too long to arrive at the zero position for the resetting operation to be completed within the permitted 10 μsec.

5.12 PRACTICAL DETAILS

The 100 kc/s input circuit is normally followed by a number of 30 kc/s stages of the type shown in Fig. 5.13.

The heater supplies for the two diodes of Fig. 5.14 and for the single diode of Fig. 5.15 require special mention. These supplies should preferably be obtained from a separate transformer winding, one side of which is connected to the +156 V line. This reduces leakage between the diode cathodes and heaters. Alternatively suitable semiconductor diodes could be used, but care should be taken to ensure that they have an adequate peak inverse voltage rating.

Care should be taken that all of the components used are within the specified tolerances or the input pulses may not have the desired shape and duration.

The fairly high value of the E1T cathode resistor greatly reduces any changes in the tube characteristics due to ageing. The ageing of the resistors in the common potential divider chain may result in a variation in the height of the peaks of the characteristic; under marginal conditions when the tube employed in the 100 kc/s stage has a low value of I_c, this may lead to counting errors. It is therefore important that the first E1T tube should be selected carefully.

If desired, reset facilities may be added to the 100 kc/s circuit by using the same technique as shown in the circuit of Fig. 5.13.

The E90CC tube is a special quality valve which has the same base connections as the ECC91 and the 6J6 and very similar characteristics.

The 30 kc/s and 100 kc/s circuits described above are normally the only ones required in an E1T scaler (with the possible exception of a circuit for coupling an E1T to an electro-magnetic counter). These decade circuits are conveniently constructed as plug in modules for ease of servicing. Such modules are available commercially from the manufacturers of the E1T tube[9, 10]. A 30 kc/s E1T module with the associated E90CC tube is shown in the photograph.

5.13 RANDOM PULSE COUNTING

If random pulses are to be counted, the average resolving time of the 30 kc/s circuit of Fig. 5.13 may be reduced by the use of the input circuit of Fig. 5.14 with the 30 kc/s flyback circuit (Fig. 5.10)[11]. R_{14} of Fig. 5.14 should be increased to 1.2 MΩ and R_{13} omitted so that the trailing edges of the pulses produced are long enough to operate any E1T tube.

The resolving time when flyback is not involved may thus be decreased from about 33 to 13 μsec. This applies to nine out of the ten positions, but in the tenth position (when flyback occurs), the resolving time remains about 33 μsec and this limits the maximum counting speed for evenly spaced pulses to 30 kc/s. The effective resolving time for randomly spaced pulses is, however, decreased to about 15 μsec.

5.14 10 KC/S E1T CIRCUIT

A circuit operating on rather different principles from those discussed previously is shown in Fig. 5.16[12]. It may be fed from the input circuit of Fig. 5.11 or from a previous decade. One advantage of this circuit is that 10% components can be used throughout, whereas the faster E1T circuits require many 1% and 2% tolerance components. In addition, rather fewer coupling components are required.

The triode $V2$ shares a common cathode resistor, R_2, with the E1T tube, $V1$. The flow of the E1T cathode current through R_2 produces a positive voltage which biases the cathode of $V2$ to cut off, since the grid of $V2$ is returned to earth via R_4.

When the beam is in position 'nine' and an additional input pulse is received, the beam will be

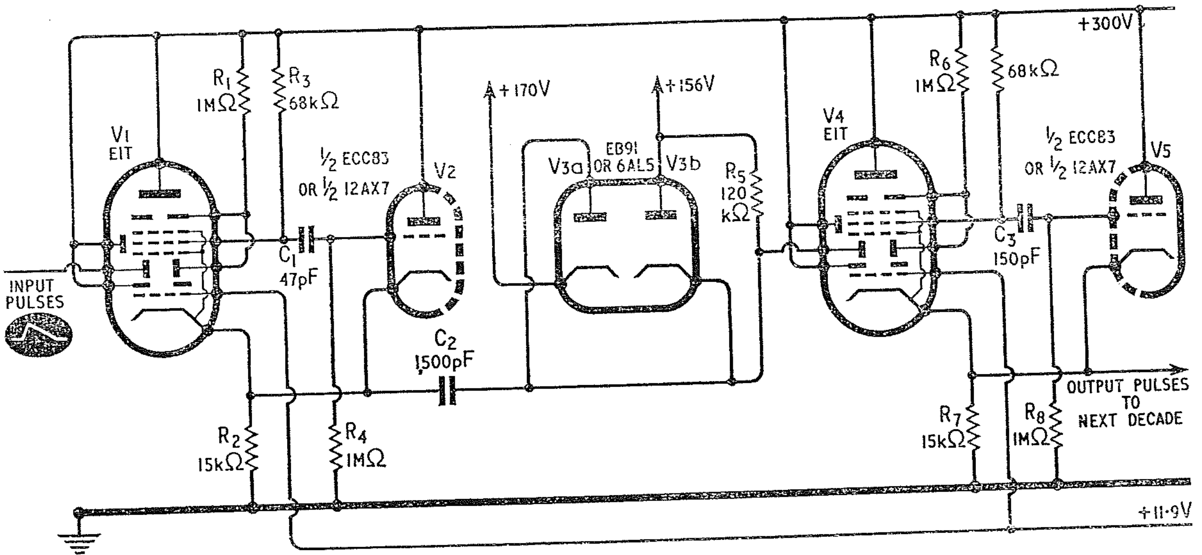


Fig. 5.16 An E1T circuit for operation at frequencies up to 10 kc/s

deflected so that it strikes the reset anode, a_1, instead of the g_4 electrode. The current passing through R_3 therefore falls and the potential of the electrode g_4 rises. This rise of potential is fed as a pulse to the grid of the triode $V2$ via the capacitor, C_1. The triode conducts and the voltage across the common cathode resistor, R_2, rises. This rise of potential of the cathode of the E1T is sufficient to cut off the tube and the electron beam is reset to the zero position by the same process as in the 30 kc/s circuit. The reset anode is not employed in this circuit.

The impulse from the cathodes passes through C_2 to the x' deflector plate of the succeeding E1T tube. The resistor R_5 maintains the quiescent potential of the x' deflector plate at +156 V. If the voltage at the cathodes of $V1$ and $V2$ becomes more positive, the pulse which passes through C_2 is limited by $V3$a to a maximum value of +170 V above earth. Thus the desired positive going 14 V pulse for $V4$ is obtained. Similarly when a negative pulse is fed through C_2, $V3$b limits the minimum potential to the quiescent value of +156 V.

The time taken for flyback (that is, for the anode and x'' potential to rise) in the circuit of Fig. 5.16 after the tube has been cut off is as long as in the circuit discussed previously (Fig. 5.10). In addition, the voltage of g_4 takes a short time to rise and the C_1R_4 circuit delays the pulse considerably. The maximum operating frequency is therefore limited to about 10 kc/s.

In any stages after the first, the value of the capacitor corresponding to C_1 may be increased to 150 pF, since the maximum operating frequency is lower. The circuit of Fig. 5.16 may be modified to incorporate a resetting circuit.

5.15 2 KC/S CIRCUIT

A number of attempts have been made to design a circuit for operation at fairly low frequencies which does not require any valve coupling stage between each two E1T tubes[2, 6, 13]. A typical circuit of this type is shown in Fig. 5.17 in which a double diode is the only valve employed between each two E1T tubes. Germanium semiconductor diodes were not used because their inverse resistance varies with temperature and this would result in variations of the amplitude of the pulses fed to the next E1T tube. Silicon semiconductor diodes are now available and these could be used to replace the EB91 valves so as to avoid the use of valves in the coupling circuits.

The resetting action is accomplished by means of the capacitor which connects the reset anode to the main anode. When the beam strikes the reset anode, the potential of this electrode falls and this fall is coupled into the main anode circuit so that the beam is moved still farther towards the x' electrode. After

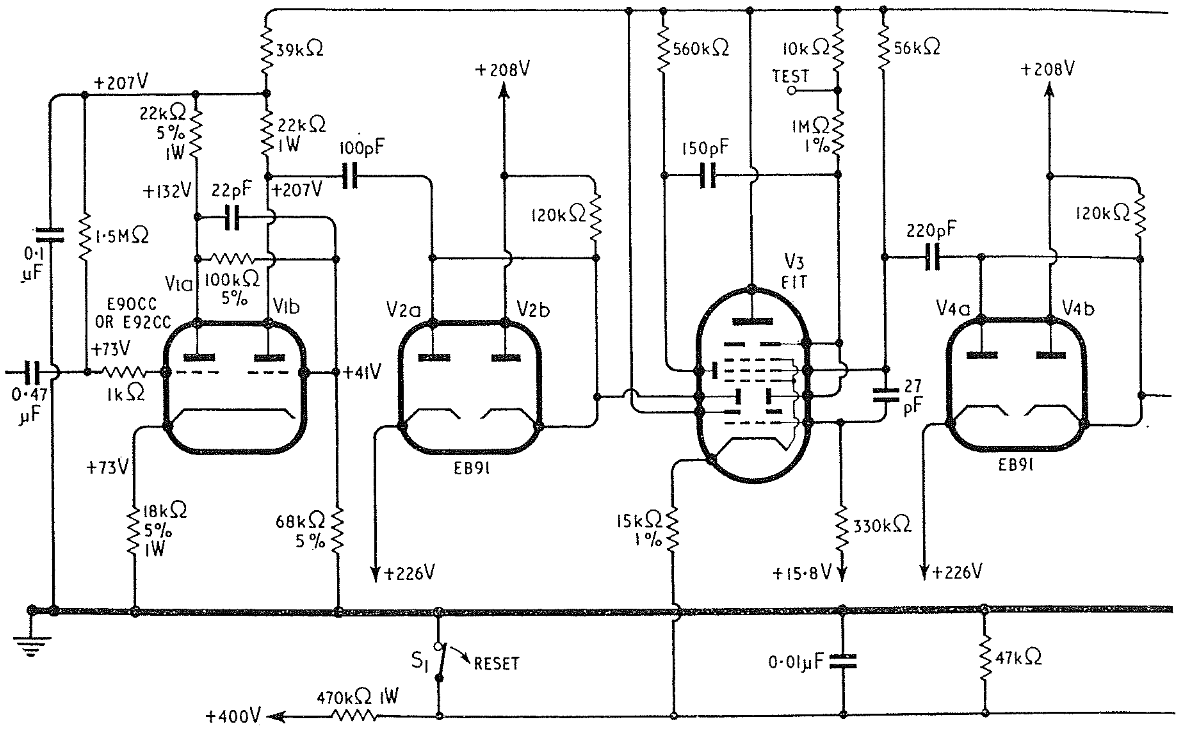
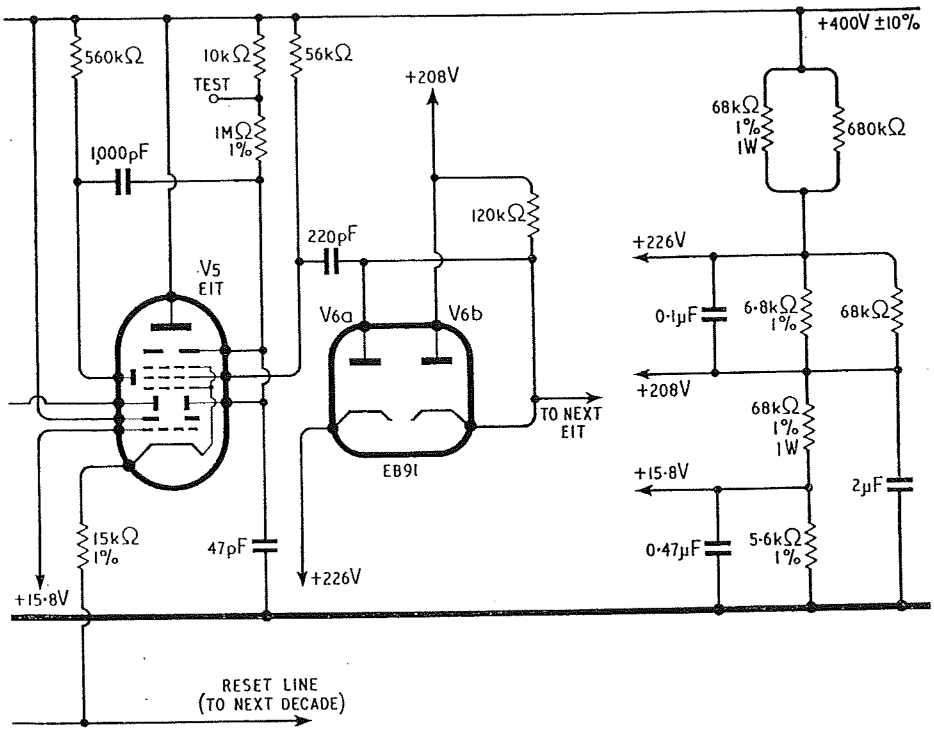


Fig. 5.17 A 2 kc/s E1T circuit which does not require a coupling amplifier.

a short time the anode and x'' voltage rises to the H.T. supply potential and the beam moves back across the tube. If the value of the coupling capacitor connecting the two anodes is large enough, the main anode potential will continue to rise until the digit zero is indicated. The maximum operating frequency depends on the value of the coupling capacitor, but if this is too small, the beam will be reset to an intermediate position. It has been found that the value of the coupling capacitor may be reduced somewhat if the beam current is reduced during flyback. This may be achieved by applying the differentiated g_4 voltage to the control grid of the counter tube $V3$ in Fig. 5.17. This prevents the reset capacitor from being recharged too quickly. The maximum operating frequency is approximately doubled by this technique(13), but there is no point in reducing the beam current in any stage after the first. A smaller value of coupling capacitor is used in the first stage than in subsequent stages.

The 'carry' pulse which operates the next decade is obtained from the g_4 electrode. When the beam is deflected from position nine, it leaves g_4 and the potential of this electrode therefore rises. When the beam returns V_{g_4} falls again. These voltage changes are differentiated in order to obtain a positive pulse followed by a negative pulse. A diode is used to remove the negative pulse and the remaining positive pulse is limited by the other diode. In all stages except the first a 47 pF capacitor is connected from the main anode to earth so that the g_4 pulse is steep enough to operate the next decade.

The reset anode resistor must have a value greater than a certain minimum or the beam will not be reset to zero. The large value of this resistor can, however, cause premature flyback when the beam moves from position eight to nine, because a small fraction of the beam will reach the reset anode. This is less likely to happen if a fairly high supply voltage is used so that the beam is focussed more accurately. The minimum supply voltage at which most tubes would operate satisfactorily was found to be 200–250 V, but some tubes required a 350 V supply when used in the circuit of Fig. 5.17 in order to avoid position nine being missed. The recommended H.T. supply voltage for this circuit is 400 V.



Components may be of 10% tolerance unless otherwise indicated

A suitable input stage is also shown in Fig. 5.17. It consists of a double triode squarer followed by a double diode pulse shaper. *V*1a is normally conducting and *V*1b is normally cut off. Negative going input pulses are required to cut *V*1a off. A negative going pulse first appears at the anode of *V*1b, but is prevented from reaching *V*3 by the presence of *V*2b. When the circuit returns to its quiescent state, *V*2a limits the positive going pulse which is fed to the E1T.

The circuit should be fed with input pulses of not less than about 20 V in amplitude and not less than about 3 μsec in duration. Sine waves of not less than 15 V R.M.S. amplitude may be used if their frequency is between 20 and 2,000 c/s.

The circuit is reset by the application of a positive pulse to the E1T tube cathodes. This method can also be used for the 30 kc/s circuit of Fig. 5.13. A suitable potential divider is shown for supplying the required voltages to the Fig. 5.17 circuit when up to four decades are used. The diode heaters should be fed from a separate transformer winding, one side of which is connected to the +208 V line.

5.16 PREDETERMINED COUNTING USING THE E1T

The same electrodes of the E1T are being used whatever the state of the count. It is therefore convenient to obtain an output pulse from an E1T scaler only when the decades are being reset to zero.

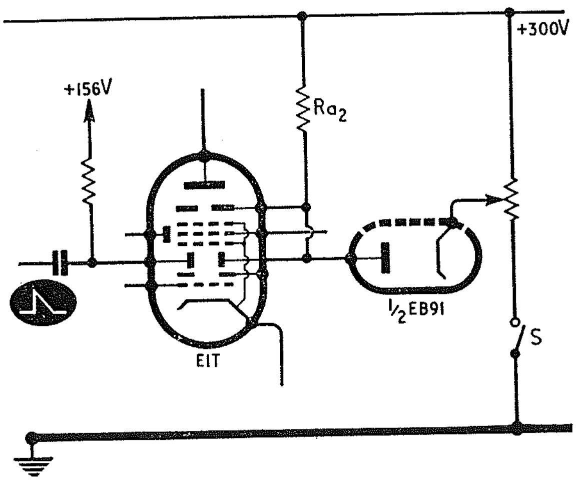


Fig. 5.18 A circuit for pre-setting an E1T

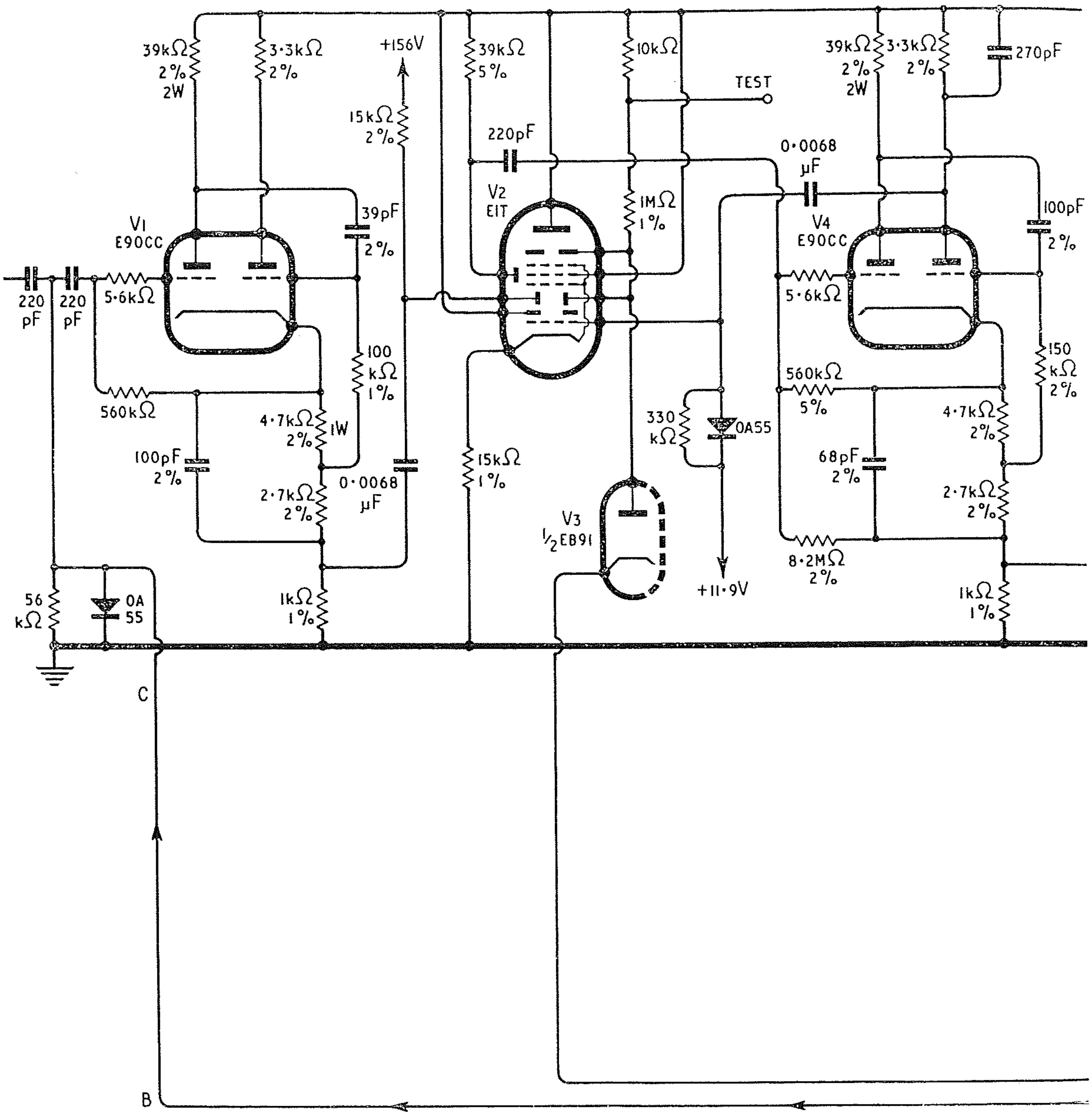
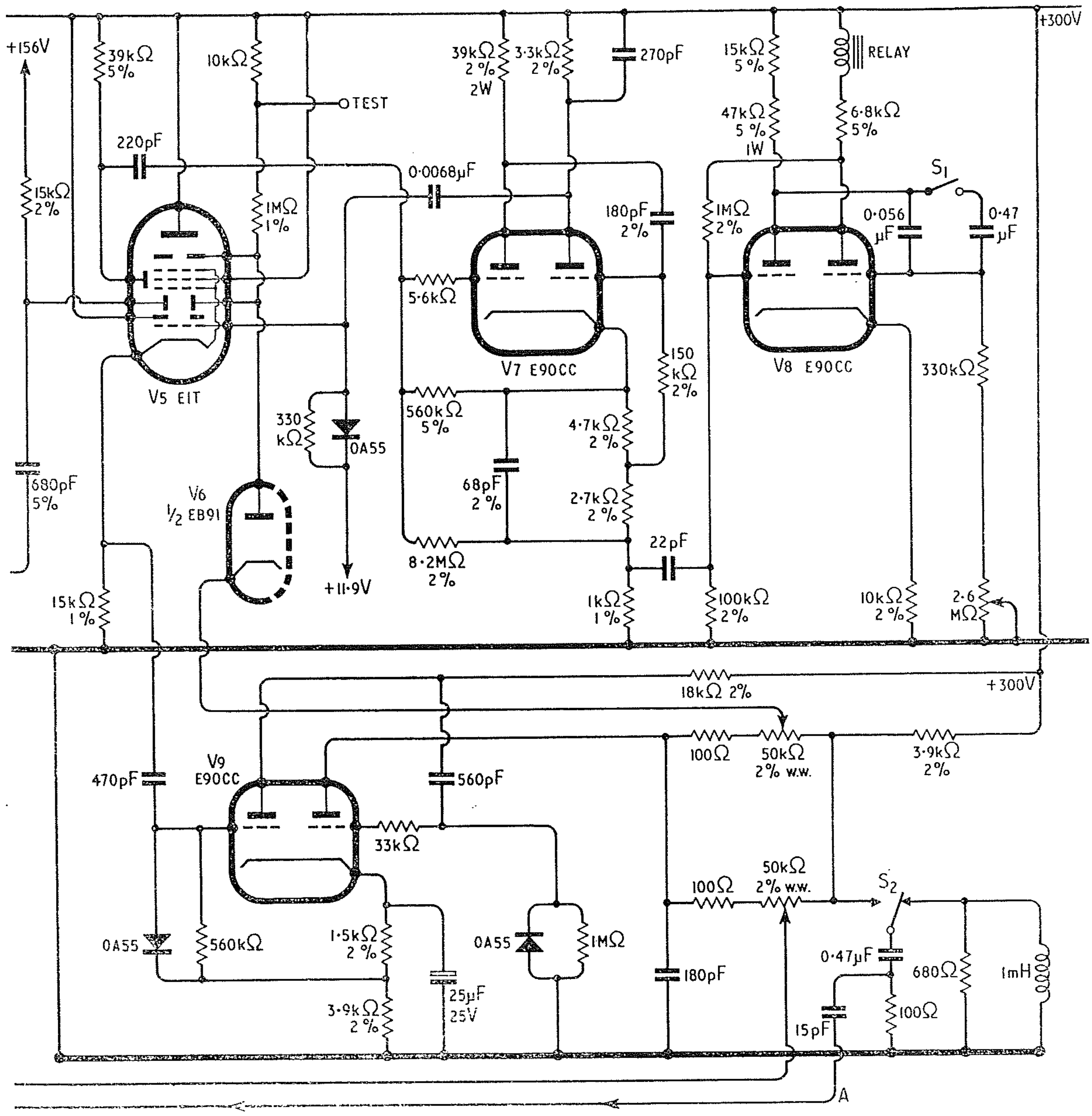


Fig. 5.19 A two decade E1T preset counter. Any additional decades should be similar



to the first decade shown above. Component tolerances not shown are 10%

In order that a pulse may be obtained after any predetermined number of counts, some means must be provided for presetting the scaler to any desired number of counts. If, for example, a four decade scaler is preset to 5,672, an output pulse can be obtained after 10,000−5,672 = 4,328 pulses have been applied at the input. Arrangements may be made for the output pulse to automatically preset the scaler to the number 5,672 so that the process can be repeated many times.

