HIVAC COLD CATHODE TUBES.
OPERATION and APPLICATION*

INTRODUCTION.

Cold cathode tubes are not in themselves new devices but interest in their application to electronic circuitry has increased very greatly in recent times. This article has been prepared to summarise sufficient information on the design and operation of these tubes and also on their application to typical circuit problems so that their potentialities can be assessed by circuit designers who may be more familiar with electro-mechanical devices or with hard valves.

The increasing realisation of the value of cold cathode tubes has resulted largely from the appearance of small, simple and low cost types which can provide not only the flexibility in design which is so important but also a standard of reliability which under proper conditions can be superior to that of electro-mechanical devices. Electronic calculating or computing equipments, the use of electronics for the automatic control of machinery or processes and the use of electronics for telegraph or telephone switching are all instances where simple mass produced cold cathode tubes can offer peculiar advantages.

It is true that in calculating circuits operating at very high speeds the use of cold cathode tubes may not be possible but this leaves a wide field in slower speed counting circuits and in almost all types of automation equipment, switching circuitry, and so on, in which small simple mass produced cold cathode tubes can provide simplicity, flexibility, economy (both in initial cost and in subsequent equipment servicing), as well as extreme reliability. In addition they are unique in having the merit of self-indication.

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SECTION I

Fundamental Characteristics of Gas Discharges

The operation of cold cathode tubes depends upon the conduction of current through a suitable gas at a relatively low pressure. Normally the inert gases, such as argon, neon, etc., either alone or in combination and generally at a pressure less than 0.1 atmospheres, are used in cold cathode tubes.

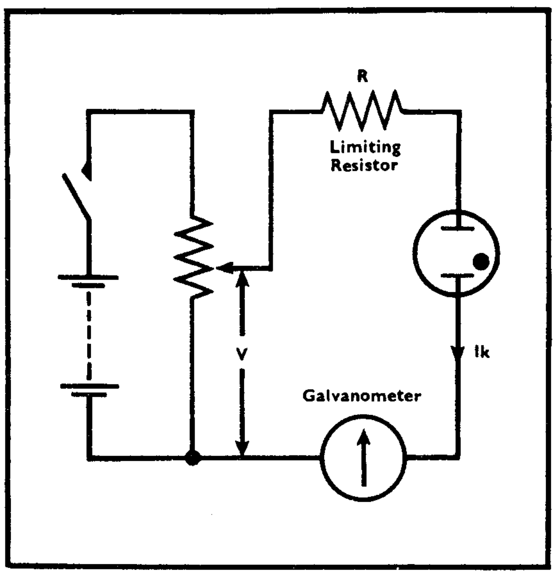

Figure 1

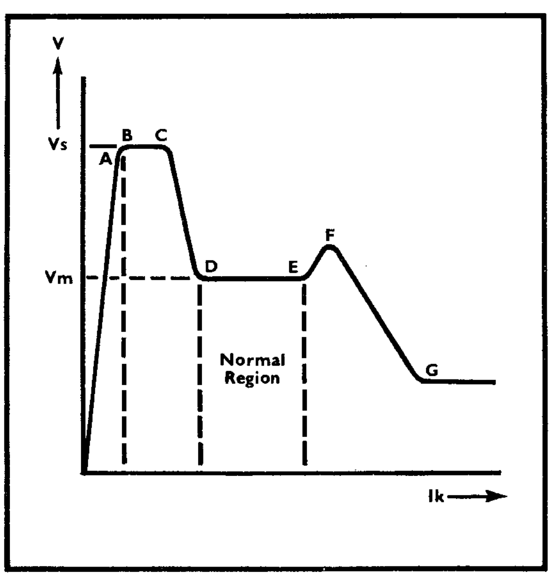

Figure 2

If a potential difference is set up between two electrodes in such an atmosphere the characteristic relating the current between the two electrodes to the potential difference across them can be determined in the circuit shown in Fig. 1. The characteristic is drawn in Fig. 2 in which the current scale is logarithmic.