The E1T tube may be preset to any desired number by means of the type of circuit shown in Fig. 5.18. When the switch S is open, the diode is non-conducting and has no effect on the operation of the tube. When S is closed the diode will conduct if its cathode is at a lower potential than the E1T anode. The flow of current through R_{a_2} causes the anode voltage to fall almost to the potential of the slider of the variable resistor. When S is opened, the beam will move to its next stable position, the anode voltage being little different from that of the potentiometer slider immediately before S was opened. After S has opened the diode cathode potential rises to the H.T. supply voltage and the diode becomes non-conducting again.

A number of such decades may be cascaded with separate potentiometers connected to a common switch. Each tube can thus be preset to the desired digit which has been pre-selected by means of the corresponding potentiometer. In practical circuits the presetting switch is an electronic device.

The full circuit of a two decade predetermined counter is shown in Fig. 5.19[6, 14, 15]. This circuit is based on the 30 kc/s E1T counter described previously (Fig. 5.13), but slight modifications have been made. The g_4 electrodes of the E1T tubes are connected directly to the H.T. + line in order to avoid negative feedback during the resetting of the beam. The amplitude of the required input pulse is thereby increased from a mean value of 13.6 to a mean value of 14.7 V. The larger pulse is obtained by shunting part of the cathode resistor in the input circuit by 100 pF instead of 82 pF. In all decades except the first, the pulse amplitude is increased by the presence of the capacitors which by-pass the anode loads of the right hand triodes of the coupling circuits.

These capacitors also serve to prevent "sticking" of the electron beam at position nine when the presetting potentiometer is adjusted so that the beam passes between the end of g_4 and the reset anode[6, 14].

5.17 THE ELECTRONIC SWITCH

An electronic presetting stage, $V9$, is used instead of the switch S of Fig. 5.18. The left-hand triode of $V9$ is normally conducting whilst the right-hand triode is normally cut off. When the final E1T, $V5$, is reset by beam cut off, the negative going pulse produced at its cathode is fed to $V9$. The pulse is amplified and phase inverted by the left-hand section of this valve and the resulting positive going pulse is used to render the right-hand section of $V9$ conducting. The anode voltage of this triode therefore suddenly falls from 300 to 95 V. This is low enough for presetting to take place to the digits determined by the positions of the sliders of the 50 kΩ potentiometers. OA55 diodes are employed in each of the grid circuits of $V9$ to ensure that the quiescent grid potential is reached at high counting rates.

The 100 Ω resistors in series with the presetting potentiometers serve to prevent excessive interaction of the potentiometer settings owing to the inductance of these wire wound components.

The scaler may be preset manually by means of S_2. When this switch is pressed, the 0.47 μF capacitor connected to it is suddenly charged so that the voltage of the 50 kΩ presetting potentiometers quickly falls and the beam in each tube moves to the ninth position. When S_2 moves back to its normal position, the capacitor discharges through the 1 mH choke and the 100 Ω resistor producing a negative going pulse which is fed to the input of the scaler along the wire ABC and causes the scaler to momentarily indicate zero. During this process the last E1T is reset and this initiates the presetting by means of $V9$.

5.18 THE OUTPUT STAGE

The output pulse from the tapping on the cathode resistor of $V7$ is applied to the monostable circuit of $V8$. The 2.6 MΩ variable resistor in the grid circuit of $V8$ can be used in conjunction with the switch S_1 to vary the time for which the relay is energised from 20 msec to 2 sec. The maximum repetition frequency of the output stage is about 20 c/s, but the relay can be replaced by a thyratron circuit in order to achieve the maximum repetition frequency of the counter of about 3 kc/s. This is, of course, the maximum number of batches which can be counted per second, but the maximum rate at which the input pulses can be counted is 12.5 kc/s.

The power supply for the circuit of Fig. 5.19 can be indentical to that used for the 30 kc/s circuit of Fig. 5.13, but the −60 V supply used for resetting the decade tubes of Fig. 5.13 is not required. The EB91 diodes connected to the E1T anodes must be fed from a separate 6.3 V transformer winding, one side of which is connected to the +156 V line. The EB91 diodes should be mounted close to the E1T tubes to which they are connected and the internal screens of the diodes should be connected to the +300 V line to avoid pulses in one section of the double diode from being picked up in the other.

The input pulses required for the operation of Fig. 5.19 have similar amplitudes and durations to those required for the circuit of Fig. 5.13. If necessary the circuit of Fig. 5.12 may be used to shape the input pulses before they are fed into the preset counter.

The optimum setting of the potentiometers for any digit will vary slightly from decade to decade according to the individual characteristics of each E1T tube used. In order to adjust the potentiometer settings, a 3 kc/s pulse generator should be connected to the input and the potentiometer which presets the units decade should be calibrated first, the other potentiometers being turned in a clockwise position to the ends of their tracks (corresponding to positions 9). The optimum position of the potentiometer for presetting a tube to any digit is midway between the points at which the tube is just preset to the adjacent digits.

The other potentiometers are then calibrated in a similar way, but the potentiometers of the previous stages are set to zero during this operation. The input pulse frequency may be raised to 12.5 kc/s during the calibration of the potentiometers which preset the decade tubes which indicate the hundreds and the thousands. The adjustment of the potentiometer which presets the thousands tube is somewhat more tedious owing to the slow rate of counting of this tube.

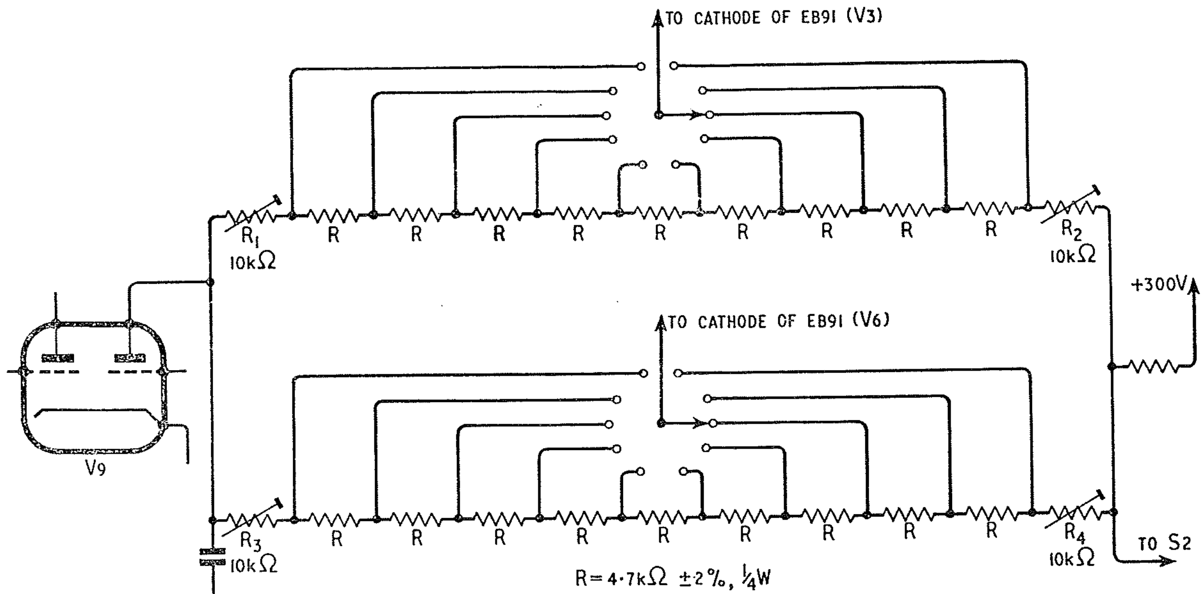


Fig. 5.20 The potentiometers of Fig. 5.19 may be replaced by the above circuit for switched presetting

When an E1T is replaced, the calibration of the potentiometers should be checked. Normally the only adjustment likely to be required is a slight rotation of the scale of some of the potentiometers, but sometimes a new scale may have to be used.

5.19 SWITCHED PRESETTING

A ten way switch may be used to preset each decade instead of a potentiometer. The type of circuit used is shown in Fig. 5.20, this replacing the potentiometers and the 100 Ω resistors used in the circuit of Fig. 5.19.

The adjustment of the variable resistors of Fig. 5.20 should be carried out with the aid of an oscilloscope and a pulse generator. The oscilloscope is connected to the test point (Fig. 5.19) of the decade being adjusted. The decade tube indicating the units should be adjusted first, then that showing the tens and so on.

When the decade is switched to position zero, the oscillogram should show a descending staircase waveform of ten distinct steps. As the digit to which the stage is to be preset is increased, some of these steps vanish. The potentiometer R_1 (Fig. 5.20) should be adjusted with the appropriate decade switched to position 1, the correct setting being obtained when the transient in the centre of the first step is of equal height above and below the level of the step. R_2 should be adjusted with the decade preset to position 7 so that the first of the three steps on the oscillogram shows a transient which has equal heights above and below the level of the step. The next decade is adjusted in a similar way, R_3 (see Fig. 5.20) being adjusted with this decade preset to one and R_4 with the decade preset to seven.

5.20 THE USE OF AN E1T TO FEED AN ELECTRO-MAGNETIC COUNTER OR RELAY

Each E1T tube can indicate only one digit, but one electro-magnetic counter can indicate a number of digits. In some scalers the input pulses are therefore fed into one or more E1T tubes and the output pulses from the final E1T circuit are counted by the

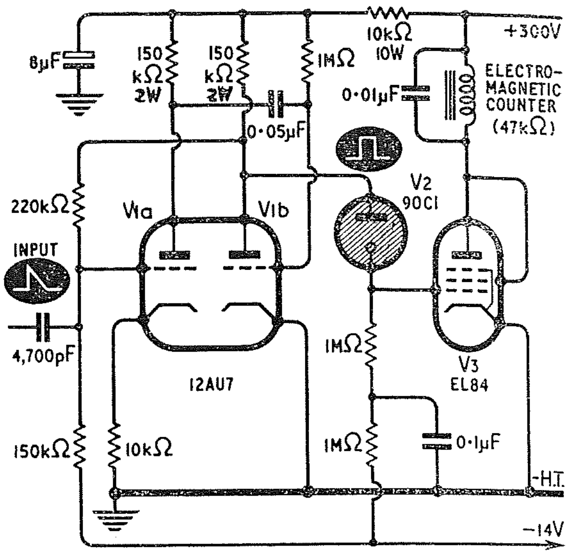


Fig. 5.21 A circuit for the operation of an electro-magnetic counter from an E1T circuit

electro-magnetic counter. The same type of circuit may, of course, also be used to operate a relay.

The output pulses from the E1T circuits such as that of Fig. 5.13 are not able to provide enough power to operate an electro-magnetic counter directly and their duration is measured in microseconds whilst an electro-magnetic counter requires pulses which are about one thousand times longer. A circuit which will both amplify and lengthen the pulses is therefore required. Normally a monostable circuit is used.

One example of a monostable circuit used to operate a relay is the output stage, $V8$, of the predetermined counter shown in Fig. 5.19. The maximum permissible cathode current for the E90CC is, however, 15 mA. If a large relay or an electro-magnetic counter taking a current in excess of about 12 mA is to be used, the circuit shown in Fig. 5.19 is not suitable, although it is always possible to use a small relay which can be operated by the E90CC to switch on a larger relay or a counter.

An alternative is to use a valve which can supply more current to the relay or counter. Such a circuit is shown in Fig. 5.21 in which an EL84 is used to provide the power. The input pulses for this circuit may be taken from the junction of the resistors R_{36}, R_{37} and R_{39} in Fig. 5.13.

*V*1 of Fig. 5.21 is a monostable circuit. Normally *V*1a is cut off and *V*1b is conducting. A positive going input pulse causes *V*1a to conduct and the resulting negative pulse at the anode of this tube is used to cut off *V*1b. A positive pulse appears at the anode of *V*1b and this is fed through the 90C1 tube to the grid of *V*3. The output tube, *V*3, is normally biased to cut off, however, but conducts when each pulse is fed to it and thus operates the counter.

Table 5.1 THE E1T — ABRIDGED DATA

Heater

6.3 V at 0.3 A. Suitable for series or parallel operation.

Operating Conditions		*Inter Electrode Capacitances*	
$*V_b$	300 V	C_{a_2}–all	10.5 pF
$*V_t$	300 V	$C_{x'}$–all	3.5 pF
$*V_{g_2}$	300 V	$C_{x''}$–all	3.8 pF
$*V_{g_1}$	11.9±0.15 V	C_{g1}–all	6.8 pF
$*V_{x'}$	156±1.5 V	C_{g_4}–all	7.7 pF
I_{g_2}	100 μA		
I_k	900 μA		
R_k	15 kΩ±1%		
R_{a_1}	39 kΩ±10%		
R_{a_2}	1.0 mΩ ±1%		
R_{g_4}	47 kΩ±5%		

Base B12A Duodecal.

Connections see Fig. 5.3.

* All voltages are quoted with respect to the chassis. Provided that the ratios of these voltages are strictly maintained by using a suitable voltage divider consisting of 1% tolerance Grade 1 resistors, the supply need not be stabilised unless variations of more than ±10% are expected.

Operating Notes

The tube may be mounted in any position except horizontal with the fluorescent screen facing downwards.

External magnetic fields can influence the operation of the tube. The external flux density should not exceed 2 G (2×10^{-4} Wb/m²) in any direction.

It is advisable to use the tube in an ambient illumination of between 40 and 500 lux. If the illumination is low, it may be difficult to read the figures on the mask of the tube and occasionally some difficulty may be experienced by the neighbouring spots showing some fluoresence. If the ambient illumination is too great, some difficulty may be experienced in the observation of the luminous spot. It is advantageous to mount the tube a short distance behind the front panel so that the amount of light falling on the tube is reduced somewhat.

The length of time for which the relay is energised is determined by the time constant of the 1 MΩ resistor and 0.05 μF capacitor in the grid circuit of *V*1b. The optimum pulse length depends on the type of counter used; the values shown are suitable for the P.O. 100 type counters which require a pulse of about 1/20 sec. If a fast counter is to be used, the value of the capacitor may be decreased to about 0.01 μF.

A capacitor can be used instead of the 90C1 tube. The circuit takes quite a large current when the relay or counter is energised and if the same H.T. supply is used for the E1T circuits and for the circuit of Fig. 5.21, it is essential that it is stabilised. It is probably simpler to use separate H.T. supplies, since neither then need be stabilised. The electromagnetic counter should not be placed near to any E1T tube or the magnetic field may affect the operation of the tube.

5.21 REVERSE COUNTING

If suitable negative going pulses with a sharp leading edge and a long trailing edge are fed to the E1T, the tube will count in reverse(16). Alternatively positive going pulses with a long leading edge and a trailing edge of high slope may be used. The resetting of the tube from zero to nine can be accomplished by employing a pulse generated at the g_4 electrode. If the tube is indicating the digit zero and a suitable negative going pulse is fed to the x' electrode, the electron beam will be deflected so that it no longer strikes g_4. The reduction in the current passing through the g_4 series resistor enables a positive going pulse to be taken from this electrode. This pulse can be used to trigger a multivibrator which in turn provides a suitable negative pulse to the x″ deflector electrode so that the tube is reset to indicate the digit nine.

Other Scales

The E1T tube is essentially intended for scale of ten counting. It is, however, possible to employ a catching diode which conducts when the E1T anode reaches a certain positive potential during flyback so that the beam stops before it actually reaches zero(2).

REFERENCES

1. 'High speed decade counter tube, type E1T', *Mullard Technical Communications*, **2**, *13*, 74 (1955).
2. R. E. NATHER, 'High speed counting with one-tube decades', *Electronics*, **27**, 174 (1954).
3. J. L. H. JONKER, 'Valves with a ribbon-shaped electron beam; contact valve; switch valve; selector valve; counting valve,' *Philips Res. Rep.*, **5**, *1*, 6 (1950).
4. J. L. H. JONKER & Z. VAN GELDER, 'New electronic tubes employed as switches in communication engineering'. Part II switch tubes', *Philips Tech. Rev,*, **13**, *4*, 82 (1951/1952).
5. 'The E1T decade counter tube'. *Electron. Appl. Bull.*, **14**, *1/2*, 12 (1953).
6. 'Philips E1T Decade Counter Tube'. Philips Gloeilampenfabrieken (20/038/D/E-3-60).
7. 'Auxiliary circuits for decade counters' *Electron. Appl. Bull.*, **14**, *5*, 76, (1953).
8. R. VAN HOUTEN, 'A decade counter stage with a counting rate of 100,000 pulses per second'. *Electron. Appl. Bull.* **15**, *3*, 34 (1954)
9. 'Philips Decade Counting Units'. Philips Gloeilampenfabrieken, (32/320/D/E-8-61).
10. 'General Introduction to the 88929 Series of Counting Units' and 'High Speed Counters for Instrumentation', Mullard Equipment Ltd.
11. R. VAN HOUTEN & M. VAN TOL, 'Improving the resolving power of decade counters for random pulses'. *Electron. Appl. Bull.*, **15**, *12*, 181 (1954).
12. R. KRETZMANN, Industrial Electronics Circuits, Philips Technical Library (1957).
13. R. VAN HOUTEN, 'Low-speed counter equipped with the E1T decade counter tube', *Electron. Appl. Bull.*, **15**, *6*, 77 (1954).
14. A. DORN, 'A multi-decade predetermined counter', *Electron. Appl. Bull.* **14**, *6/7*, 91 (1953).
15. R. KRETZMANN, Industrial Electronics Handbook, 3rd Ed., Philips Technical Library (1959).
16. P. PALIC & H. HERTWIG, 'Rückwärtszählung mit der E1T', Interner Applications labor-bericht der Valvo GmbH, Hamburg (1954).

6

Beam Switching Tubes

Beam switching tubes are high vacuum devices with heated cathodes which can be used to count at maximum frequencies of between 1 and 10 Mc/s. They may be classified into two main types which are known as 'Trochotrons' and 'Beam X' switching tubes. The trochotrons have a fairly large external magnet; they are manufactured by the Ericsson and Mullard Companies in Great Britain and by the Burroughs Corporation in the United States. The Beam X switching tubes have ten small rod shaped magnets inside the evacuated envelope which also serve as electrodes. Beam X tubes are smaller than trochotrons and not so susceptible to external magnetic fields. The name 'Beam X' is a registered trade mark of the Burroughs Corporation who manufacture these tubes. The basic principles of operation of trochotron and Beam X tubes are the same, but there are many constructional differences.

Although the disadvantage of the relatively long ionisation and deionisation times of gas filled tubes may be overcome by the use of high vacuum devices, the latter cannot be switched by the same mechanism as that used in polycathode gas filled tubes, since there are no critical values of striking and maintaining potentials and the absence of positively charged ions prevents any priming from taking place.

In beam switching tubes the electron beam rotates in a complete circle through ten stable positions when ten successive input pulses are applied to a tube. The switching process cannot therefore be accomplished by simple electrostatic deflection as in the other type of high vacuum tube, the E1T, in which the electron beam is merely deflected through an angle into ten successive stable positions and is then reset. The necessity for resetting the E1T limits the maximum counting speed and complicates the circuitry. The E1T has the advantage over beam switching tubes that it is self indicating, whereas some form of external readout must be used when beam switching tubes are employed in counting circuits.

6.1 ELECTRON PATHS IN MUTUALLY PERPENDICULAR MAGNETIC AND ELECTRIC FIELDS

In order to understand the functioning of beam switching tubes it is first necessary to consider the paths which electrons take under the influence of perpendicular magnetic and electric fields. This should really be done by manipulation of differential equations[1, 2], but the following simple description will suffice for a qualitative account of the functioning of beam switching tubes. The situation is, in any case, complicated by space charge effects.

In Fig. 6.1 a potential is applied between the two plates and a magnetic field is present with the magnetic intensity perpendicular to the plane of the paper. Lines joining points of equal potential (equipotential lines) have been drawn in the space between the plates. If an electron is placed at point *a* and its velocity is initially small, it will start to move under the influence of the electric field towards the positive electrode in a direction which is almost perpendicular to the equipotential lines.

As the electron accelerates towards the anode, however, it receives an additional force from the magnetic field. This additional force acts in a direction which is perpendicular to both the direction of the instantaneous motion of the electron and to the magnetic field. As the electron moves from a, the magnetic force therefore gives it an acceleration either to the left or to the right (depending on the polarity of the magnetic field) along an equipotential line. If the magnetic force tends to move the electron to the left, its path will curve away from the anode under the influence of the two forces as shown at b.

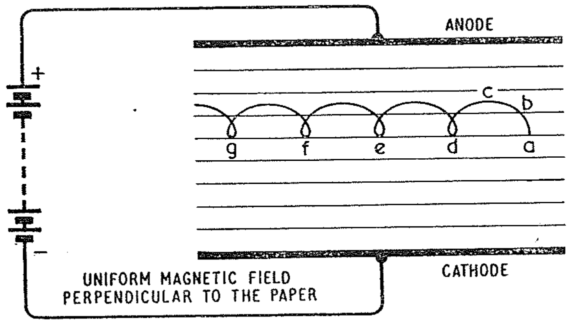


Fig. 6.1 The trochoidal path of an electron in perpendicular electric and magnetic fields

The electrostatic force is constant, but the magnetic force increases with the velocity of the electron. When the electron is moving parallel to the equipotential lines (as at c), the magnetic force will be acting towards the cathode, since it always acts in a direction at right angles to the path of the electron. The latter therefore moves towards d.

As the electron approaches d its velocity is almost in the opposite direction to the velocity it had immediately after leaving a. The electrostatic field is now opposing the motion and the electron slows down until momentarily the component of its velocity in the direction of the electric field becomes zero (at d). During the time the electron is moving away from the anode the force on it due to the magnetic field tends to accelerate it towards the right-hand side of Fig. 6.1 and this reduces the component of its velocity along the equipotential lines to zero at point d. The electron is accelerated from d by the electric field and completes further similar loops de, ef and fg. The magnitude of each step is determined by the relative magnitudes of the electric and magnetic fields.

It can be shown mathematically that the curve shown in Fig. 6.1 which the electron follows is a

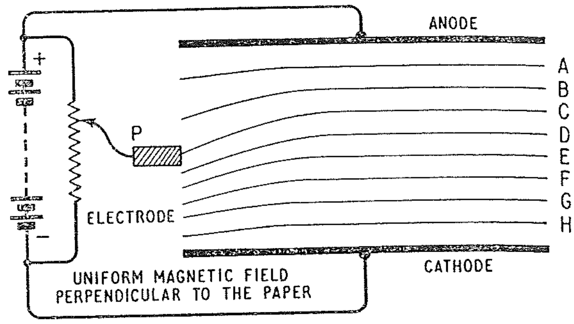


Fig. 6.2 The distortion of equipotential lines in the region of an electrode

trochoid, but the important point is that the electron beam, as a whole, 'drifts' along the equipotential line from a to g. Under the influence of the electric field alone the electron beam would move in a direction perpendicular to the equipotential lines. The effect of the magnetic field is, therefore, to alter the direction of the beam by 90°.

If the magnetic field intensity is small relative to the electric field intensity, the electron beam will commence to move in a trochoidal path, but the magnetic field may be too small to prevent the electrons from reaching the anode. There is a value of magnetic field strength which is just large enough to prevent electrons from reaching the anode and in this case the point c of Fig. 6.1 will be at the surface of the anode.

If an additional electrode, the plate P, is placed in the system as shown in Fig. 6.2, the equipotential lines will be deflected in a way which depends on the potential of P. In the case shown in Fig. 6.2, P has the same potential as that of the equipotential line marked C.

It has been shown that the electrons travel along equipotential lines in the systems being discussed. If therefore a source of low energy electrons (such as a heated cathode) is placed successively on various equipotential lines (which necessitates the source having the same potential as the line on which it is placed), a large number of electrons will reach P only if the electron source is situated on or very near to the line C. If the electron source is placed on any other equipotential line, the electrons will travel along the line and the majority of them will pass above or below P.

Similarly if the electron source is placed on the line C and the potential of P is varied by means of the variable resistor shown, the number of electrons reaching P will be a maximum when the source has such a potential that it lies on the equipotential line C. If the electrode does not have this potential, the distortion of the equipotential lines will be different from that shown; P will therefore no longer be situated on the line C so that electrons passing along this line will not strike P.

The current/voltage characteristic curve for the electrode P shows a single maximum at the potential of the line C, the current falling off steadily on each side of this maximum. The curve thus shows a negative resistance effect on the one side. The so-called spade electrodes of beam switching tubes have a characteristic similar to that of P; the importance of this will be seen shortly.

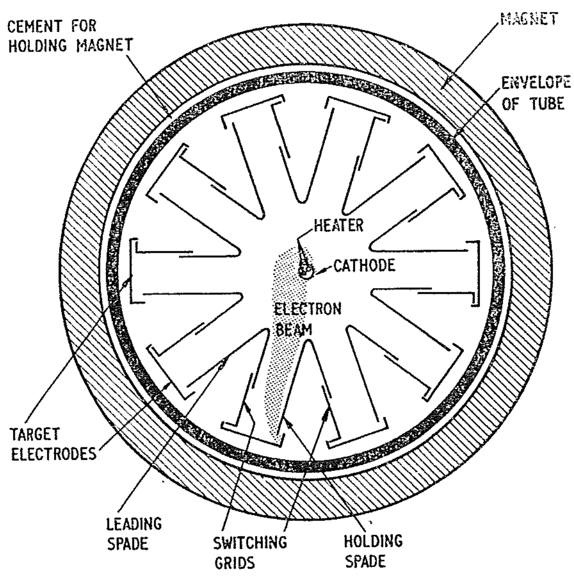


Fig. 6.3 A typical trochotron tube seen in cross section

6.2 TROCHOTRONS

Tubes operating on the trochotron principle were first described in 1947 by H. Alfvén[3, 4] who derived the name trochotron from the trochoidal path of the electrons in the mutually perpendicular electric and magnetic fields used in these devices. In some ways the trochotron resembles the magnetron valve in which similar perpendicular fields are used.

6.2.1 Construction

Several different basic designs of trochotron tubes are possible; for example, the linear or plane trochotron, the binary trochotron and the cylindrical trochotron. Trochotrons with two dimensional electrode structures have also been described[3]. This discussion will be limited to the cylindrical type, since the others are not generally available.

The shape of a typical trochotron, the Ericsson VS10G, can be seen in Plate 11, the magnet being cemented around the tube as shown. The dome is merely a cap which protects the vacuum seal. A cross sectional diagram of a typical Ericsson trochotron is shown in Fig. 6.3. The shape of the electrodes varies somewhat according to the type of tube; in particular, the Mullard and Burroughs tubes have rod shaped switching grids.

It can be seen from Fig. 6.3 that there are four different types of electrode in the tube. In the centre there is a cylindrical oxide coated cathode which is indirectly heated. Thirty electrodes are placed around this cathode as shown so that the tube as a whole is symmetrical. Ten of these electrodes are main anodes or target electrodes; they collect most of the electron beam and are used as output electrodes in most applications. The ten spade electrodes enable the beam to be formed and to be stabilised at any desired target electrode. The remaining ten electrodes are known as switching grids and are used to produce the distortion of the electric field in the tube which causes the switching action to occur. The five evenly numbered switching grids are connected to a common base pin and the five odd switching grids are also connected together. These two sets of grids are usually shown on the left-hand side of the circuit symbol (Fig. 6.4) for the tube, since the input is fed to them.

6.2.2 Operation

The basic circuit for the operation of a trochotron is shown in Fig. 6.4[5]. The same positive potential is initially applied to all of the target and spade electrodes whilst the switching grids are held at about

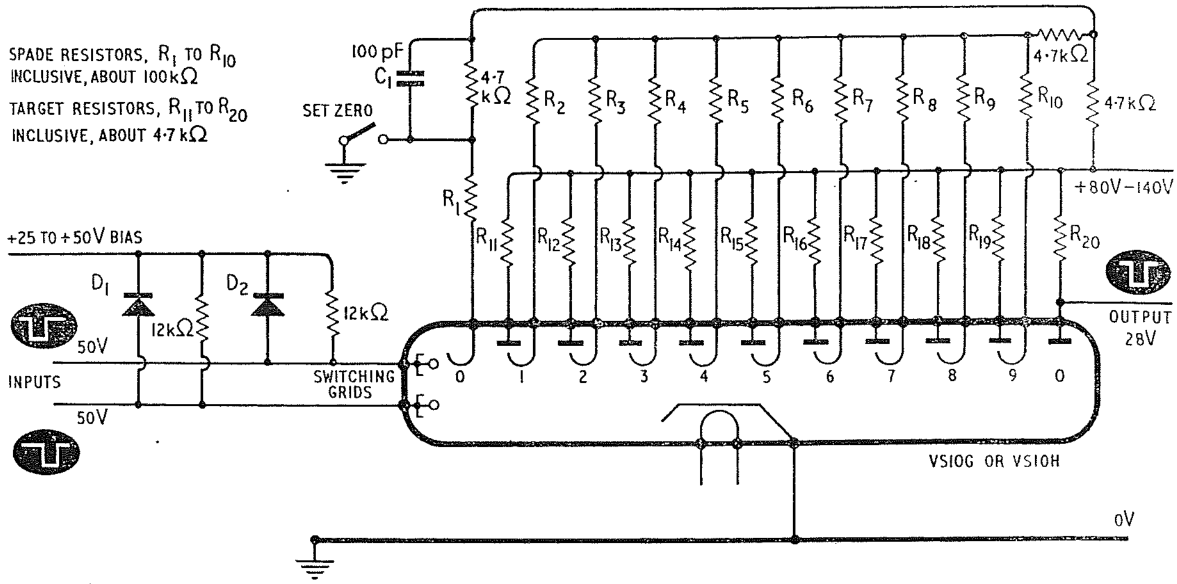


Fig. 6.4 The basic trochotron circuit with typical component values

half this voltage. The uniform magnetic field (normally some 200 to 500 Oersteds) is large enough to prevent electrons from reaching any of the electrodes surrounding the cathode when the normal working potentials are applied to the tube. The electric field is symmetrical and therefore the equipotential lines are concentric circles around the cathode. Electrons which leave the cathode will rotate around it following one of the equipotential lines. They form a space charge or virtual cathode. This is the cut off condition of the tube.

If the 'set zero' switch is closed momentarily, the potential of the zero spade will fall to that of the cathode, thus distorting the electric field. It is now possible for the electron beam to leave the cathode and travel along an equipotential line to the zero spade. Once the beam is within the enclosure formed by two spades, one switching grid and one target, the effect of the electric field becomes more important than that of the magnetic field and about 90% of the electrons pass to the target (which, of course, has a positive potential) as shown in Fig. 6.3. The remaining 10% pass to the spade electrode. Only a small fraction of the maximum possible cathode current is used to form the electron beam.

When the "set zero" switch opens again, the spade current will flow through the spade resistor. The voltage drop across this resistor results in the potential of the spade being held at a value which is not very different from that of the cathode and therefore the electrons can continue to flow along the equipotential line from the region of the cathode to the spade. Thus the beam is effectively locked at the zero position until the distortion of the electric field is altered by changing the switching grid potential.

6.2.3 Spade Characteristics

The action of the spade potentials can be studied more thoroughly by means of the characteristic curves. Curve I of Fig. 6.5 shows a typical spade current/spade voltage static characteristic for the holding spade[5] (the holding spade is the spade which is conducting). The potentials of the non-conducting spades, the targets and the switching grids are all held at a constant potential (often +100 V) relative to the cathode of the tube whilst the curve is being plotted. The peak of curve I occurs at about 2–3 mA for a typical trochotron. It should be noted that it occurs when the spade has a potential of approximately zero volts with respect to the cathode. At this potential the electrons can flow to the spade along the equipotential line in the same way that they could flow to the electrode P in Fig. 6.2.

A typical load line, *abc*, intersects curve I at three points. At point *a* the current is zero and the spade concerned has ceased to conduct. At point *b* the slope is negative. If the current taken by the spade should increase very slightly, the spade potential will decrease (owing to the voltage drop in the spade resistor) and this will cause a further increase of spade current which results in a cumulative effect. Similarly if the spade current decreases slightly, a cumulative effect will occur in the opposite direction. Thus the point *b* is unstable. Point *c* is the normal operating point of the conducting spade and is stabilised by feedback; if the spade current increases slightly in the region of point *c*, the spade potential will decrease and this tends to counteract the increase of spade current.

The upper dotted load line of Fig. 6.5 represents the minimum value of spade load resistor which should normally be employed. If a smaller value is used, the load line will be steeper and will no longer cut the characteristic at points such as *b* and *c*. The only stable operating point will therefore be at *a* where the spade current is zero.

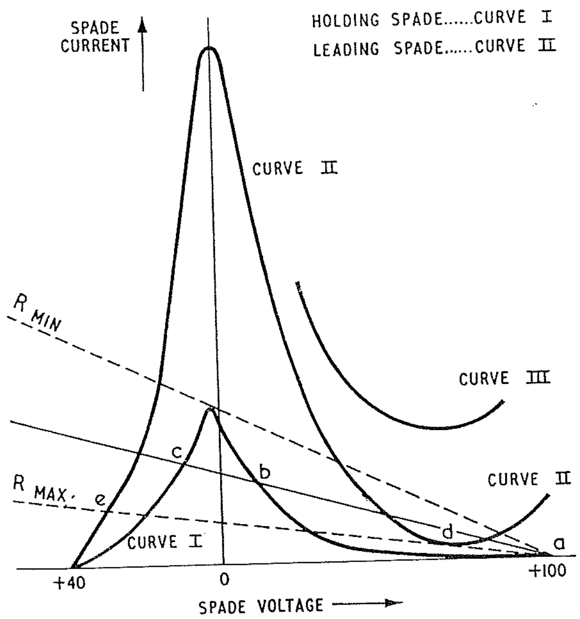


Fig. 6.5 Spade characteristics.

Curve II of Fig. 6.5 is the dynamic or leading spade characteristic curve. It is obtained by maintaining one spade (the holding spade) at the cathode potential and plotting the current/voltage curve for the succeeding spade whilst the targets, the switching grids and the other spades are kept at a constant potential (often +100 V) with respect to the cathode. The spade succeeding the holding spade is known as the leading spade. When the tube is switched, the leading spade becomes the holding spade and the characteristic of curve II is transformed into curve I at a rate which depends on the value of the spade load resistors and the stray capacity in the spade circuits.

The lower dotted line of Fig. 6.5 represents the maximum value of the spade load resistor which should be used. It is a tangent to the dynamic spade characteristic at point *d*. If a value of spade load resistor greater than that corresponding to the lower dotted line is employed, the load line would always intersect the leading spade characteristic at only one point, *e*, which will result in a continuous rotation of the beam.

The shape of the curves are altered somewhat by variations of the spade potentials. The maximum and minimum values of the spade resistors are therefore also functions of the spade supply voltage. If the supply voltage to the spades is steadily reduced, a point will be reached at which the beam will be extinguished. The extinguishing voltage, however, depends somewhat on the values of the spade resistors.

The holding spade potential may be negative with respect to the cathode by up to about 20 V[6]. Thus the electrons are flowing against the electric field and must be giving up energy to the field. Currents of this type are known as '*N*' (negative) currents. They arise from an interchange of energy between the electrons as a result of oscillations in the trochoidal beam[1, 2]. Electrons which gain energy reach the spade electrode in spite of the small opposing electric field. These electrons flow through the spade resistor and maintain its potential at a negative value with respect to the cathode. The holding spade voltage is dependent on the spade supply voltage and the value of the spade resistor employed.

6.2. Switching Grids

The switching grids are normally held at their quiescent positive bias potential. If the potential of the switching grids is lowered, the position of the equipotential lines in the region of the cathode is not appreciably affected owing to the screening effect of the spade electrodes. If the electron beam is passing to one of the target electrodes, however, the reduction of the potential of the associated switching grid will cause the equipotential lines to move across towards the grid so that the leading spade receives some of the beam current. The flow of current through the leading spade resistor lowers the potential of this spade which causes the equipotential lines to move further in a clockwise direction (in Fig. 6.3) so that the leading spade receives more current and falls further in potential. A cumulative action thus takes place which results in a rapid movement of the electron beam so that the leading spade momentarily takes the whole of the beam current. The magnetic field causes the beam to rotate to the side of the spade which is nearest to the target which is about to conduct. The spade potential falls and most of the beam passes to the target. The counting operation has now been completed.

It should be noted that this action can only be initiated by a lowering of the switching grid potential when the beam has already been formed at one target. Only the switching grid which is nearest the target at which the beam is resting produces any effect, since the other switching grids are screened from the electron beam by the spade electrodes.

If the potential of all the switching grids were lowered simultaneously, the beam would switch to its next stable position and would then continue to switch from target to target until the input pulse at the grids terminated. The frequency of rotation of the beam would be determined by the values of the resistors used in the spade circuits and by the stray capacitances. In order to prevent continuous switching, the switching grids are usually connected alternately in two groups of five. When a negative pulse is applied to one set of switching grids, the beam will move into the succeeding position but will not move any further, since the next switching grid is connected to the other set of guides and is not therefore receiving a negative pulse. The input switching pulses are applied alternately to the two sets of guides from a valve or transistor bistable circuit. Other methods of driving trochotrons will also be discussed.

The direction of rotation of the electron beam is determined by the polarity of the magnetic field and by the fact that the tube geometry is not symmetrical in each direction. The beam can move only in a clockwise direction in the trochotron of Fig. 6.3, the switching grids pulling the beam off the target towards the leading spade.

It is instructive to consider the effect of the switching grid potential on the shape of the leading spade characteristic (curve II in Fig. 6.5). If the potential of the switching grid is reduced, the tail of the leading spade characteristic is raised to a position such as that of curve III of Fig. 6.5. The load lines now cut the leading spade characteristic only at negative spade voltages. As the operating point moves towards a negative spade potential the tube is switched, therefore, to the next stable position.

The degree of lift of the tail of the leading spade characteristic for a certain negative switching grid pulse is a measure of the reliability of the switching process in the tube concerned and is determined mainly by the geometry of the switching electrodes. These electrodes may consist of flat plates or of small diameter rods. The flat plate type of switching grid (as used in Ericsson tubes and as shown in Fig. 6.3) has the advantage that it can produce a much greater lift of the tail of the leading spade characteristic and therefore an improved switching action[2], but it suffers from the disadvantage that it draws a current of a few hundred microamps during the switching operation. In addition, five of the plate type of switching grids connected in parallel have an input capacitance of about 25 pF and therefore a low impedance circuit must be used to drive this type of tube at high frequencies. The rod type of switching grid (such as used in the Mullard ET51 and in the Burroughs tubes) takes an almost negligible current and has a much smaller input capacity (five grids in parallel have a capacity of about 9 pF to earth); higher impedance drive circuits may therefore be used.

The quiescent switching grid potential or bias which is required is proportional to the spade supply voltage used. If the switching grids receive a positive bias which is too large, the input pulses which are used to overcome this bias and cause switching must be of larger amplitude. On the other hand if the bias is too low, the trochotron may switch automatically without any input pulses being applied. The flat plate type of switching grids requires a bias equal to about half the spade supply voltage, whilst the bias required for the rod type of switching grid is about one quarter of the spade supply voltage. Suitable switching grid bias voltages and input pulse voltages for the operation of various types of beam switching tubes are shown in Table 6.1.

The diodes D_1 and D_2 in Fig. 6.4 are used to clamp the switching grid voltage to the bias level; that is, they prevent the grids from becoming more positive than the potential of the bias supply.

6.2.5 Target Characteristics

The potential of the target electrodes has little effect on the beam current owing to the screening effect of the spade and switching grid electrodes. The target current/target voltage characteristic is therefore very similar to that of the anode current/anode voltage characteristic of a pentode valve. A prominent 'knee' is present in the target characteristic at a target voltage of approximately half the spade supply voltage(6). At target voltages above this knee the targets can be used as output sources of constant current; trochotrons are therefore ideal devices for driving numerical indicator tubes. The target loads should be chosen so that the targets do not operate below the knee of the characteristic, since the switching action of the tube is affected if the target current is not independent of the target voltage.

The magnitude of the target current is determined by the spade potential. The tube manufacturers normally attempt to obtain the maximum possible target current for a given spade voltage. At counting speeds greater than about 200 kc/s the target current will tend to decrease(6), since after each switching operation the holding spade voltage has to rise to the spade supply potential and this takes a short time. The effect is the same as if the spade supply voltage had been reduced. The drop in output current at 2 Mc/s is about 40% of the output current at low speeds. This fall in output can be reduced by using suitable circuits, for example the spade resistors may be returned to the corresponding targets instead of to the common voltage supply line. A lower value of spade resistor can then be used and this reduces the spade recovery time constant.

The maximum output voltage from a target is limited by the maximum permissible voltage across the tube and by the fact that the target voltage should not be allowed to fall below the knee of the characteristic (which is approximately half the spade supply voltage). The maximum pulse output voltage is thus equal to the maximum permissible target to cathode voltage minus half the spade voltage.

If the output pulse voltage from a target exceeds about 75 V, it is necessary to consider the effect of internal feedback via the inter-electrode capacities of the tube, since this may impair reliability. If the tube will not be required to operate at very high speeds, this feedback may be reduced by means of small capacitors (about 10 pF) connected across the spade resistors.

The target current will not be exactly the same at each position owing to small variations in the magnetic field strength and to small geometrical differences in the electrodes at various positions. This effect can be reduced by the use of a cathode resistor to raise the cathode potential to between 50 and 75 V above earth(2). The resistor should be by-passed by a capacitor of about 1,000 pF. The use of a cathode resistor enables circuits with directly coupled inputs to be designed more easily.

If an output pulse is required from only one target (e.g. for triggering the next decade), the other targets may be joined together and fed from a single resistor. Any target from which a separate output pulse is to be taken must have a separate resistor.