The first stage up to the point (A) on the curve covers a very low current range (of the order of 10^{-16} to 10^{-12} A) known as the Townsend current, which flows during the period of the gradual build up of ionised particles. The next stage from (A) to (C) indicates a very rapid increase in the degree of ionisation with a virtual breakdown occurring at the point (B). The voltage at (B) is known as the striking voltage and the value of this voltage depends upon the gas mixture and pressure, the electrode materials and the physical construction or "geometry" of the tube.

When the discharge has been established the current through the tube is determined by the value of the external limiting resistance. For a range of current the potential drop across the tube stabilises at a value substantially lower than the striking voltage. This is known as the maintaining voltage. This stable region from (D) to (E) where the voltage drop across the tube is substantially independent of the current through it is known as the "normal region" and is the one generally used in the operation of cold cathode tubes. In this normal condition the discharge is clearly visible, the colour being determined by the gas filling.

If the external resistance is further reduced the nature of the discharge changes. There is an abnormal glow condition from (E) to (F) in which the potential difference across the tube rises as the current rises but subsequently from (F) to (G) the potential drops until the arc condition is reached.

The earliest work on the phenomena of gas discharges was that of Geisler in Germany. Further

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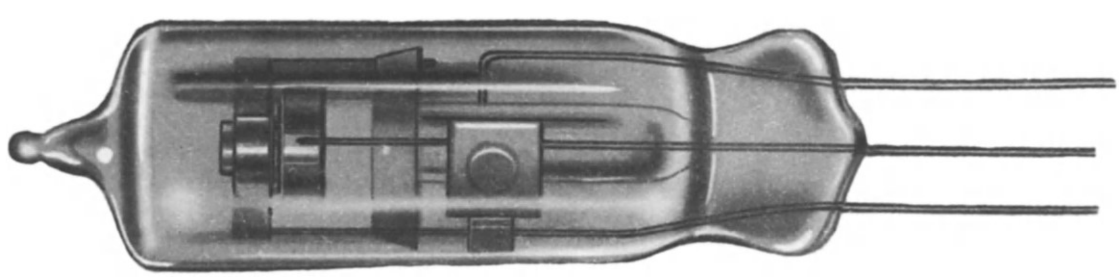
HIVAC COLD CATHODE TUBES OPERATION and APPLICATION. (continued)

work carried out by the British physicist Townsend at the beginning of the twentieth century and subsequently by other physicists has established two stages in the mechanism by which the current is conducted through the gas. Initially a certain potential difference between the electrodes results in the ionisation of the gas and subsequently the bombardment of the cathode by the positively charged ions carrying the Townsend current results in electron emission from the cathode surface, these electrons in turn producing ionisation of the gas. It is this electron emission from the surface of the unheated cathode, as the result of ionic bombardment, which distinguishes cold cathode tubes from the better known thermionic valves.

In the same way as the electronic emission from a hot cathode depends upon the cathode material and at a given temperature is greater for materials having a low "work function", so in the cold cathode tube the electronic emission depends upon the work function of the cathode surface. A wide range of materials may be used depending upon the characteristics required and in many cases the combination of mechanical and emissive properties is obtained by means of an active coating on a relatively inactive metallic cathode.

It will be realised from the above very brief description of the mechanism of the gas discharge, that the initiation of the Townsend current is dependent upon some residual ionisation in the gas. In practice this necessary minimum is normally provided by the effects of ambient illumination, cosmic radiation, radioactivity, etc.

Cold cathode tubes operate reliably over a very wide range of ambient illumination both in day-light and in artificial light. Excessive illumination however, such as direct sunlight, may result in sufficient ionisation to reduce the strike voltage of cold cathode tubes appreciably below the normal value. On the other hand, the reliable operation of cold cathode tubes in total darkness may call for the use of an ionising agent such as a radioactive material incorporated in the gas or in the mechanical construction of the tube.



TYPICAL HIVAC COLD CATHODE TUBE. (much enlarged)

SECTION II

Characteristics of Diode Cold Cathode Tubes

The diode is the simplest type of cold cathode device and consists of two electrodes mounted in a suitable bulb containing the inert gas.