6.2.6 Leakage Currents

When the trochotron is cut off (that is, when the beam has not been formed in any position), the magnetic field should, in an ideal tube, ensure that no current passes to any of the spades or other electrodes. In actual tubes there are small leakage currents of the order of 5 μA per spade due to the following three factors. In a rotating space charge some of the electrons will gain sufficient energy from other electrons to enable them to reach the spade electrodes. In addition, further leakage currents arise from the slight non-uniformity of the magnetic field and from leakage across the external and internal connections to the tube.

The leakage current must not be large enough to cause an appreciable change in the spade potential when it flows through the spade resistor. The current tends to increase somewhat during life as the magnet ages, but if the magnet comes into contact with any magnetic materials, a large increase of the leakage current may occur and the performance of the tube may be impaired.

6.2.7 Maximum Speed of Operation

The British trochotron tubes which are commercially available have a nominal maximum continuous operating speed of 1 or 2 Mc/s. The Burroughs MO-10R tube and its magnetically shielded version, the BD309, will operate at frequencies up to 10 Mc/s; the spade resistors of these particular tubes, however, are included inside the evacuated envelope in order to reduce the stray capacities to a minimum.

It has been shown[2] that a trochotron with a maximum continuous counting speed of 2 Mc/s has a typical resolving time of about 0.16 μsec when up to nine pulses are to be counted. The maximum continuous operating speed is, however, determined by the time taken by the spade electrodes to reach their quiescent potential after a switching operation. Calculations show that a maximum continuous operating speed of about 3.7×10^6 pulses per second may be expected[2]. Speeds of about this value are obtained when the switching grids are all connected to the cathode and the electron beam is allowed to rotate freely, but in actual counting circuits a lower limit is imposed on the maximum continuous counting speed so that there is no possibility of the beam being extinguished.

6.2.8 Reset

If the beam is formed at any target and it is desired to reset the trochotron, the tube must first be returned to the cut off condition. The beam may then be reformed at the zero target or at any other desired target. The 'set zero' switch of Fig. 6.4 can be used to carry out both of these operations. When this switch is closed, the spade potentials are all momentarily reduced to the cathode potential (owing to the effect of C_1) and the beam is cut off. As C_1 charges, the potentials of spades one to nine inclusive increase to about half the supply voltage. The zero spade remains at the cathode potential and the beam therefore forms at this electrode. When the set zero switch is released, spades one to nine return to the H.T. supply potential immediately, but the capacitor C_1 delays the rise of the potential of the zero spade and ensures that the electron beam remains in the zero position.

If the trochotron is fed from a bistable circuit, the latter must be reset before the trochotron beam is formed in the zero position, or the tube may switch to position one.

6.2.9 Practical Precautions

Magnetically shielded versions of some types of trochotron tubes are available (see table of tube data). These shielded versions are of larger diameter, somewhat more expensive and about three times heavier than the unshielded tubes, but they have the advantage that they can be used in magnetic fields and in close proximity to magnetic materials (including other trochotron tubes). The shielding is achieved by the use of a mu-metal screen and a tapered magnet. The following precautions concerned with the operation of trochotron tubes in magnetic fields or near to magnetic material apply only to unshielded tubes.

A magnetic field strength of less than about 25 Oersteds will generally cause a negligible effect on the operation of a trochotron, whilst field strengths from about 25 to 50 Oersteds will cause changes in the tube currents without impairing the functioning of the tube[6]. Field strengths above about 50 Oersteds will probably affect the operation of the tube.

Care should be taken that the magnet of a trochotron tube does not receive any mechanical shock and that no magnetic material comes into contact with it. Unshielded tubes should not be mounted within 2 in. of any magnetic material or within 4 in. of another trochotron, a magnet or a mu-metal screen.

If the tubes are placed end to end, they may be spaced somewhat closer than the recommended 4 in. When placed end to end with the magnetic fields of the two tubes assisting each other, the magnets should be separated by a distance of at least 3 in. Generally, however, it is more convenient to place them end to end with their magnetic fields opposing each other, since the base connections of the two tubes are then at opposite ends of the combination. In this case the separation between the magnets may be as low as 2 in.[6] which results in a separation of about $^1/_4$ in. between the domes of the tubes.

Trochotrons may be mounted through a steel panel or chassis provided that they are inserted in holes which are not less than $2^1/_8$ in. in diameter and provided that they are placed in the hole so that the steel panel is within $^1/_4$ in. of the centre of the tube magnet[6].

The spade resistors should be soldered as closely as possible to the base of the tube so that stray capacities are reduced to a minimum. If the stray spade capacities are appreciably increased by poor circuit layout, the maximum operating frequency will be reduced. Care should also be taken that the values of the spade resistors and of the spade supply voltage are suitably chosen or the tube may either oscillate or not switch at all.

6.3 TROCHOTRON CIRCUITS

6.3.1 Drive Circuits

There are three basic ways in which the input voltages required for the operation of trochotron tubes may be obtained. If the input is a sine wave, the type of circuit shown in Fig. 6.6 may be employed[2, 6]. It has the advantage of being very simple, but the switching rate is twice the input frequency since both the positive and negative peaks of the sine waves are counted. The output of the centre tapped secondary winding of the high frequency transformer is 50 – 0 – 50 V.

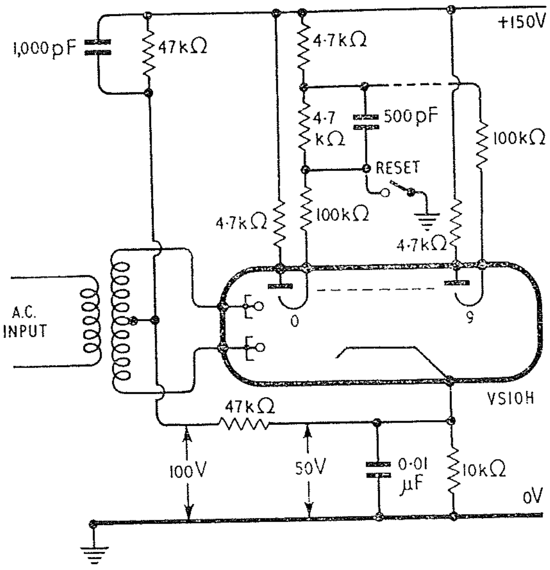


Fig. 6.6 A sine wave input circuit for a trochotron

Another type of trochotron drive circuit is shown in Fig. 6.7[2, 6]. The two sets of switching grids are connected together and small capacitors (marked C) may be connected from each spade to earth so that the switching speed of the tube is deliberately reduced. The input pulses for the switching grids may be obtained from the blocking oscillator circuit shown. It is essential that the duration of the pulses to the switching grids be kept shorter than the switching time of the tube so that double switching on one input pulse cannot occur; the output from the blocking oscillator satisfies this condition. This type of circuit is known as discrete or single pulse drive. The potential divider resistors marked R_1, R_2 and R_3 should be chosen so that their junctions have the potentials marked in the circuit diagram.

The most common type of trochotron input circuit employs a bistable multivibrator circuit, the two sets of switching grids of the trochotron being fed from the two anodes of the multivibrator. Each input pulse reverses the state of the bistable circuit so that the potential of one set of switching grids is lowered at the same time as the potential of the

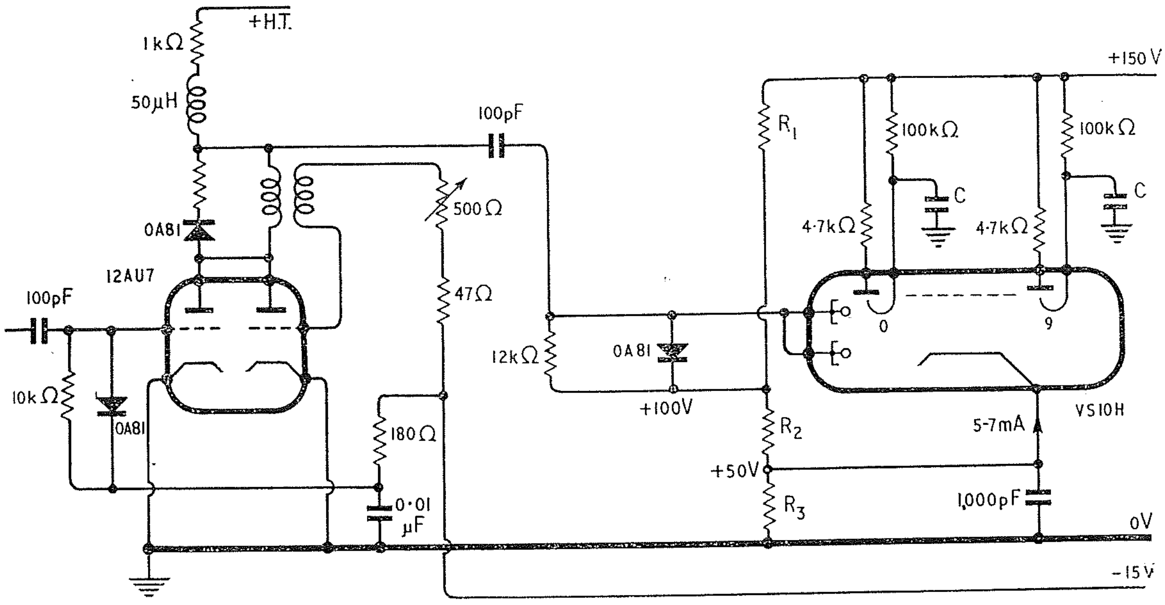


Fig. 6.7 A discrete pulse drive circuit for a trochotron

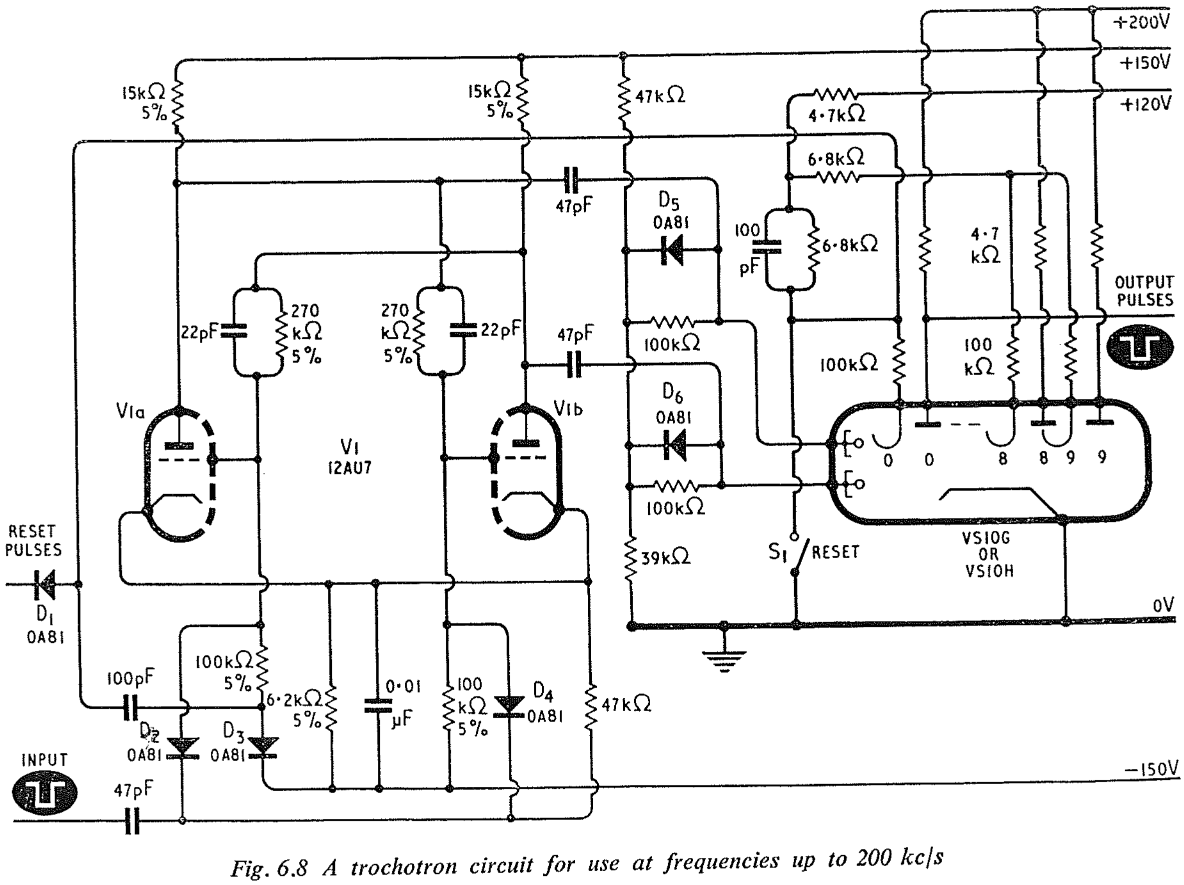


Fig. 6.8 A trochotron circuit for use at frequencies up to 200 kc/s

other set is raised. A circuit of this type which can operate at frequencies up to about 200 kc/s is shown in Fig. 6.8[7].

The negative going input pulses to the multivibrator circuit of Fig. 6.8 should have a minimum amplitude of about 10 V and a minimum duration of about 2 μsec. The negative going output pulses have an amplitude of about 35 V; if they are to be used to drive a second identical decade, the resistor in the zero target circuit may be replaced by a 3.3 kΩ and a 1.5 kΩ resistor placed in series, the 3.3 kΩ resistor being connected to the target. The output may then be taken from across the 1.5 kΩ resistor and will consist of the required pulses of about 10 V in amplitude for the operation of the next decade. The diodes D_2 and D_4 enable the input pulses to be fed to the valve grids whilst isolating the grids from each other. The diode D_3 normally returns the grid of *V*1a to earth, but when a resetting pulse is received D_3 is cut off so that the pulse is fed to the grid of *V*1a. The bistable circuit is thus reset with the trochotron tube reset pulse. The diode D_1 prevents a negative pulse from the grid of *V*1a from being fed into the bistable circuit of another decade where it would trigger the latter. The manually operated reset switch also resets both the trochotron and the bistable circuit.

If a trochotron which employs the flat plate type of switching grid is to be used at frequencies above about 200 kc/s, the grids of the tube should be fed from low impedance sources (such as power amplifier tubes or cathode followers) which can supply the current required by the switching grids, including that required to rapidly charge the switching grid capacitance.

Fig. 6.9 shows a circuit which can drive the VS10H at frequencies up to the maximum recommended for the tube, namely 2 Mc/s[2, 8]. The negative going input pulses should have an amplitude of not less than 15 V and a duration of not less than 0.25 μsec. They are fed via two diodes to the grids of the bistable circuit, *V*2 and *V*3. The outputs from this circuit are fed into *V*4 and *V*5 which are EL821 power amplifier valves in a push-pull circuit. These tubes can provide ample current to feed the switching grids of the VS10H even at high operating speeds. The EB91 diode, *V*6, serves to clamp the switching grid potential to that of the cathode of the GD90M voltage stabiliser tube.

The circuit of *V*1 in Fig. 6.9 enables the trochotron to be reset electronically. The positive going reset pulses of 50 V amplitude and not less than 1.5 μsec duration are fed to the grids of *V*1a and *V*1b. The output from the anode of *V*1b is used to reset the bistable circuit (*V*2 and *V*3) and also to reset the trochotron by the same mechanism as that used in the circuit of Fig. 6.8. The output from the anode of *V*1a can be used to reset a succeeding decade. A manual reset switch is also provided.

If the circuit is operating at its maximum frequency of 2 Mc/s, the output pulses will have a frequency of 200 kc/s and can be counted by the circuit of Fig. 6.8. The amplitude of the output pulses from the circuit of Fig. 6.9 is too large for feeding into the circuit of Fig. 6.8 directly, but a tapping may be made on the zero target resistor of the Fig. 6.9 circuit so that the desired fraction (about one eighth) of the output pulse may be obtained for feeding into the input stage of the next decade.

6.3.2 Readout

The target current of a trochotron may be used to operate a relay, a miniature neon diode in series with the target electrode, a transistor which switches on a lamp, etc., but normally readout is effected by means of a cold cathode indicator tube. The target current of a trochotron is almost independent of the target voltage provided that the tube is operated above the knee of the target characteristic; a trochotron is a very suitable device for driving a numerical indicator tube, since the operating voltage of the latter is substantially independent of the current over the working range.

A circuit for the operation of the GR10A indicator tube is shown in Fig. 6.10[5, 9]. This tube has the same type of display as the cold cathode counting tubes discussed in Chapter 4 and is therefore very useful when the trochotron circuit is followed by cold cathode decade tubes. The input circuit of Fig. 6.10 comprises a bistable circuit which is directly coupled via a cathode follower to the VS10G. The low impedance of the cathode follower provides enough switching grid current to drive

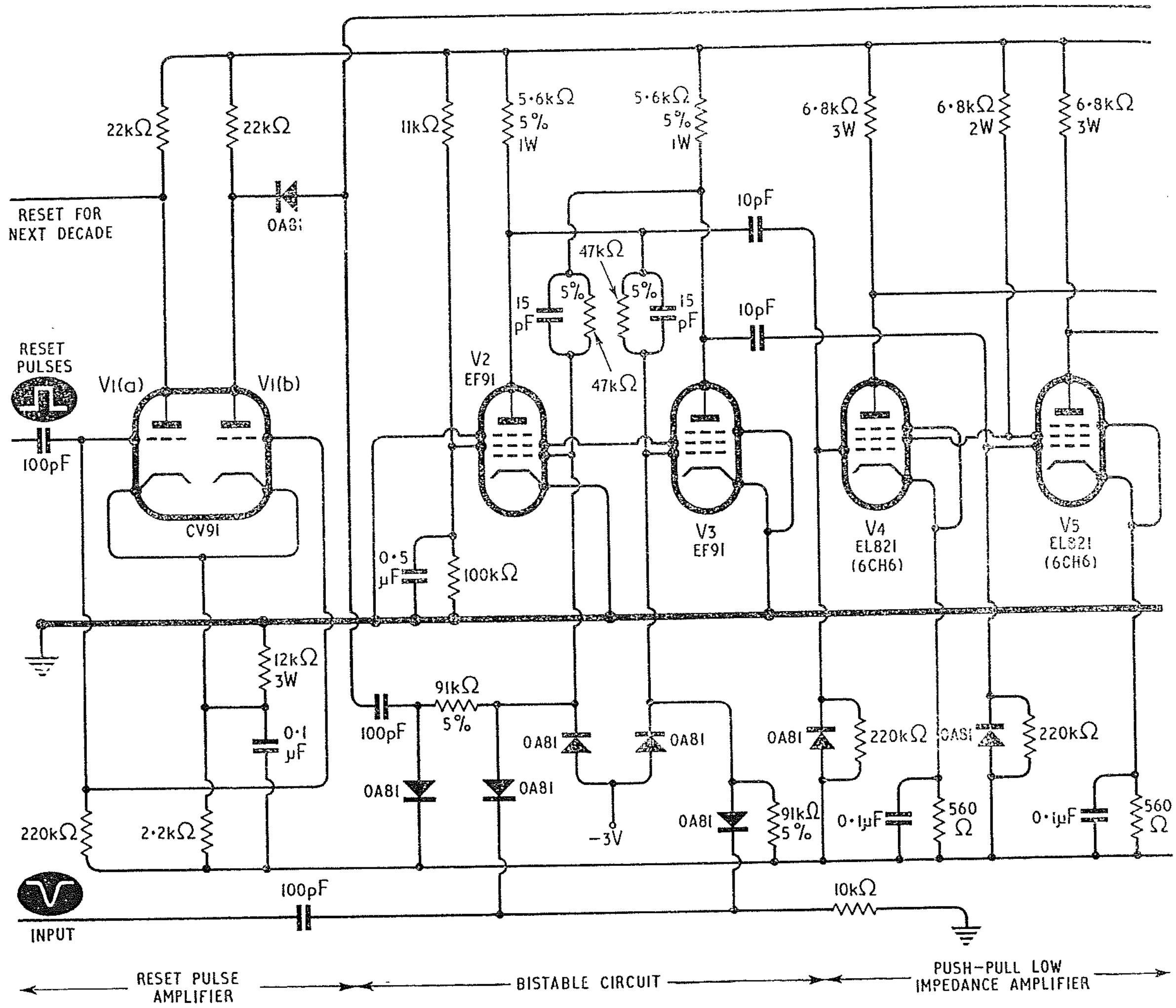
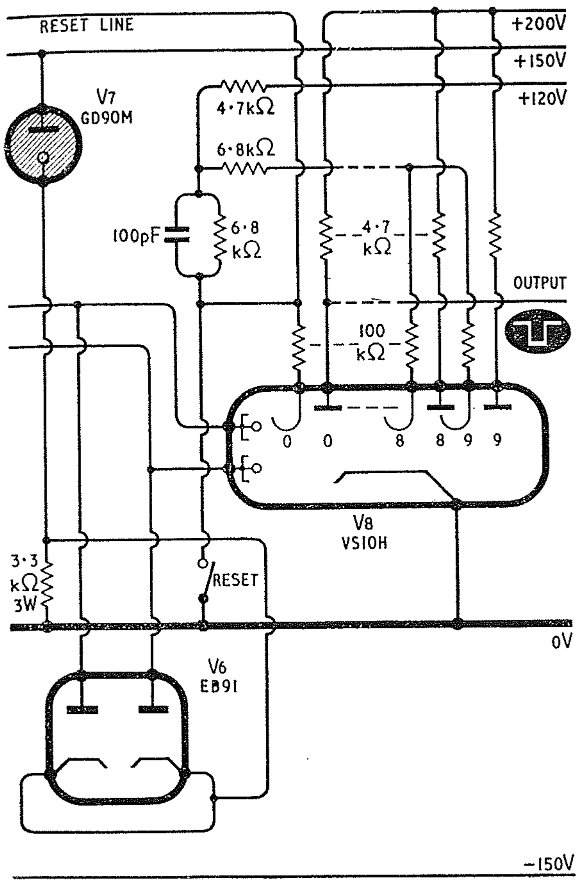


Fig. 6.9 A VS10H circuit for operation at up to

the trochotron at any frequency up to the maximum recommended for the tube (1 Mc/s). The current flowing through the cathode resistor enables a suitable value of the switching grid bias to be obtained and also stabilises the value of the trochotron cathode current. The input pulses to this circuit should have an amplitude of 30 V and a duration of not less than 0.2 µsec.

In the circuit of Fig. 6.11(a), a VS10G trochotron is used to drive the Ericsson GR10G side viewing Digitron numerical indicator tube[10], whilst in the circuit of Fig. 6.11(b) a VS10H tube is used to drive the GR10H end viewing Digitron[11]. Any of the input circuits discussed previously may be used with these circuits. The GR10H requires a smaller current than the GR10G.

In such circuits the Digitron is extinguished when the operating frequency of the trochotron exceeds about 200 kc/s, but as soon as the counting speed falls, the Digitron will indicate the correct count. In order to ensure that the trochotron operates on the constant current part of the target characteristic, the circuit must be arranged so that the target voltage never falls below half the spade supply voltage even if the Digitron current is zero during high speed counting. The targets must therefore be supplied with current from an H.T. line as well as from the Digitron. A potential of about 100 V is maintained



2 Mc/s with electronic and manual reset

permanently across the Digitron. The additional voltage drop in the target resistor which is conducting is sufficient to cause the appropriate Digitron cathode to conduct. The target current divides itself between the target resistor and the Digitron. The anode resistor of the Digitron may be omitted in some cases, but this may restrict the choice of circuit values.

The value of the target resistors required in circuits employing Digitrons and trochotrons (such as those of Fig. 6.11) may be calculated as follows. If:

V_T = target supply voltage
V_D = digitron anode supply voltage
I_D = digitron current
R_D = digitron anode resistance (if used)
V_R = digitron maintaining voltage
I_T = trochotron target current

Target to cathode voltage $= V_T-(I_T-I_D)R_T =$
$= V_D-I_DR_D-V_R$

$$\text{Hence } R_T = \frac{V_T-(V_D-V_R-I_DR_D)}{I_T-I_D}$$

It is also important that R_T should be less than $\frac{V_T-0{\cdot}5V_S}{I_T}$ where V_S is the spade supply voltage, or the trochotron target current will not be independent of the target voltage.

6.3.3 The VS10K

The VS10K trochotron is a low voltage tube with flat plate switching grids which has been designed for use with transistor drive circuits. The magnetic field strength is about half that used in the higher voltage tubes, and the target current is about 2 mA.

A typical VS10K circuit which can operate at frequencies up to about 1 to 1.5 Mc/s is shown in Fig. 6.12[6, 12]. This circuit operates from a 28 V supply. The input pulses (of about 10 V amplitude and 0.25 μsec duration) are fed to a bistable circuit employing 2N269A or ASZ20 transistors which drive the trochotron. If the left-hand transistor is conducting, the potential drop across its collector resistor will keep the base of the other (non-conducting) transistor relatively positive. Positive going input pulses will reach only the base of the conducting transistor, since the OA81 diodes in the input circuit prevent them from reaching the more positive base of the non-conducting transistor. The pulses from the output target are inverted in phase by a third 2N269A or ASZ20 transistor so that they are suitable for the operation of a similar succeeding decade. The reset switch will reset both the bistable circuit and the VS10K.

If some form of readout is required, an OC76 transistor may be used in any target circuit to switch on a small 6.3 V tungsten filament bulb as shown in the inset of Fig. 6.12. Alternatively, the trochotron

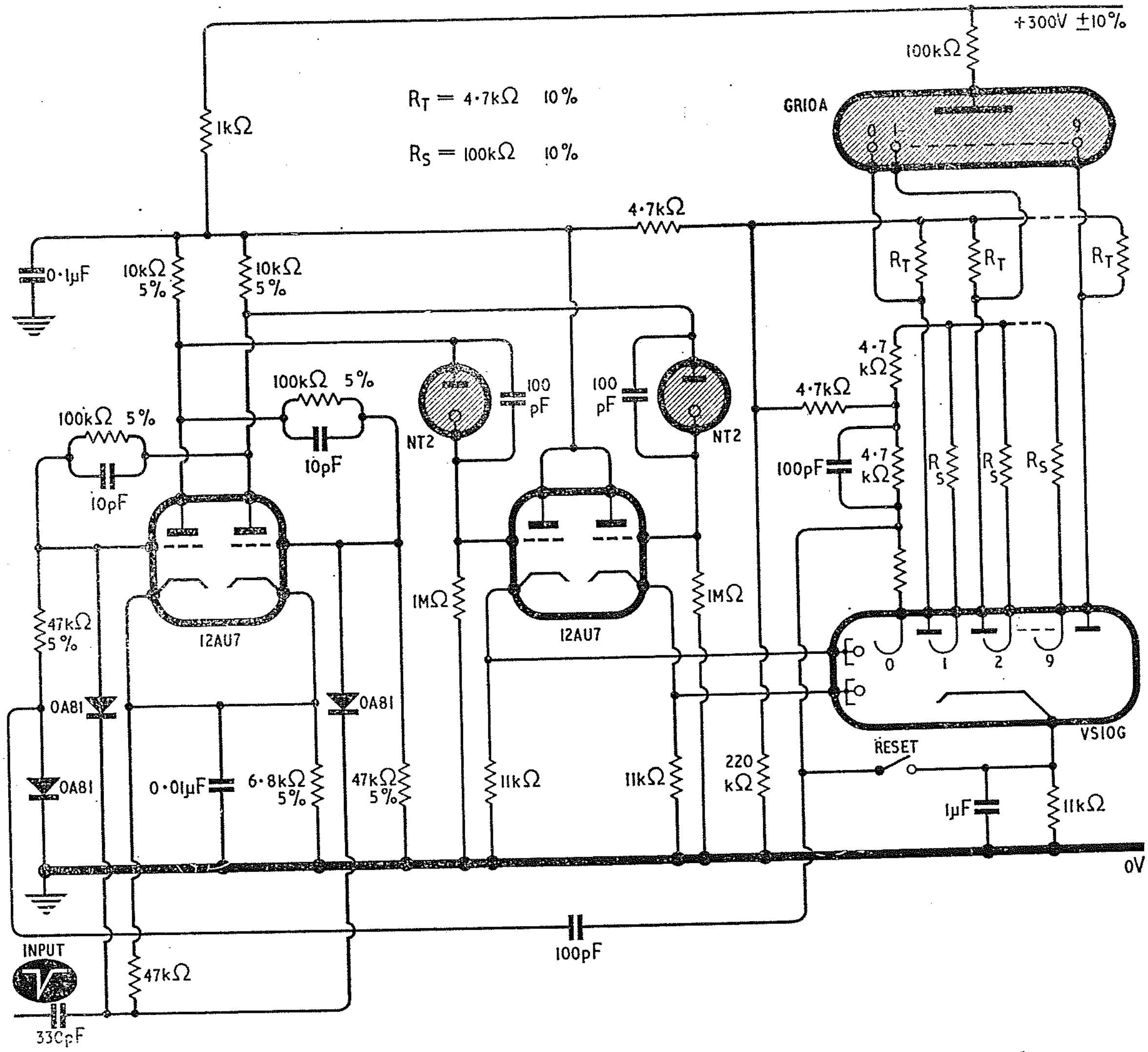


Fig. 6.10 A 1 Mc/s trochotron circuit driven by a cathode follower stage with GR10A readout

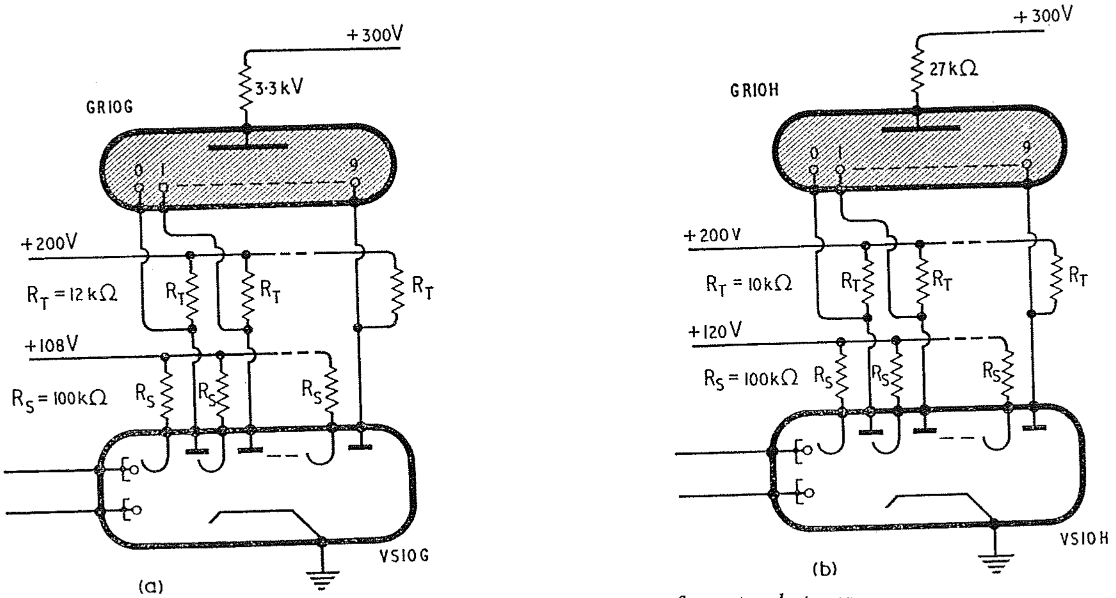


Fig. 6.11 The operation of Digitrons from trochotrons

may be used to control an OC76 transistor which operates a relay as shown. A diode is placed across the relay to remove inductive surges.

If a transistor driven VS10K circuit is required to operate a Digitron tube, a high voltage supply is essential. A typical circuit is shown in Fig. 6.13 in which two OC44 transistors are used in a bistable circuit to drive the VS10K at up to 200 kc/s[5]. The spade resistors are by-passed with 12 pF capacitors in order to reduce the interaction between the target pulses and the spade circuits. The beam may be formed by closing S_1.

If Digitron readout is required from a trochotron circuit, one of the high voltage trochotron tubes is normally used as a high voltage supply is available.

6.3.4 Fast Electronic Resetting

The circuit of Fig. 6.14 can be used to rapidly reset a trochotron by means of a negative going resetting pulse of about 30 V in amplitude and 1 msec in duration[6]. Normally the cathodes of the 12AU7 tube and the trochotron have a potential of about +50 V with respect to earth, whilst the grid of the 12AU7 is maintained at about +20 V above earth. The 12AU7 is therefore cut off.

When the EL821 is cut off by the resetting pulse, the trochtron is also cut ofi. The common cathode potential of the trochotron and the 12AU7 falls until the triode conducts. The zero spade is reduced to a low potential by the flow of the triode anode current through the spade resistor and this results in the beam being formed at the zero spade. The 12AU7 is then cut off again. The resistor values shown are suitable when a Digitron is employed, but they may be altered according to the circuit being used. If the trochotron cathode current is less than 8 mA, the other half of the 12AU7 may be used in place of the EL821.

6.3.5 Presetting

Outputs may be taken from one preselected target in each decade and fed into a coincidence circuit (somewhat similar to that of Fig. 3.20) so that an output pulse is obtained only at the preselected count. Alternatively the beam in each tube may be formed at any desired target. If the beams of a three decade scaler are preset to, say 628, an output pulse will be obtained after 1,000–628 = 372 input pulses have been fed to the circuit.

6.3.6 Coupling to Dekatrons

It is often desirable to use a fast trochotron circuit to drive a suceeding slower (but more economical)

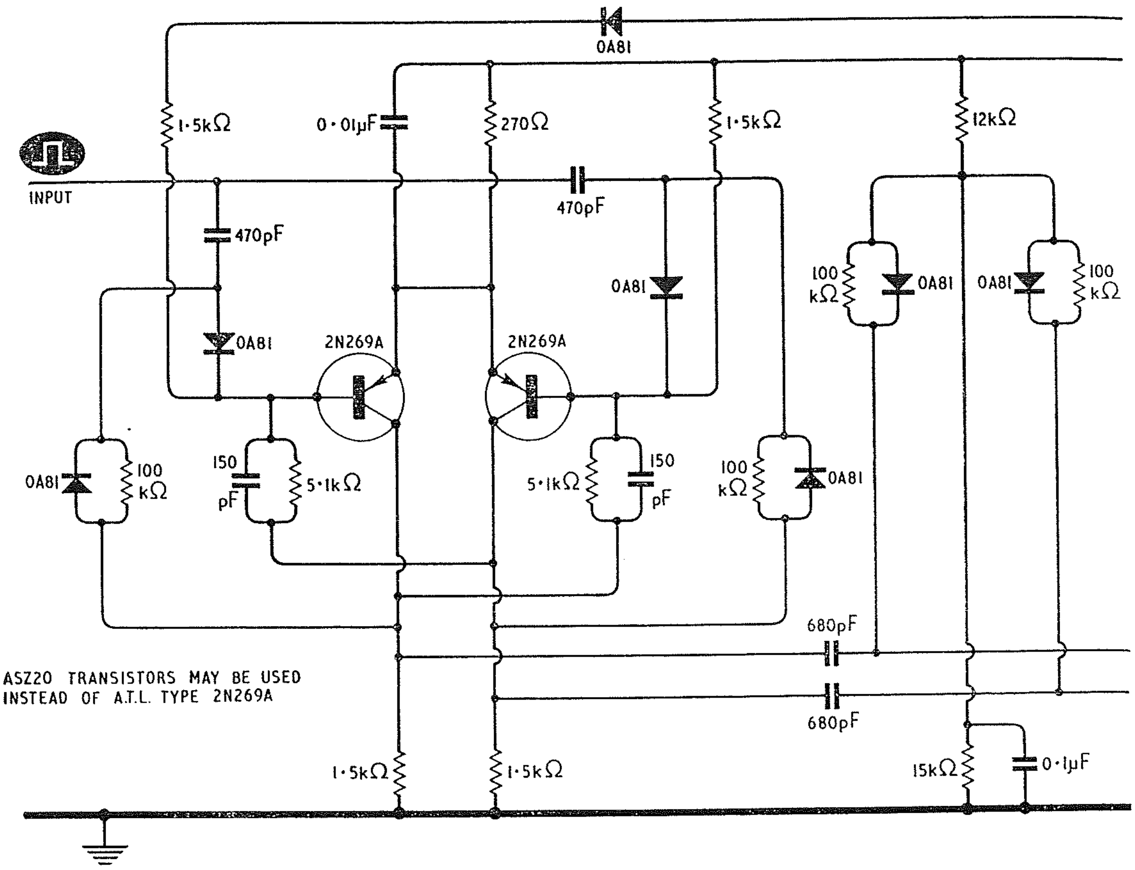
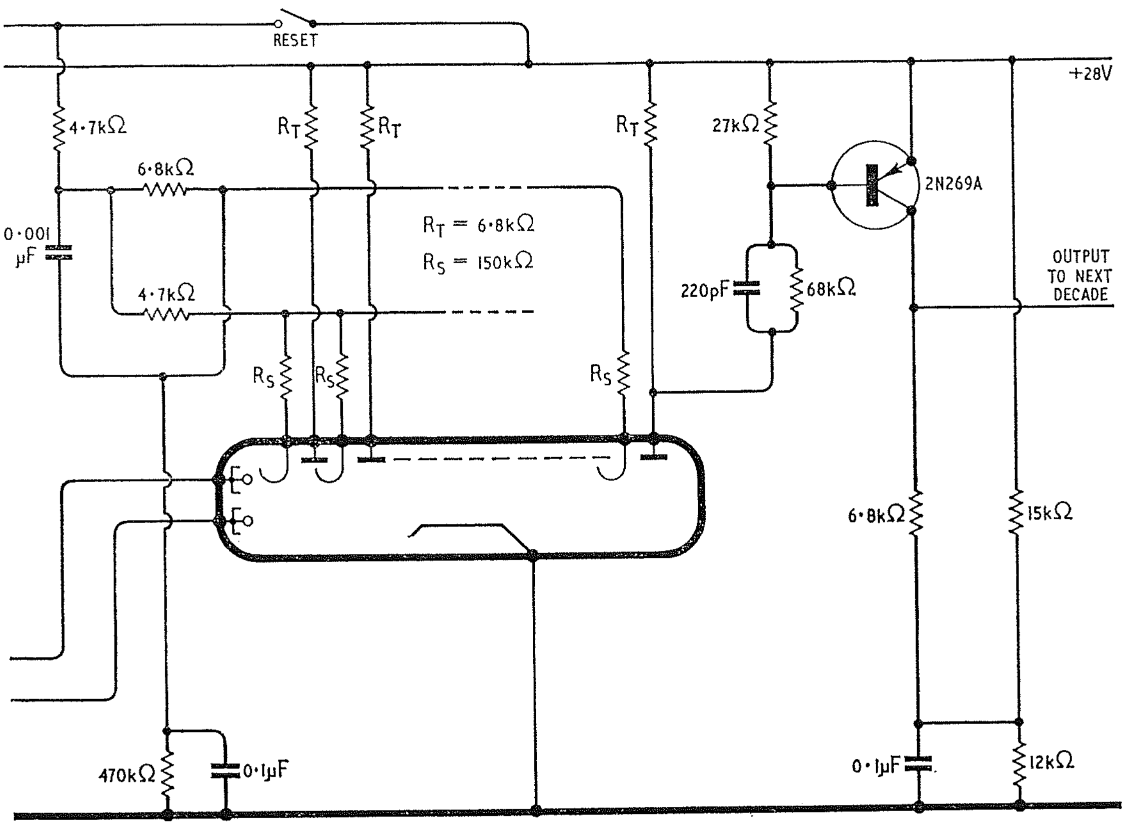
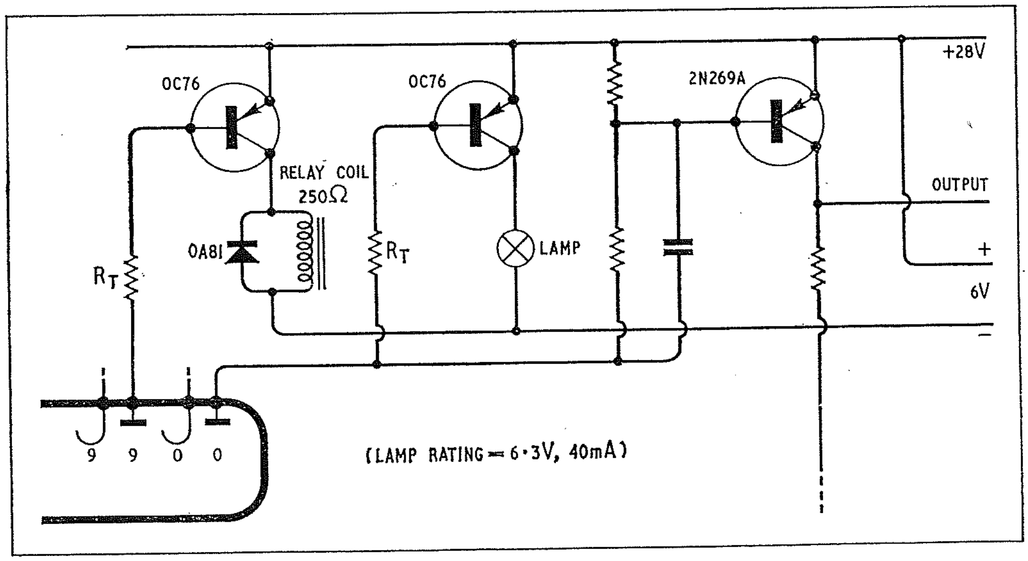


Fig. 6.12 A 1 Mc/s transistor circuit using the low voltage VS10K tube


RESET
+28V
4·7kΩ
6·8kΩ
R_T
R_T
R_T
27kΩ
2N269A
0·001 μF
R_T = 6·8kΩ
R_S = 150kΩ
4·7kΩ
220pF
68kΩ
OUTPUT TO NEXT DECADE
R_S
R_S
R_S
6·8kΩ
15kΩ
470kΩ
0·1μF
0·1μF
12kΩ


+28V
OC76
OC76
2N269A
RELAY COIL 250Ω
OUTPUT
OA81
R_T
R_T
LAMP
+
6V
−
9
9
0
0
(LAMP RATING = 6·3V, 40mA)