The following paragraphs define the principal characteristics of cold cathode diodes and indicate briefly the significance of them and the method of measurement.

(a) **Striking Voltage** (V_s)—the minimum voltage which must be applied across two given electrodes to establish a glow discharge between them.

This can be measured by slowly increasing the voltage applied to the tube through a current limiting resistor and noting the reading of the voltmeter at the moment the tube strikes.

The usual experimental layout is shown in Fig. 3.

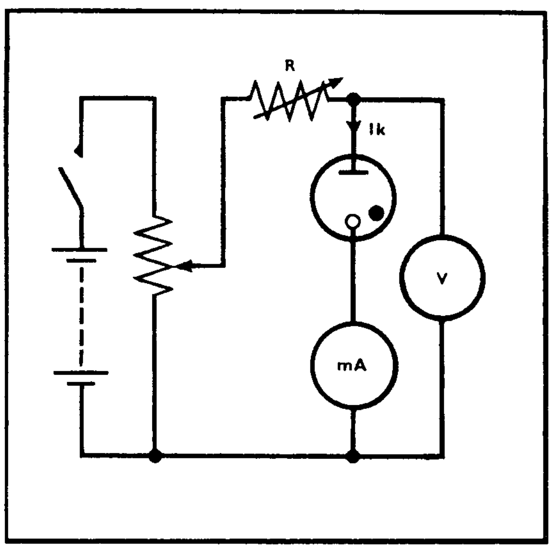


Figure 3

(b) **Maintaining Voltage** (V_m)—the voltage appearing across two electrodes whilst a glow discharge passing a specified current exists between them.

The test circuit shown in the previous paragraph for the measurement of strike voltage can also be used for the measurement of maintaining voltage. When the tube has struck, the limiting resistance R in Fig. 3 is adjusted to produce the specified current through the tube and the maintaining voltage is noted.

(c) **Regulation**—the change in the maintaining voltage of a glow discharge established between two given electrodes when the current is altered from one specified value to another.

The characteristic relating the current through a cold cathode tube to the maintaining voltage approximates very closely in practice to a straight line parallel to the current axis. The small amount by which the maintaining voltage increases as the current through the tube rises towards the rated maximum serves as a measure of the tube quality in certain engineering applications. Using the same test circuit as in Fig. 3 the current is adjusted by means of R to successive values and the corresponding maintaining voltages noted.

The results can be plotted on a curve as shown in Fig. 4 below.

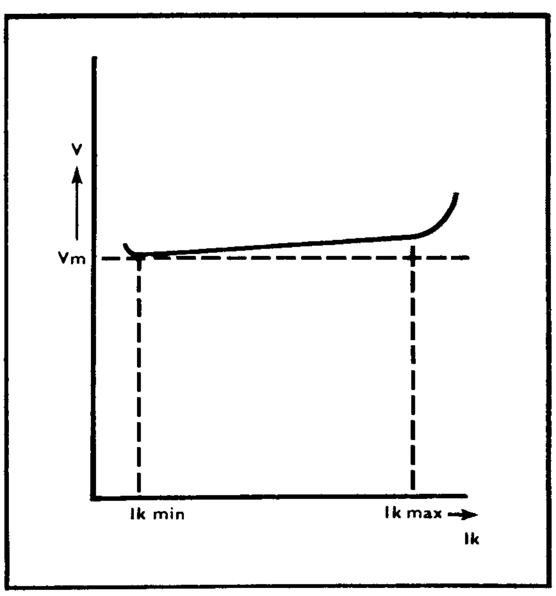


Figure 4

(continued)

(d) **Ionisation Time** (T_i)—the time interval elapsing between the application of a voltage, greater by a specified amount than the striking voltage of a given gap, and the formation of a complete glow discharge in it.

For the purpose of measuring the ionisation time of a cold cathode diode, an oscilloscope is required and also a square wave generator in which the pulse amplitude, pulse duration and the repetition rate are independently controllable.