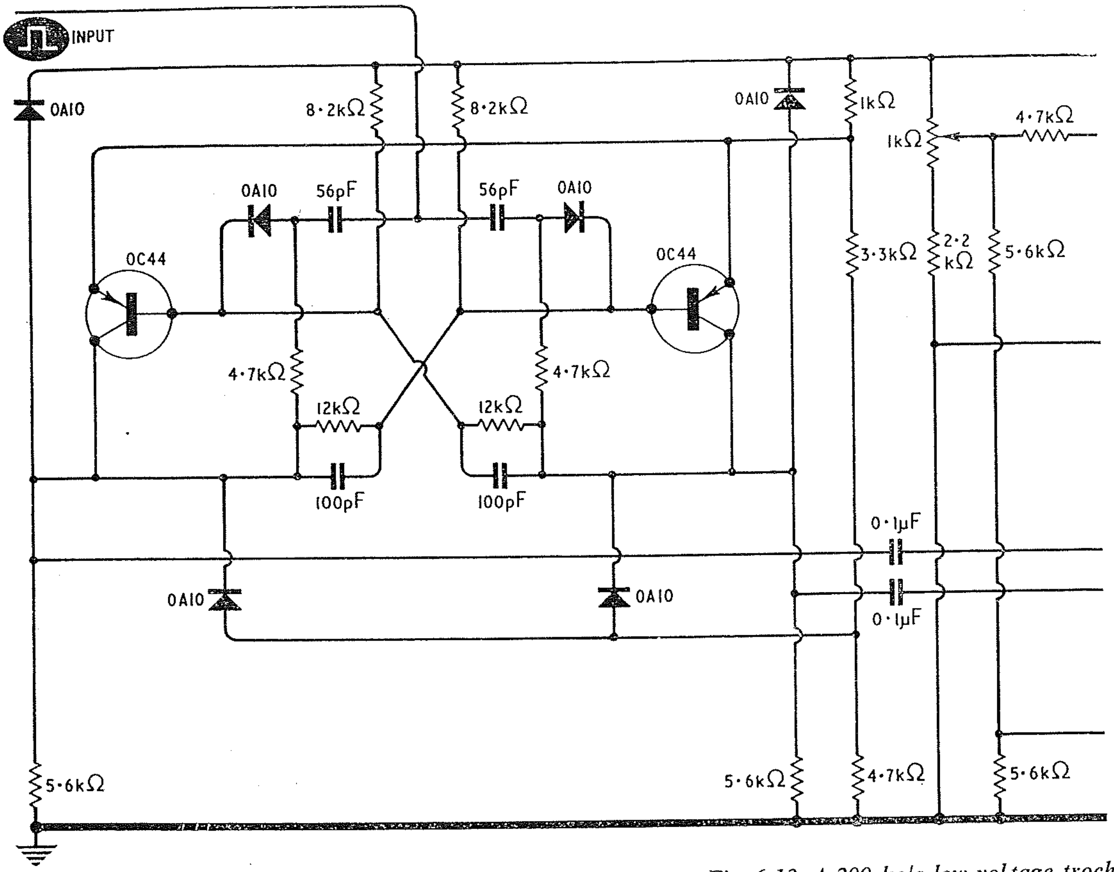


Fig. 6.13 A 200 kc/s low voltage trochotron

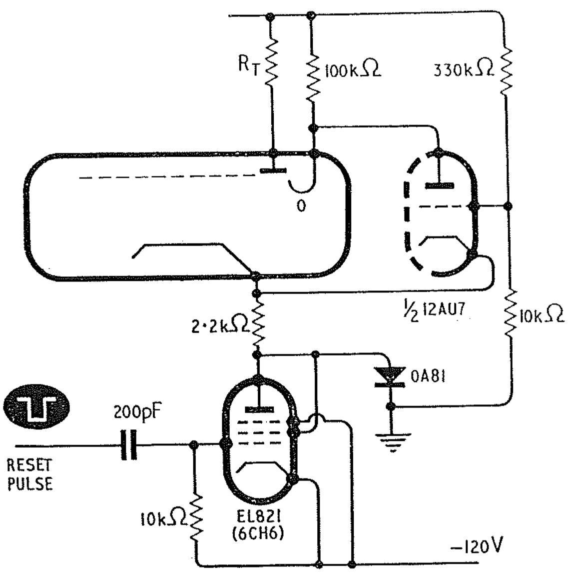
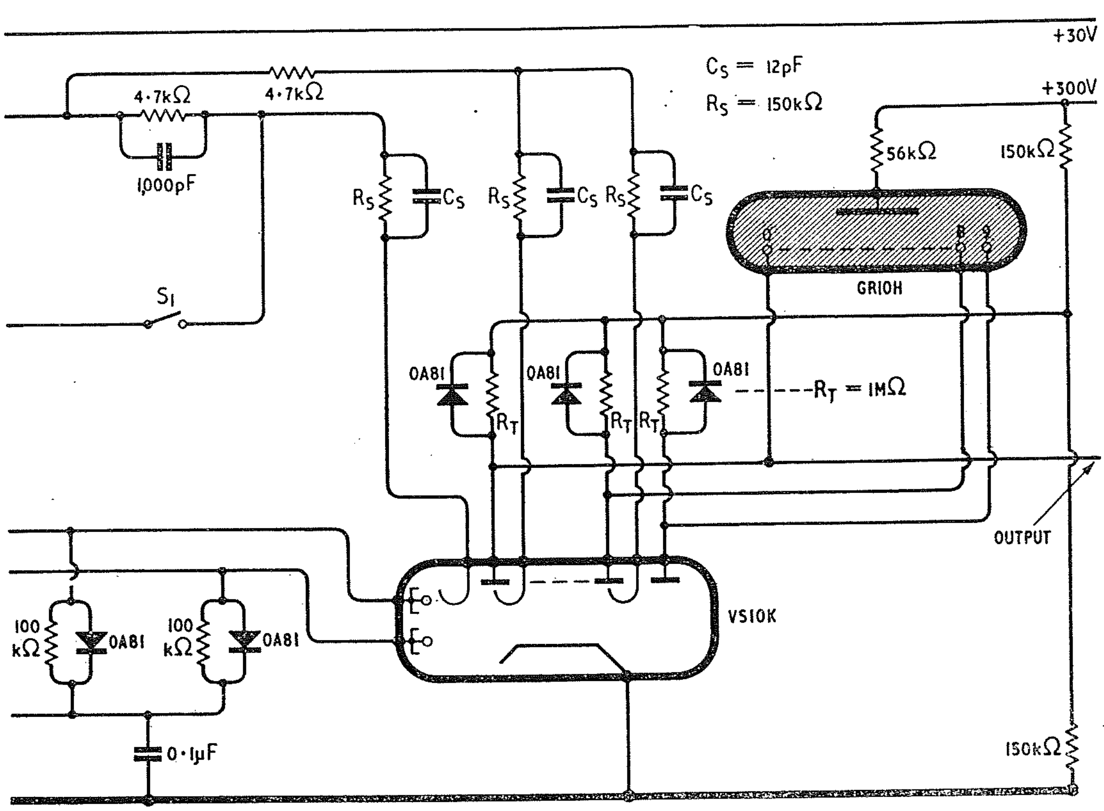


Fig. 6.14 An electronic resetting circuit

cold cathode decade tube circuit. The pulses from the trochotron output target will vary with the counting speed and will not in general be suitable for driving a cold cathode decade tube directly. The circuit of Fig. 6.15[6] may be used to convert the output pulses from the trochotron into pulses of about 140 V in amplitude and of about 25 µsec duration which are suitable for driving a GC10D single pulse Dekatron. The value of the coupling capacitor (100 pF in the circuit shown) may be altered so as to provide pulses of a different duration which are suitable for operating other types of cold cathode decade tube.

Normally the right-hand triode is conducting whilst the left-hand triode is cut off by the bias developed across the common cathode resistor. The trochotron output pulse is coupled to the grid of the right-hand triode and cuts it off. The OA81 diode prevents the trailing edge of the pulse from the trochotron from causing the monostable circuit to return prematurely to its quiescent state.



circuit with GR10H readout

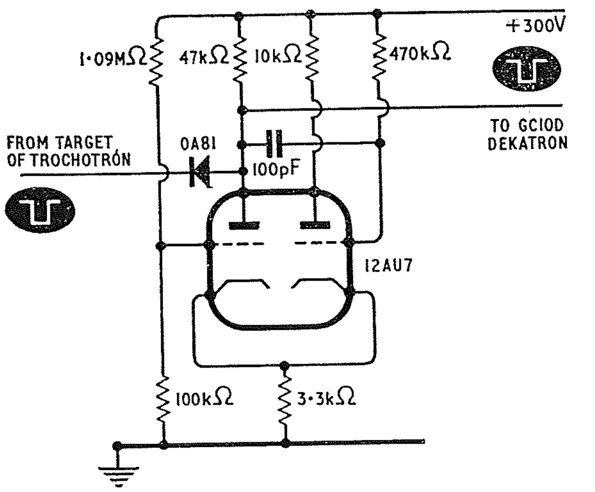
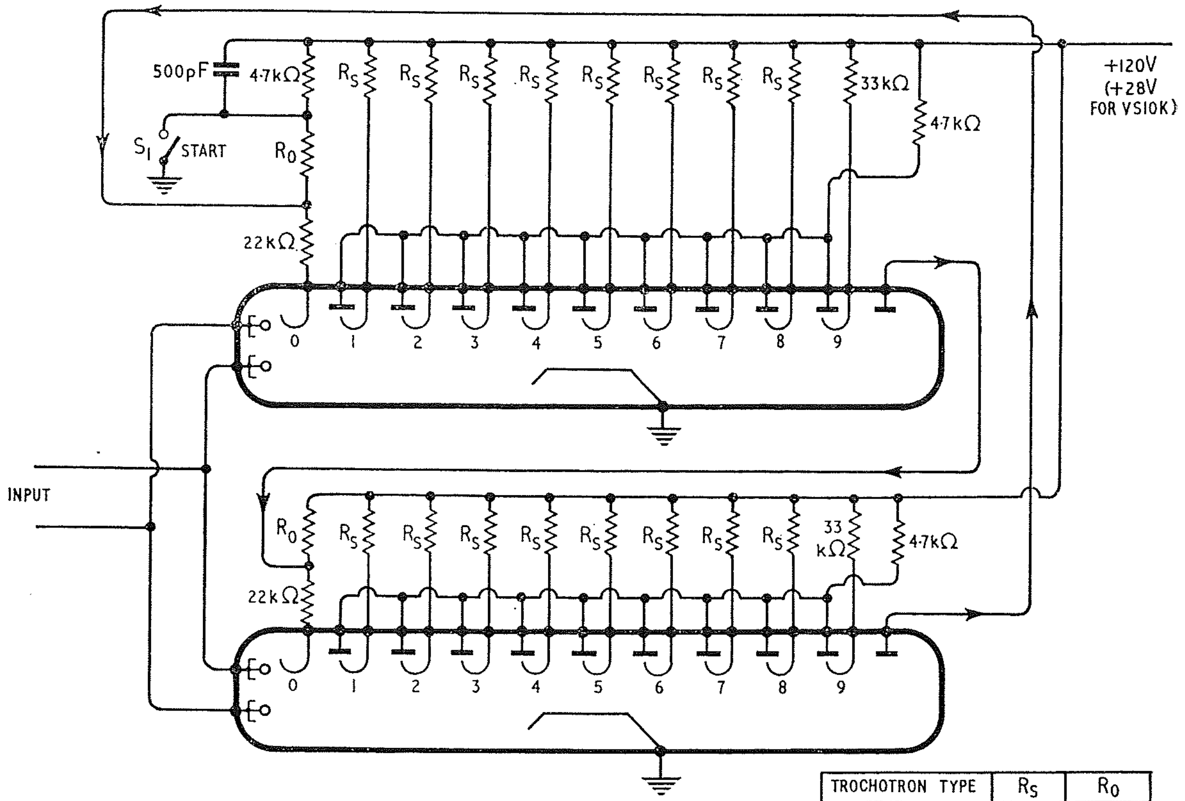


Fig. 6.15 A circuit for coupling a trochotron to a GC10D Dekatron

6.3.7 Scaling Factors Other than Ten

Although basically intended for use as a decade tube, trochotrons can be used to divide the incoming pulses by various factors other than ten. For example, if targets 0 and 5 are joined together and all of the other targets are also joined, the circuit will divide the incoming pulses by five. The output is taken from the common connection to the targets 0 and 5. Similarly if alternate targets are connected together so as to give two separate groups of five targets per group, the circuit will divide by two[6]. Each group has its own target resistor.

If spade 4 is connected to spade 5, when the beam moves from spade 3 to spade 4, the potential of spades 4 and 5 will be lowered. Thus the beam will switch to position 5. Unless the input pulse is extremely short, the fifth switching grid will still be at a low potential, since it is connected to the odd grids. The beam will therefore move to position 6. Thus a scale of eight has been formed.



TROCHOTRON TYPE	R_S	R_0
VS10G, VS10H	100kΩ	82kΩ
VS10K	150kΩ	120kΩ

Fig. 6.16 A scale of eighteen circuit using two trochotrons

The circuit of Fig. 6.16 may be used to extend the number of stable positions up to 18[2, 13]. A third trochotron could be included in the ring to provide up to 27 stable positions. The ninth spade resistor of each tube has a smaller value than the other spade resistors so that the slope of its load line (Fig. 6.5) is greater than the maximum value for normal operation (R_{min}) but is small enough to cut the leading spade characteristic (curve II). When the beam reaches the ninth position, the target current flows for an instant and then the beam is extinguished in this tube. The pulse from the target is used to reduce the potential of the zero spade in the second tube so that the beam is formed in this tube. When the beam reaches the ninth spade in the second tube, it is automatically extinguished and a beam is re-formed in the first tube at the zero spade by the same process as that already discussed. The switching action from tube to tube is very fast. A switch to form the beam in the first tube (S_1) is required. One of the input circuits discussed previously can be used, but it should be remembered that if several trochotrons are connected together in this way to obtain a large scaling factor, the input capacitance will be relatively large and a low impedance driving circuit will be required at high frequencies.

Any desired scaling factor can be obtained using trochotrons by combining the circuit techniques described above.

6.3.8 Circuits for Tubes Using Rod Shaped Switching Grids

The same basic circuits as those already described may be used for tubes which employ rod shaped switching grids, but the component values will be slightly different and rather less switching grid driving power will be required. The circuit of Fig. 6.17[14] employing the Mullard ET51 trochotron may be used at frequencies up to about 1 Mc/s without any buffer amplifier between the bistable circuit and the trochotron owing to the high input impedance of this trochotron. The negative going input pulses should be of about 15 V amplitude and be rectangular in shape or at least have sharply rising fronts. They are fed into the E88CC bistable circuit via OA81 diodes. The outputs from the E88CC anodes are coupled directly to the trochotron switching grids, but this direct coupling necessitates the use of a negative H.T. supply line. The reset switches, S_1 and S_2, may be ganged. When more than one decade is used, common cathode resistors can be employed for the E88CC valves. The values of these resistors (550 Ω and 1.5 kΩ in Fig. 6.17) should then be reduced in proportion to the number of stages.

The Burroughs Company of America have produced various shielded and unshielded tubes (see table of tube data) which can be used in similar circuits to those described previously. In miniature equipment the Burroughs Beam X tubes are especially useful, but other Burroughs tubes can provide higher target currents, whilst the MO-10R is important for its high maximum operating frequency of 10 Mc/s. This tube has the spade resistors inside the

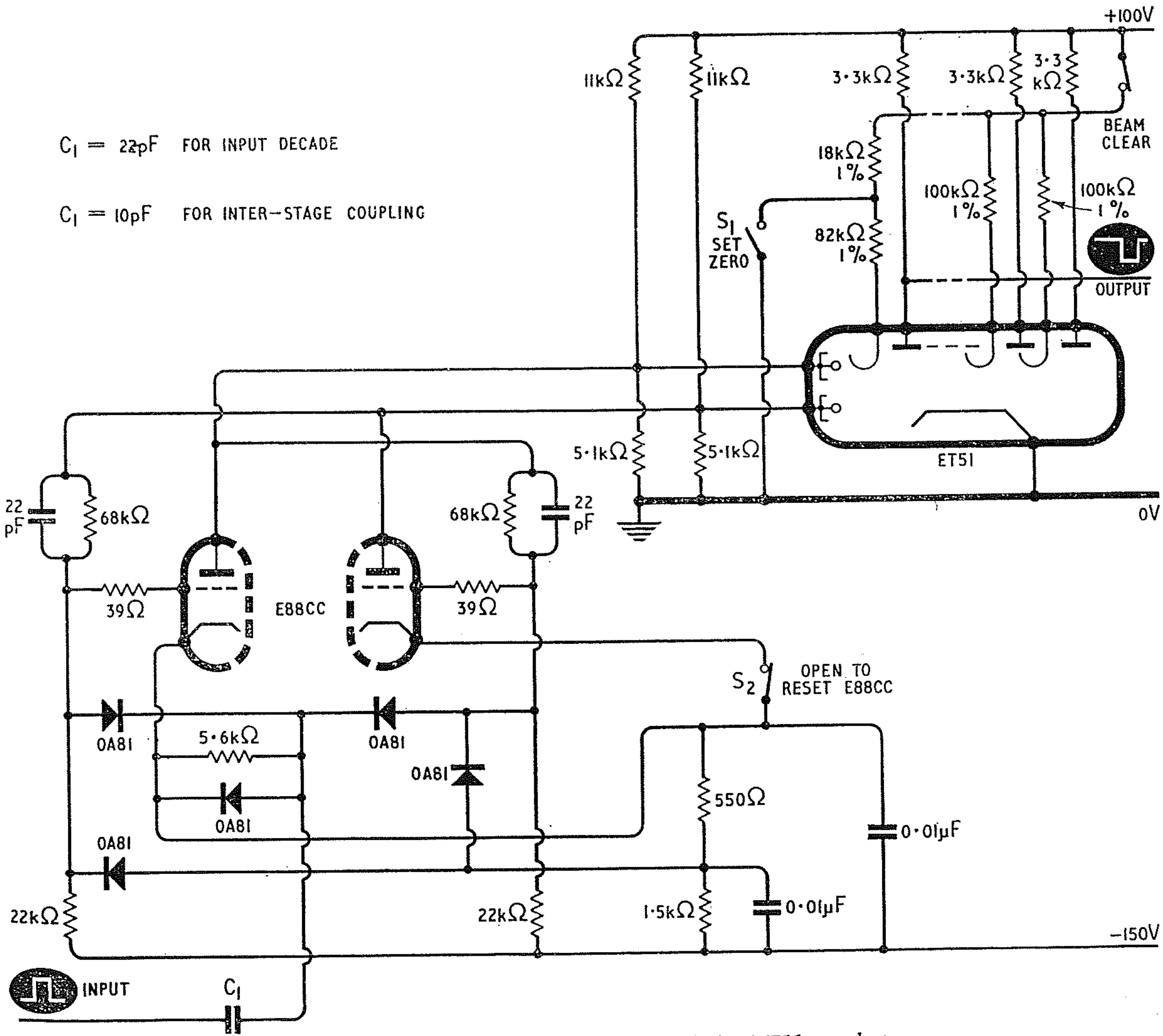


Fig. 6.17 A circuit for the operation of the ET51 trochotron

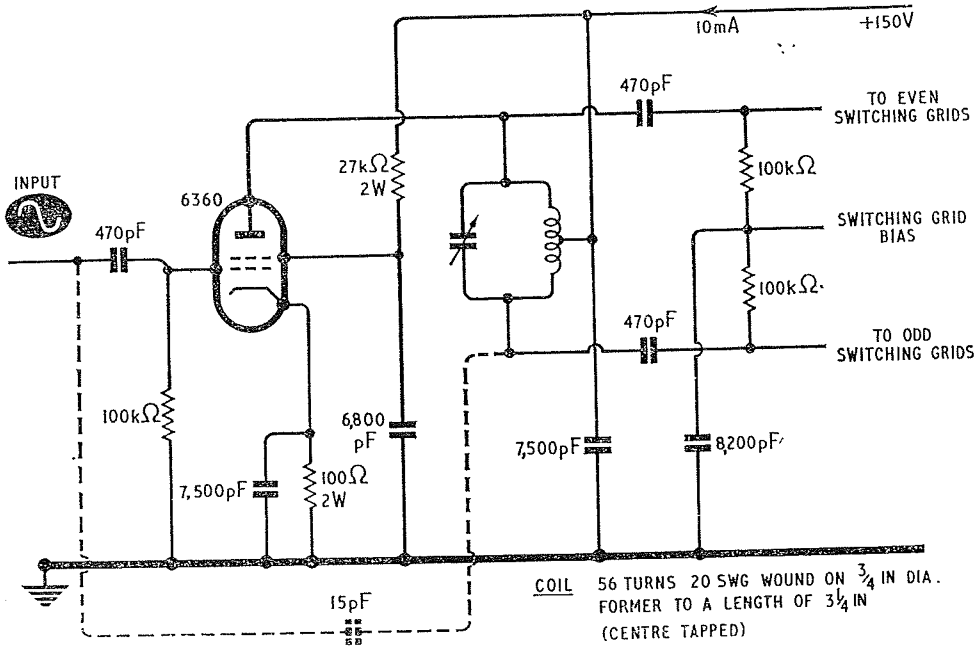


Fig. 6.18 A circuit for driving the MO-10R at 10 Mc/s from a sine wave input of 5 Mc/s

tube envelope so that the stray spade capacitance is reduced to a minimum. At 10 Mc/s the capacitance of even the rod type of switching grid becomes important and therefore buffer amplifiers are normally employed between the bistable circuit and the MO-10R at very high speeds. The pulses which are fed to the switching grids of this tube should have an extremely short rise time and an amplitude of about 150 V.

The circuit of Fig. 6.18 can be used to drive a MO-10R tube at 10 Mc/s when it is fed with a 10 V R.M.S. 5 Mc/s sine wave input signal[15]. The output voltage is greater than 300 V peak to peak at each switching grid. If the extra capacitor shown dotted is added in the position shown, a self oscillating Hartley circuit is formed which will drive the MO-10R without any input being required.

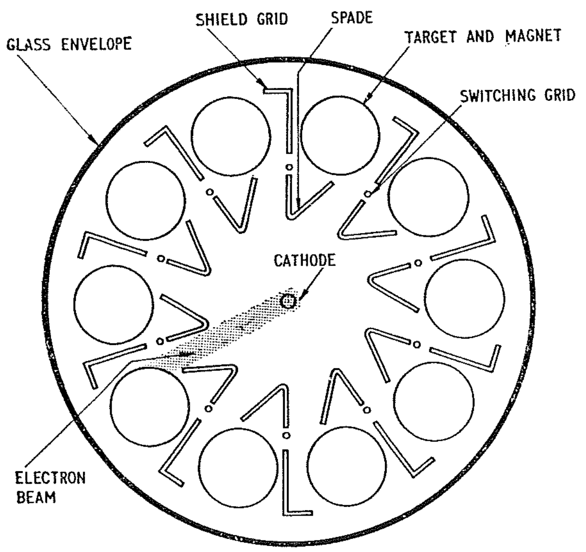
6.4 THE BURROUGHS 'BEAM X' SWITCHING TUBES

The Burroughs Beam X switch is basically a miniature trochotron with internal magnets. Initially a Beam X tube was produced with circular spade electrodes (each of which contained a magnet), circular switching grids and targets resembling those shown in Fig. 6.3. The current Beam X tubes have circular target electrodes (each incorporating a magnet) and circular or rod shaped switching grids as shown in Fig. 6.19. In addition, extra electrodes known as shield grids have been introduced which offer alternative output facilities and, in some cases, simplified circuitry.

The use of internal magnets close to the electron beam renders the Beam X tubes less sensitive to stray magnetic fields than other beam switching tubes and simplifies the magnetic field requirements. In addition to their small size and weight, the Beam X tubes have the advantage of being appreciably cheaper than the other Burroughs beam switching tubes. Magnetically shielded versions of some of the Beam X tubes are available, the amount of shielding required being quite small. Such shielded tubes can be operated in contact with other tubes or with magnetic materials.

The beam current divides itself between the target and shield grid electrodes, whilst a small fraction flows to the spades. If the target electrode is at or above the spade supply potential, it will receive almost the whole of the beam current. As the target voltage is lowered, more of the beam current passes to the shield grid until the target reaches the cathode potential, when almost the whole of the beam will travel to the shield grid. Either the target or the shield grid or both should have a potential above that of the spade supply voltage or the tube will switch automatically whatever the switching grid potential. The greater the target voltage, the greater the amplitude of the negative pulses required at the switching grid to move the beam to the next position. The ability of the shield grid to collect all of the excess electrons enables the tube to operate at low target potentials which may occur momentarily, for example, when the target load is inductive or when a gas filled tube which takes a minute fraction of a second to ionise is included in the target circuit. No target resistors or an additional target supply voltage (such as the +200 V supply in Figs. 6.11(a) and 6.11(b)) are required when Beam X tubes are used with numerical indicator tubes provided that the current taken by the indicator tube is the same as that provided by the Beam X tube. All of the shield grids of a Beam X tube are connected to a common base pin.

The methods of driving Beam X tubes are the same as those used for other beam switching tubes. The circuits which have already been discussed may be adapted for use with Beam X tubes by merely choosing suitable component values (Table 6.1). Normally bistable driving circuits are used, but at



6.19 A Beam X tube seen in cross section

low operating speeds (less than 10 kc/s) the two sets of switching grids may be connected together and the switching accomplished by pulses of a limited duration (as in the circuit of Fig. 6.7).

General information on the principles of operation, design and applications of Beam X circuits for decade counting, bidirectional counting, preset decade counting, multiposition pulse distribution, step function generation, data transfer and storage, sampling, etc. has been published by the manufacturers of the tubes[16].

A Beam X tube has also been specifically designed to provide decimal readout from binary coded information.

6.4.1 Beam X Circuits Using Valves

A decade circuit using a Burroughs 'Nixie' numerical indicator tube for readout is shown in Fig. 6.20[17]. The input pulses are fed to the 5695 bistable circuit and a negative supply voltage is used so that the 5695 tubes may be directly coupled to the Beam X switch. Output pulses suitable for operating the next decade are provided by the T I 496 NPN transistor. Small capacitors are connected from each spade to earth to increase the stability of the circuit.

A 1 Mc/s decade counter has been developed and is shown in Figs. 6.21 to 6.24 inclusive[18]. A Nixie tube is used to provide the readout. RCA 'Nuvistor' valves were chosen for driving and coupling the Beam X tubes owing to their small size, low anode resistance and good mechanical construction.

The input pulses (of 12 to 18 V amplitude and of at least 0.04 μsec duration) are fed to the 1 Mc/s input stage of Fig. 6.21. Tetrodes are used in the bistable circuit of this decade so that a high speed binary circuit can be designed with a fairly low power dissipation. The anode potentials of the bistable circuit swing between about −18 and −90 V and these potentials are directly coupled to the Beam X tube switching grids. The spades are connected to a −20 V line via the spade resistors and the cathode of the Beam X tube has a quiescent potential of −75 V, thus giving the recommended spade supply voltage of +55 Volts relative to the tube cathode. The switching grids fall to a potential of −15 V relative to the Beam X cathode when the

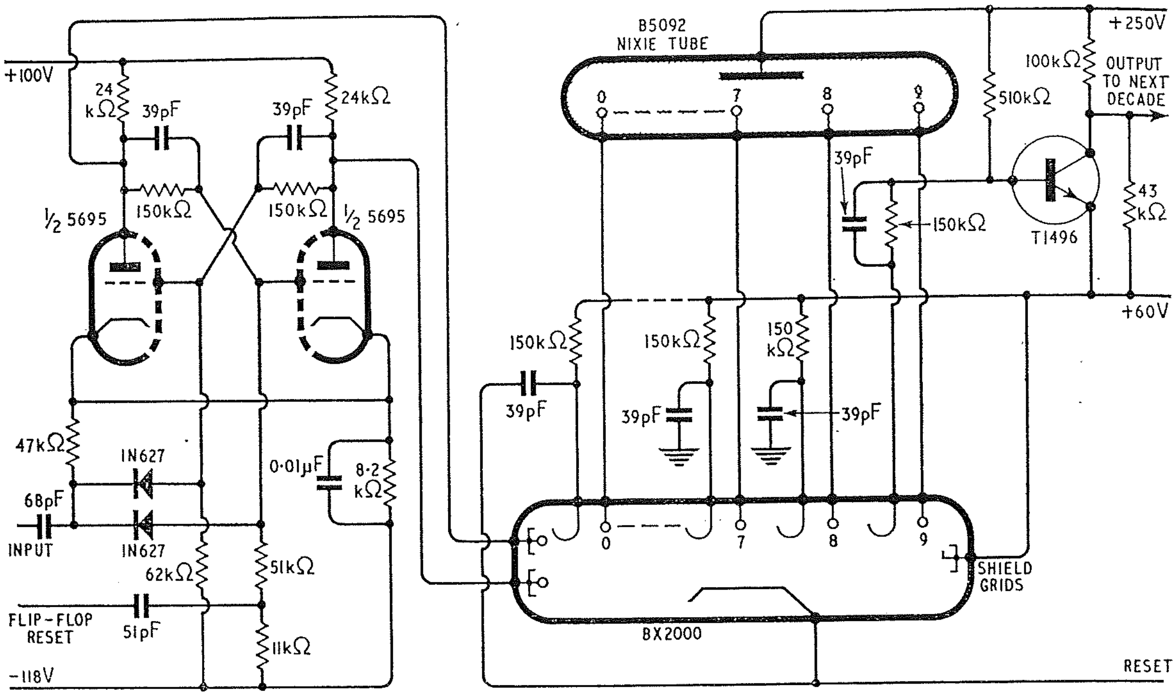


Fig. 6.20 A 110 kc/s Beam X circuit with Nixie tube readout

corresponding section of the binary conducts, this being sufficient to drive the circuit at up to 1 Mc/s.

The 7586 tube provides an 18 V pulse for operating the 100 kc/s decade of Fig. 6.22. This coupling tube operates from a −20 V supply. If the electron beam in the Beam X tube is not resting at position nine, the ninth spade current is zero and the coupling tube conducts. When the beam reaches position 9, the current in the coupling valve falls relatively slowly, but when the beam leaves the ninth position, the coupling valve anode current rises very rapidly. The resulting sharp negative pulse at the anode is used to trigger the next decade.

The 100 kc/s circuit (Fig. 6.22) is very similar to the 1 Mc/s circuit, but two 7586 Nuvistor triodes are employed in the bistable circuit. The anodes of the triodes drive the switching grids of the Beam X tube with a swing of −18 to −85 V. Stabilising capacitors are added to the spade circuits.

A cathode follower stage is used to provide a positive going output pulse of about 20 V amplitude for triggering the succeeding 10 kc/s decade. The cathode resistor of the coupling tube is associated with the input circuit of the next decade and is not shown in Fig. 6.22; it is effectively returned to a −20 V supply. Normally the coupling tube is biased to cut off and will remain cut off when it receives a negative pulse as the ninth spade conducts. The coupling valve will not conduct until the beam moves from the ninth to the tenth position in the Beam X tube. A positive going output pulse is then obtained.

The 10 kc/s circuit of Fig. 6.23 is especially interesting, since the Beam X tube forms part of the feedback loop of the bistable circuit. The odd spades are returned to the grid of *V*1 and the even spades to the grid of *V*2. In the absence of even spade current, *V*2 will conduct owing to the positive grid bias applied to this tube through the 750 kΩ resistor. Similarly *V*1 will conduct when the odd spade current is zero. If the beam is in one of the even positions, a current of about 380 μA will flow in the even spade supply line and *V*2 will be cut off. If an input pulse is now received, *V*1 will remain conducting for a moment, but *V*2 will also pass a current, since the input pulse overcomes the bias due to the even spade current. A fall of potential of about 80 V is therefore fed from the anode of *V*2 to the even switching grids

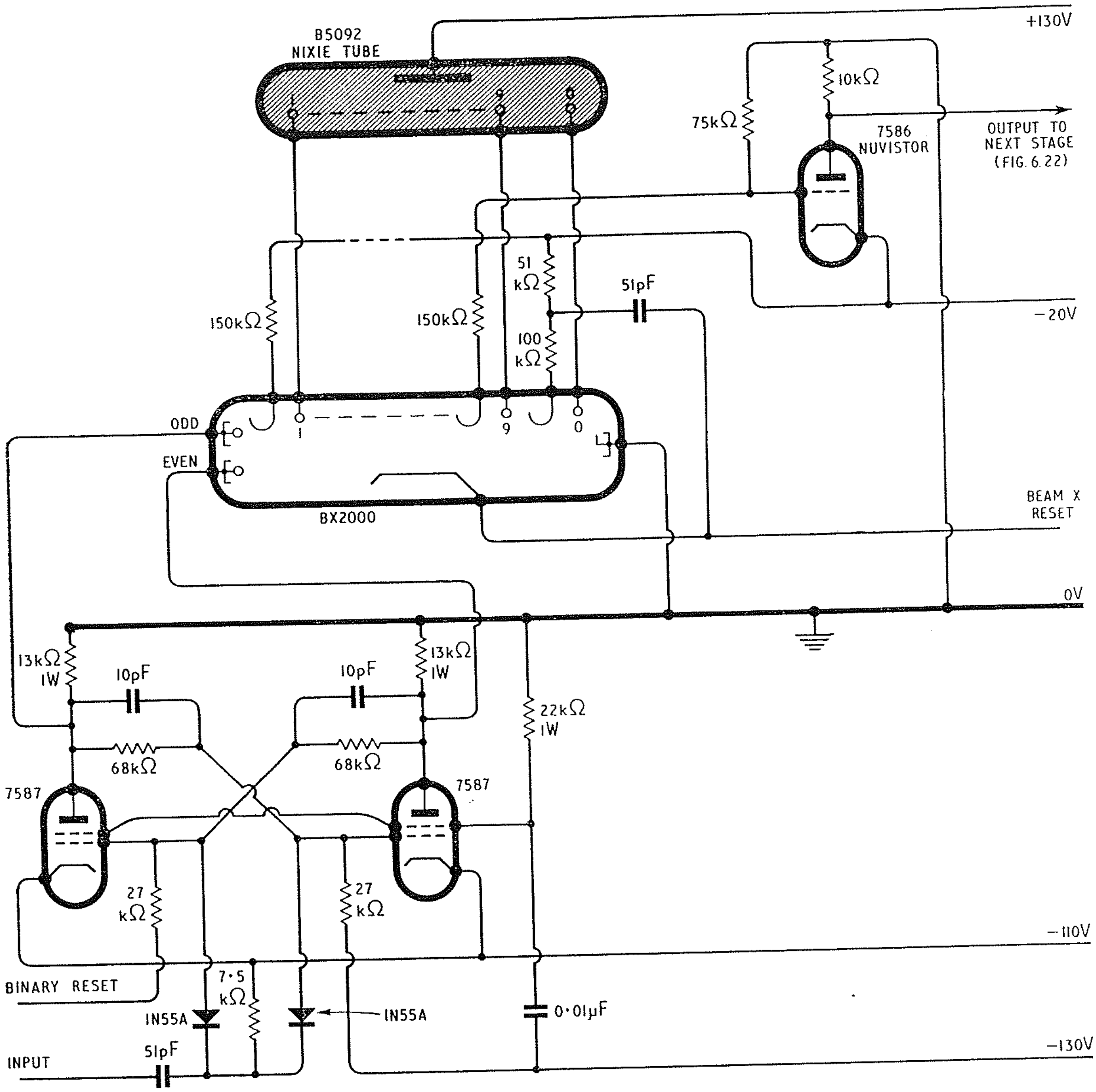


Fig. 6.21 A 1 Mc/s decade counter using R.C.A. 'Nuvistor' tubes

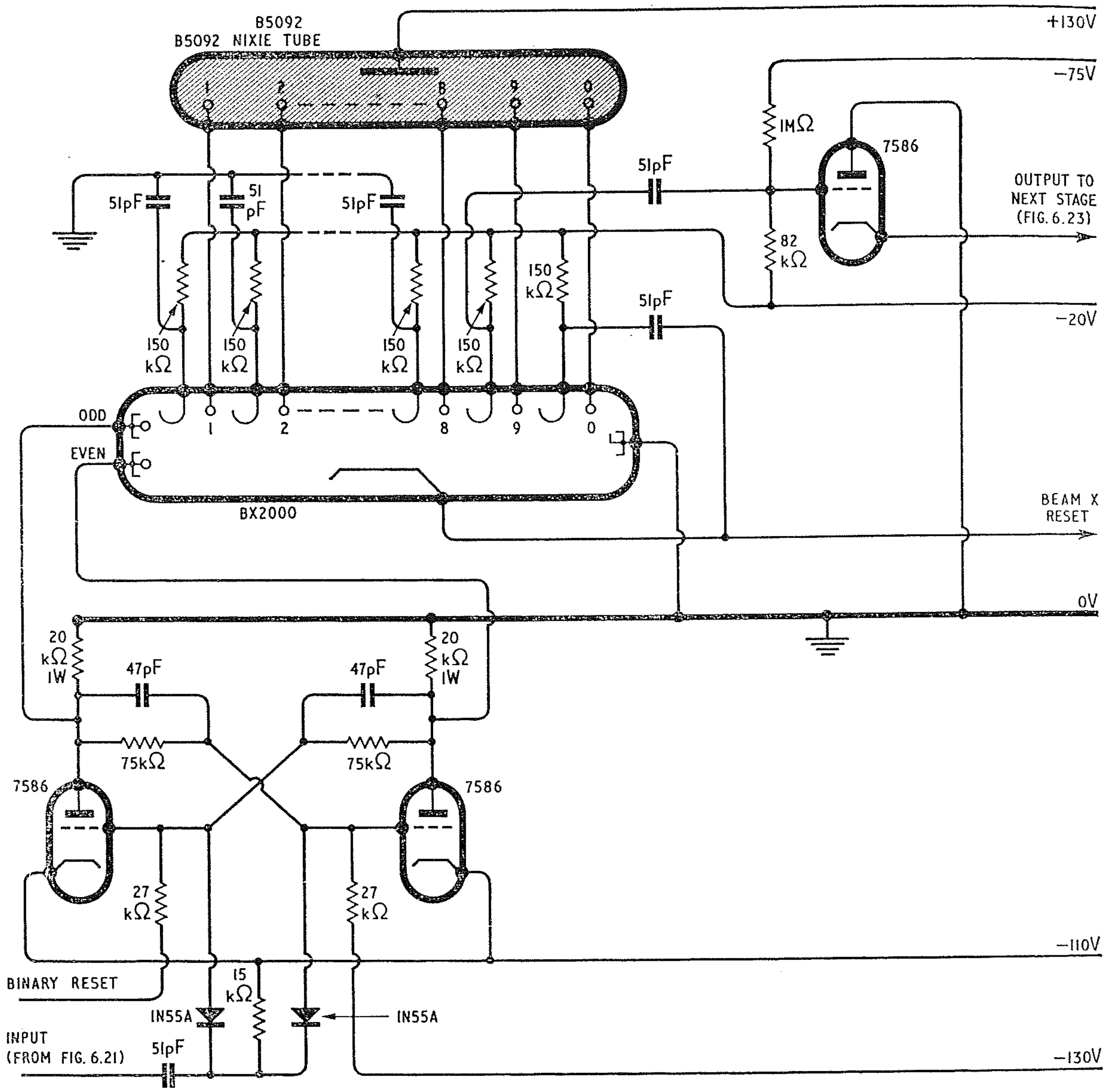


Fig. 6.22 A 100 kc/s Beam X stage

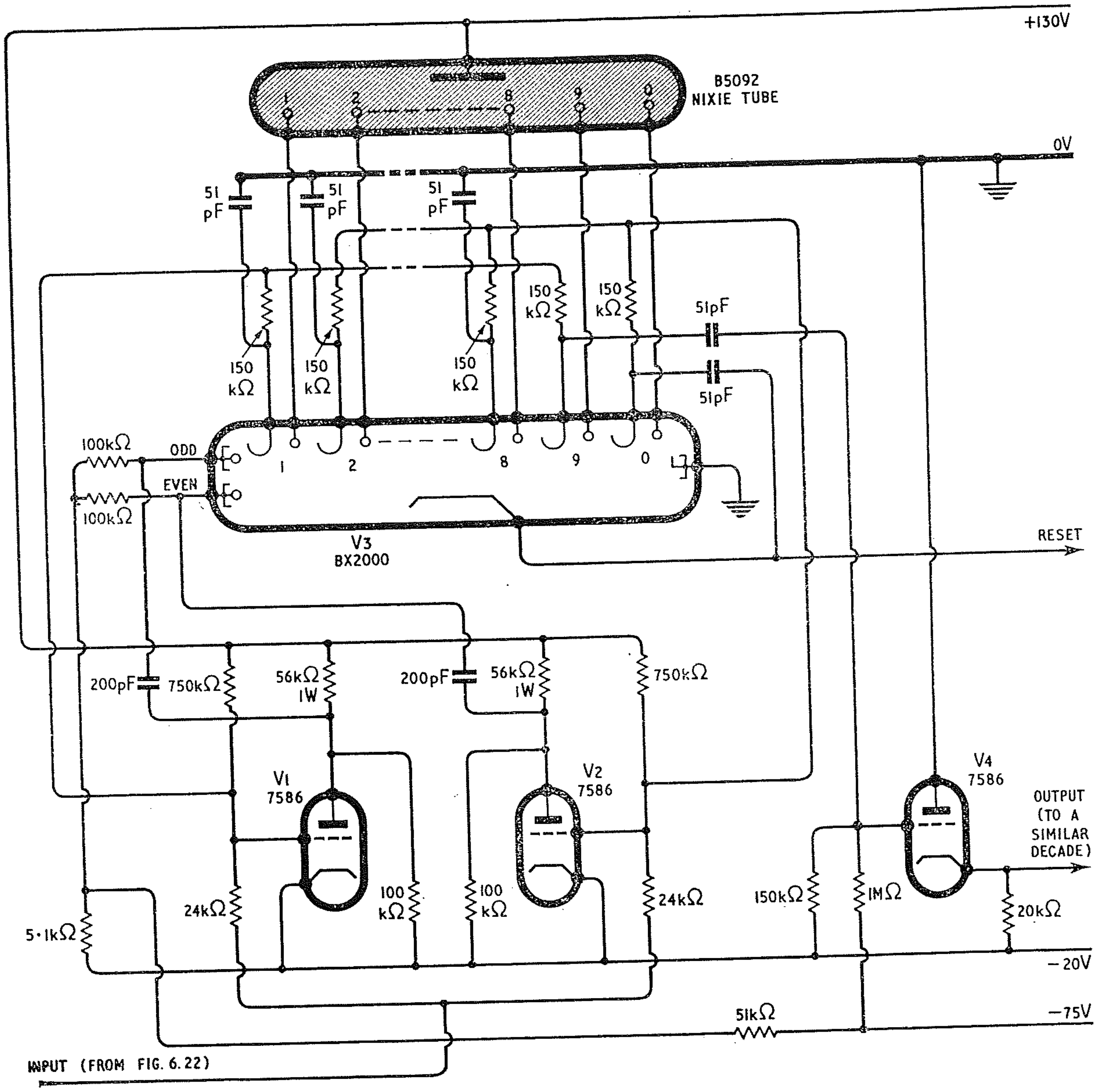


Fig. 6.23 A 10 kc/s Beam X stage

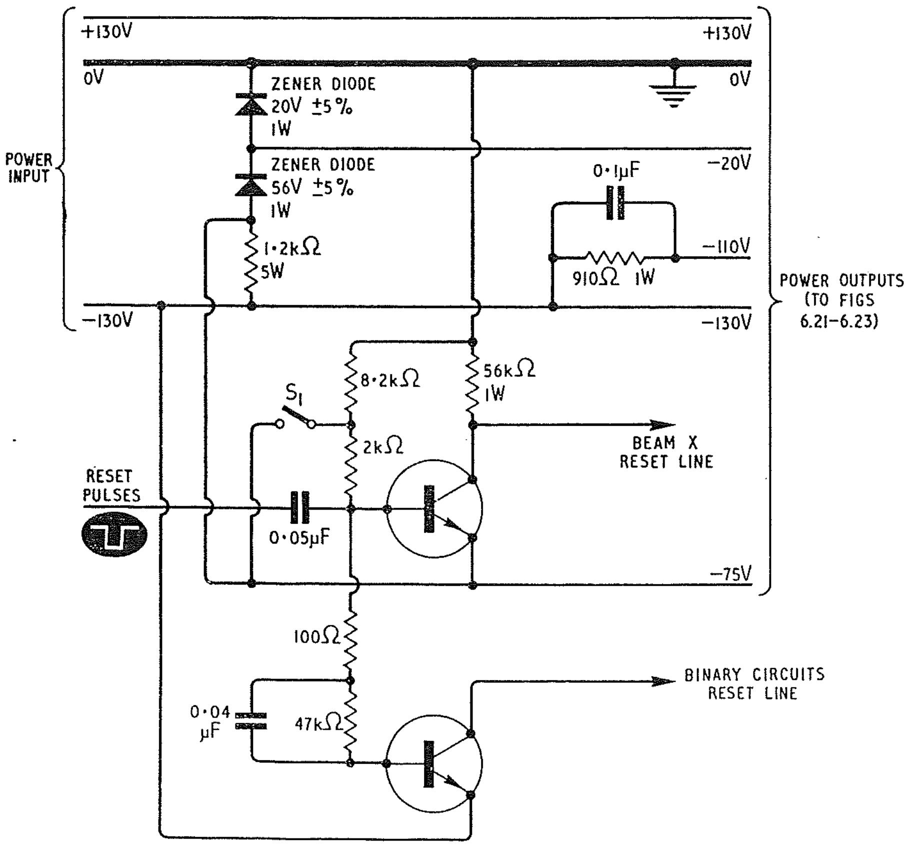


Fig. 6.24 Reset and power supply unit for Figs. 6.21–6.23

causing the beam to move to the succeeding odd position. The spade current therefore causes $V1$ to be cut off, whilst $V2$ remains conducting, since the even spade current is now zero.

The coupling circuit is similar to that of the 100 kc/s decade, since any further decades added will normally be of the same design as the 10 kc/s stage and will all require the same type of input pulses. An advantage is that the bistable circuit is automatically reset when the Beam X tube is reset.

A suitable method of obtaining the power supplies required to operate these counting circuits is shown in Fig. 6.24. A method for obtaining the two sets of resetting pulses is also shown. Both of the transistors are normally saturated, but resetting may be effected by the application of a negative pulse of about 15 V amplitude and 30 μsec duration to the base of the upper transistor. This pulse is coupled to the base of the lower transistor and both transistors are cut off. Manual reset facilities are offered by the switch S_1. The upper transistor is cut off whilst this switch is closed, but the lower transistor is cut off for only a few microseconds, thus ensuring that the binary circuit is reset before the Beam X tube. A positive going pulse of about 75 V in amplitude and 30 μsec in duration is required to reset the Beam X tubes.

If it is desired to construct a scaler using only the 100 kc/s units of Fig. 6.22, the type of coupling amplifier shown in the circuit of Fig. 6.21 should be employed so that the output pulses from this amplifier are of a suitable polarity to operate the 100 kc/s circuits. The cathode follower coupling circuit of Fig. 6.22 does not provide pulses suitable for the operation of a similar succeeding decade.

6.4.2 Low Frequency Circuit

One of the simplest possible circuits for a Beam X scaler is shown in Fig. 6.25[19]. A simple bistable

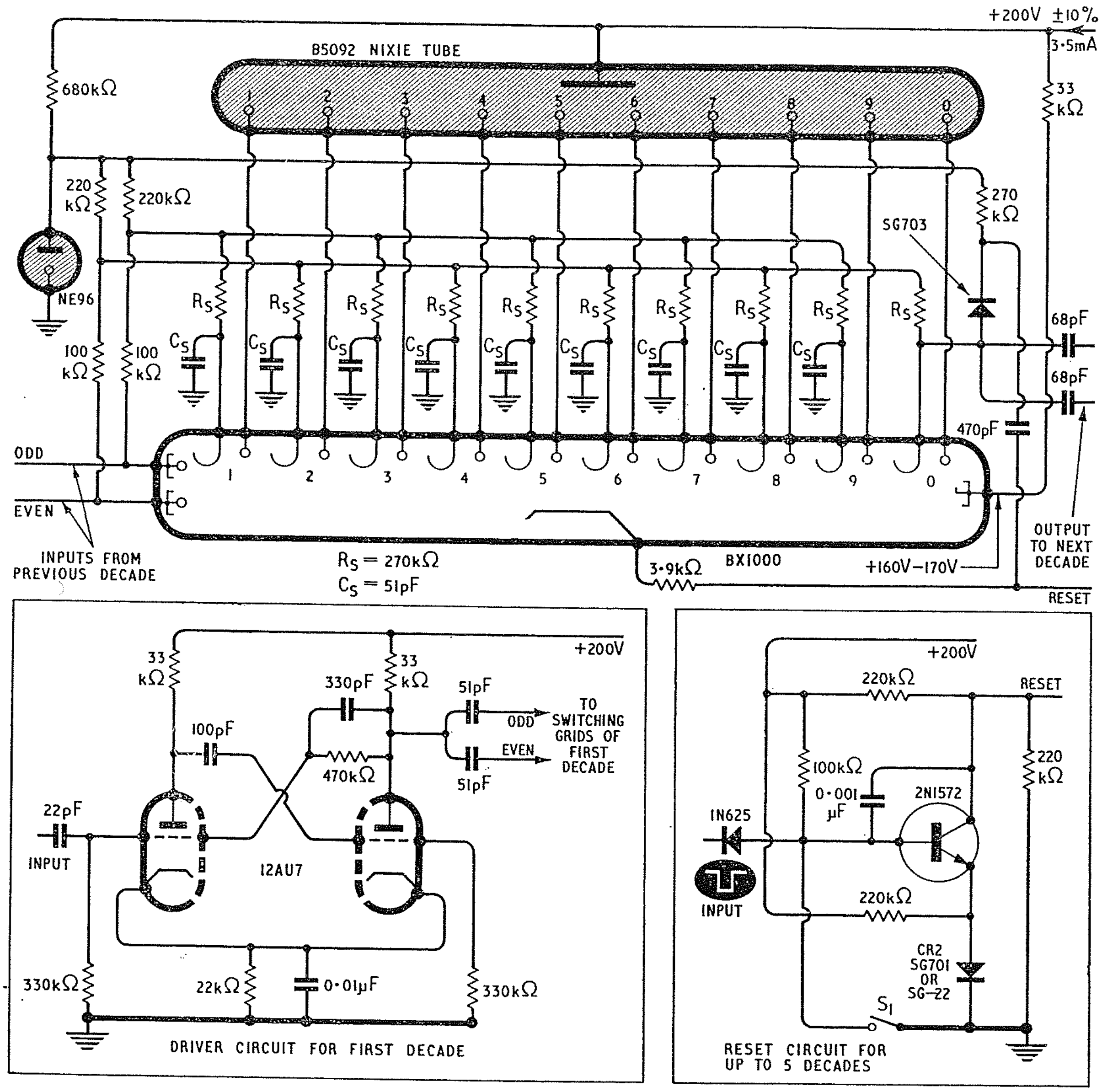


Fig. 6.25 A simple 1 kc/s Beam X circuit with input and reset circuits

valve circuit (as shown) may be used to drive the first Beam X tube, but no coupling amplifiers are required between the decades. This circuit is available in the form of modules (excluding the Nixie tube) from the manufacturers of the Beam X tube.

The beam is initially formed in the zero position by means of a reset pulse. The potentials of the switching grids depend on the voltage drop across the 220 kΩ spade supply resistors. When an even spade conducts, the potential of the even switching grids is kept near the switching level, whilst that of the odd switching grids is above this level. These potentials are reversed when an odd spade is conducting. At each input pulse the tube will therefore switch only one position. When the beam moves from position 9 to position 0, the flow of spade current through the zero spade resistor produces a negative going pulse of about 60 V amplitude and 150 μsec duration which is used to operate the next decade.

The wires coupling one decade to the next decade should be kept as short as possible to minimise stray capacitance. A 200 pF capacitor should be connected between one of the unused output terminals of the final decade and earth.

The input required at the switching grids of the first Beam X tube is about −80 to −100 V for at least 5 μsec. This may be obtained from the type of driver circuit shown which requires an input of at least −50 V for a minimum of 1 μsec. Whatever type of input circuit is to be used, a 51 pF capacitor must be placed in each switching grid circuit of the first tube.

The pulses required to reset the Beam X tubes in this type of circuit should have an amplitude of 90 to 110 V for a minimum duration of 1.5 msec with a trailing edge duration of 90 to 130 μsec. Such pulses are conveniently obtained by cutting off an NPN transistor in the reset circuit shown, the transistor being connected between the cathode of the Beam X tube and earth.

6.4.3 Circuits with Transistor Drive

Beam X tubes, transistors and small numerical indicator tubes form very convenient components for use in plug in modules for fairly high speed counting when they are mounted on printed circuit boards. Such modules (including the Nixie indicator tubes) are available commercially, two of the most useful circuits being shown in Figs. 6.26 and 6.27[19]. The first of these circuits is a 1 Mc/s decade counter with a transistor coupling amplifier which provides suitable output pulses for the operation of the 100 kc/s decade counter of Fig. 6.27. Any number of the decade circuits shown in Fig. 6.27 may be cascaded, since the output pulses from these units satisfy their input pulse requirements.

The beam is formed at the zero spade in the circuit of Fig. 6.26 by the application of a reset pulse. The input pulses should have an amplitude of 12 V ±15% and a minimum duration of 0.3 μsec. They are fed to the bistable circuit which uses Fairchild S-3281 transistors to drive the Beam X tube.

The NS422 transistor in the coupling circuit is used to provide output pulses which will operate the circuit of Fig. 6.27. If the circuit of Fig. 6.26 is counting at 1 Mc/s, the beam current is available at any one target for only 1 μsec, but the 100 kc/s circuit requires a pulse of at least 2 μsec duration. When the beam is at any of the positions 4, 5, 6, 7, 8 or 9, spade current flows through the 560 kΩ resistor connected to the base of the coupling transistor making the base more negative and cutting the NPN transistor off. The output potential (about 90 V) is then determined by the values of the 330 kΩ and 30 kΩ resistors connected to the output. When the beam moves to the zero position, the coupling transistor conducts again and the potential of its collector falls to about 78 V, thus providing the required 12 V negative step.

The alternative reset connection is normally earthed in the reset circuit. The reset transistor (inset of Fig. 6.26) normally conducts and holds the cathode of the Beam X tube at about earth potential. If the reset transistor is turned off for 25 μsec or more, the cathode will reach a potential of 80 to 100 V and the beam will be cut off. When the transistor conducts again, the zero spade is held at a low potential by a capacitor so that the beam forms in the zero position. A 10 V positive going pulse is applied to reset the binary at the same time as the Beam X tube is reset. A single reset circuit will operate up to six decades.

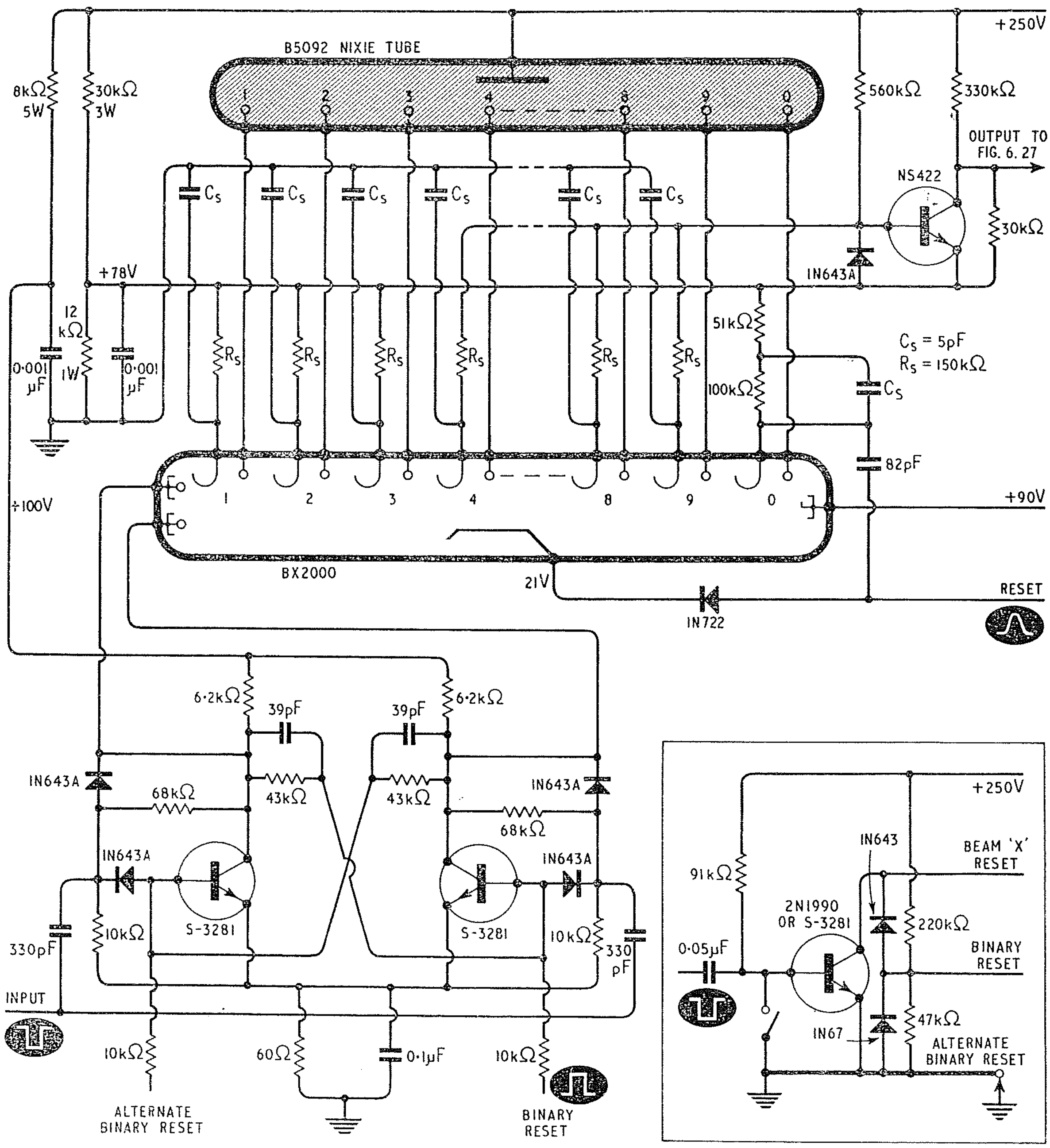


Fig. 6.26 A 1 Mc/s circuit with transistor drive. (Inset: reset circuit)

Table 6.1 BEAM SWITCHING TUBES. BASIC DATA

					Recommended Operating Conditions						*Max. Dimensions*				*Heater*		
											Unshielded		*Shielded*				
Unshielded Tubes	*Shielded Versions*	*Max. freq. (Mc/s)*	*Target current (mA)*	*Spade current (mA) Typical*	*Spade Supply voltage*	*Spade Resistor (Ω)*	*Target Supply voltage*	*Target Resistor (Ω)*	*Grid Bias (volts)*	*Pulse input*	*Seated Height (mm)*	*Diam (mm)*	*Seated Height (mm)*	*Diam (mm)*	*V*	*A*	*Remarks*
Ericsson Trochotrons																	
VS10G (CV5290)	VS10G/M	1	10	1.2	108	100k ±10%	108	4.7k	+54	−54	81.5	44	81.5	75	6.3	0.5	Low cost tube
VS10H (CV6103)	VS10H/M	2	18	1.0	125	82k	125	4.7k	+62	−67	81.5	44	81.5	75	6.3	0.55	High current
VS10K	—	1	2	0.4	28	150k	28	6.8k	+15	−17	81.5	44	—	—	6.3	0.3	Low voltage
Mullard/Philips Trochotron																	
ET51 (CV5277)	—	1	5.5	1.0	100	100k ±10%	100	3.3k	+30	−75	84	44.4	—	—	6.3	0.5	General purpose
Burroughs Trochotrons																	
6700	BD301 (6703)	2	6	1.0	100	100k	100	3.3k	+25	−50	84	44.5	82	57.5	6.3	0.3	General purpose
6701	BD308	1	0.6	0.1	20	270k	20	6.8k	+12	−20	84	44.5	82	57.5	6.3	0.3	Low voltage
BD311	—	2	10	1.7	130	82k	130	3.3k	+30	−70	84	44.5	—	—	6.3	0.3	High current
MO-10R (6704)	BD309	10	6	1.0	100	100k (Internal)	100	3.3k	+25	−60	84	44.5	82	57.5	6.3	0.3	High speed
BD-203	BD-316	1	3	0.5	55	130k	55	3.3k	+25	−50	82	33	82	44.5	6.3	0.15	Miniature (superseded by Beam X switches)

Unshielded Tubes	Shielded Versions	Max. freq. (Mc/s)	Target Current (mA)	Spade current (mA)	Recommended Operating Conditions: Spade Supply voltage	Spade Resistor (Ω)	Target Supply voltage	Target Resistor (Ω)	Grid Bias (volts)	Pulse Input	Max. Dimensions: Unshielded Seated Height (mm)	Unshielded Diam (mm)	Shielded Seated Height (mm)	Shielded Diam (mm)	Heater V	Heater A	Remarks
Burroughs Beam X Tubes																	
BX1000 (6710)	BX2000 (6711)	2	2.7	0.4	55	150k	55	3.3k	+40	−55	73	29.5	73	32.5	6.3	0.15	General purpose
BX3000 (6712)	—	2	5.0	0.5	80	150k	55	3.3k	+50	−55	73	29.5	—	—	6.3	0.15	High current
—	BX4000	1	1.0		30	270k	30	10k	+26	−24	—	—	73	32.5	6.3	0.15	Low voltage (BX4000 superseded by BX4001)
—	BX4001 (6714)	2															
—	BX2012	As for BX 2000															Specially tested for decoding of binary coded decimal information

Base connections:

VS10G, VS10G/M, VS10H, VS10H/M, VS10K, ET51, 6700, BD301 and BD311:

Pin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	19	20	21	22	23	24	25	26	27
Electrode	S_0	T_9	T_8	SG_{odd}	T_7	S_7	T_6	T_5	S_5	T_4	I.C.	T_3	T_2	S_2	T_1	SG_{even}	T_0	S_9	S_8	h	S_6	S_4	S_3	h	S_1	k

B27A base.

All Beam X tubes: – As above, but pin 11 is the common shield grid connection. 6701, BD203, BD308 and BD316: – As above except that pin 16 is connected to the zero switching grid whilst all other even grids are connected to pin 11.

MO-10R and BD309:

Pin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Electrode	S_0	T_8	SG_{odd}	T_7	T_6	T_5	S_1 to S_9	T_4	T_3	SG_{even}	T_2	T_1	T_0	k	T_9	h	NC	NC	H	NC

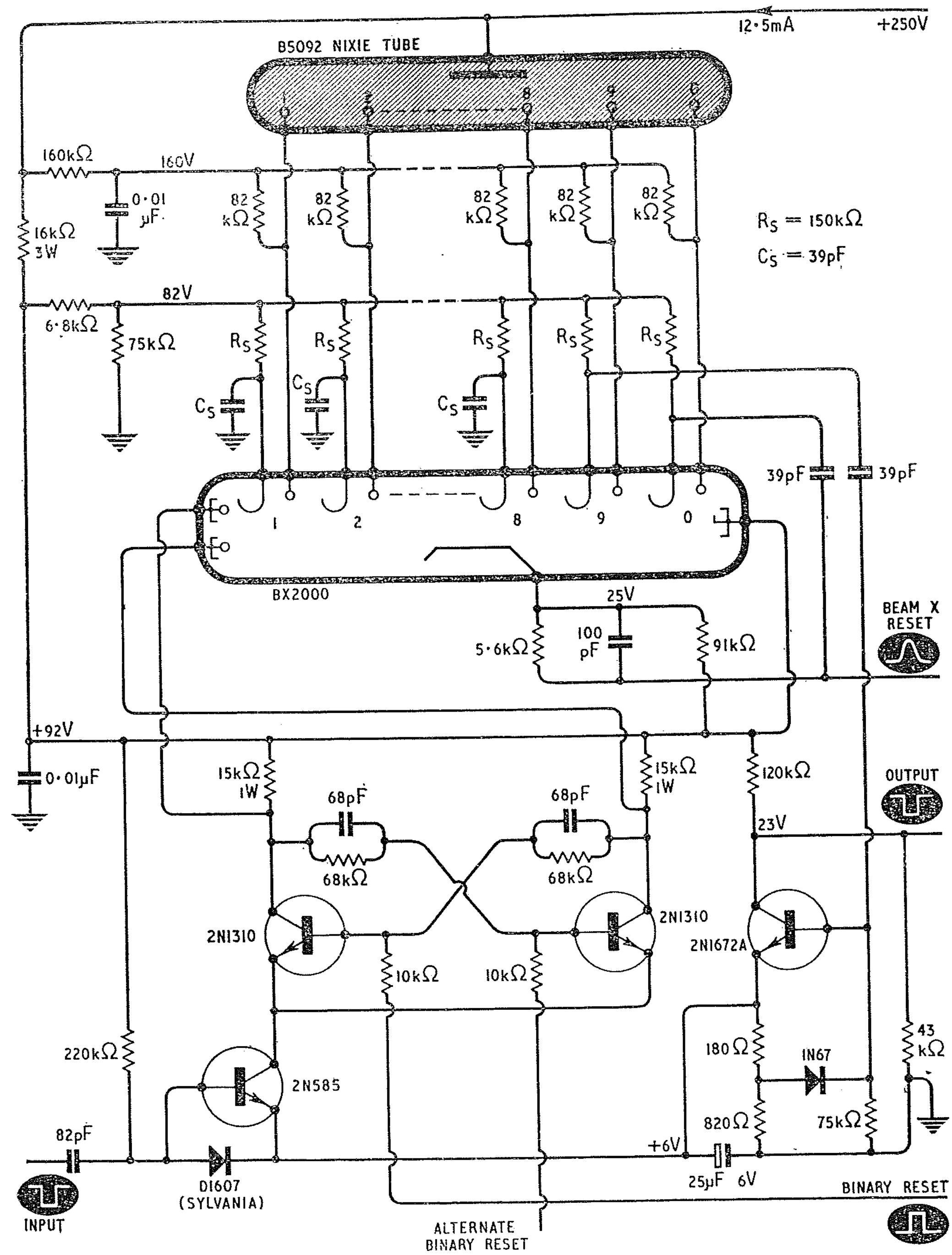


Fig. 6.27 A 100 kc/s circuit with transistor drive

An additional transistor is used in the input of the 110 kc/s circuit of Fig. 6.27. The input pulses are differentiated by the input capacitor and resistor and are then used to cut off the 2N585 transistor for a period which is longer than that required for the binary circuit to change its state. The NPN 2N1672A coupling transistor is normally cut off. When spade nine conducts, the negative pulse applied to the base of this transistor will therefore have no effect. As the beam advances to the zero position, however, a positive pulse is fed to the coupling transistor which conducts for about 10 μsec and a negative going output pulse of about 17 V amplitude is obtained.

REFERENCES

1. S. P. FAN, 'The magnetron beam switching tube', *J. Brit. I.R.E.*, **15**, 335, (1955).
2. D. REANEY, 'Trochotron high-speed beam switching tubes'. *J. Brit. I.R.E.*, **23**, 99 (1962).
3. H. ALFVÉN & H. ROMANUS, 'Valve with trochoidal electronic motion'. *Nature*, **160**, 614 (1947).
4. H. ALFVÉN, L. LINDBERG, K. G. MALMFORS, T. WALLMARK & E. ASTRÖM. 'Theory and applications of trochotrons'. *Trans. Roy. Inst. Technol., Stockholm*, **22** (1948).
5. The Ericsson Tube Technical Handbook.
6. Trochotron Beam Switching Tubes, Ericsson Telephones Ltd. B. 6003/1 issue 2 (1962).
7. Ericsson circuit LK 165.
8. Ericsson circuit LK 164.
9. Stabilizer and Reference Tubes, Ericsson Telephones Ltd. B. 6201/1 (1962).
10. Digitron Display Tubes, Ericsson Telephones Ltd. B. 6207/2 issue 2 (1962).
11. Ericsson circuit LK 192.
12. Ericsson circuit LK 167.
13. Ericsson circuit LK 183.
14. Mullard Ltd. (Private Communication) and ET51 data sheets.
15. Burroughs circuit 70351.
16. 'Beam X Applications Orientated Switch', Burroughs Technical Brochure BX535C (1965).
17. 'Nixie Indicator Tubes', Burroughs Technical Brochure 616.
18. 'A Beam X Switch 1 Mc/s Counter'. Burroughs Publication 602 (August 1962).
19. 'Beam X Modules and Circuits' Burroughs Technical Brochure 405B (1965).