The experimental layout may be as shown in Fig. 5. The measurement is carried out by observing the pulse displayed on the oscilloscope as the pulse duration is slowly changed.

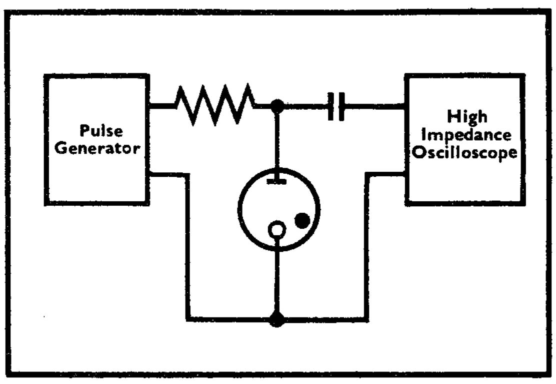


Figure 5

If the pulse duration is sufficiently short to ensure that the tube does not have time to strike, the display on the oscilloscope will be as in Fig. 6a below. If then the pulse duration is increased until the tube is just able to fire, a deformation on the trailing edge becomes apparent as shown in Fig. 6b.

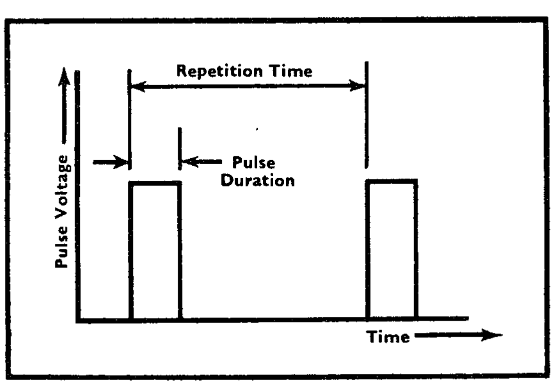


Figure 6a

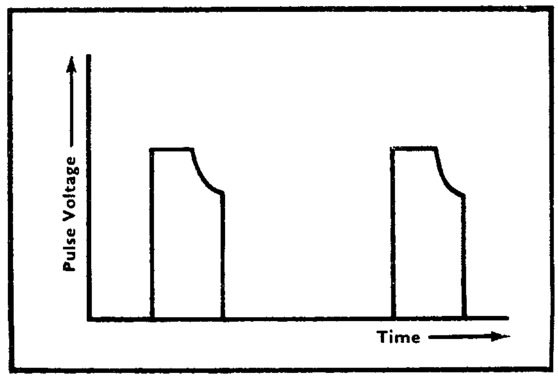


Figure 6b

The ionisation time of the tube is then taken as being equal to that pulse duration which gives a just noticeable deformation.

The ionisation time depends upon the pulse amplitude and the general shape of the characteristic is as indicated in Fig. 7.

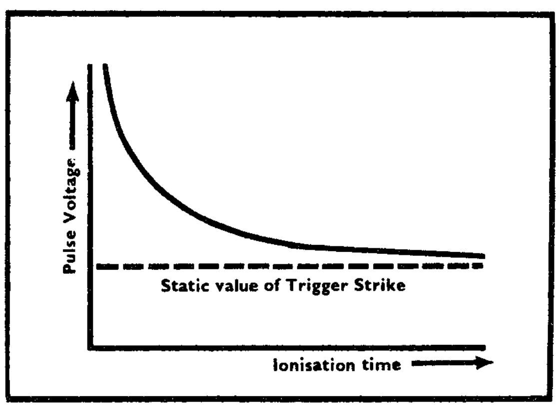


Figure 7

(e) **Recovery of Extinction Time** (T_x)—the minimum time interval between the extinction of a discharge by the reduction of the voltage across a tube from V_m to V_1 to the instant at which the application of a voltage V_2 (where $V_m < V_2 < V_s$) will not re-establish a glow discharge.

This characteristic can be measured in the test circuit indicated in Fig. 8.

The glow is established by raising the applied DC voltage to a figure above the striking value for the tube and then resetting it to the specified lower value V_2. The pulse source is connected in series with the applied DC voltage and results in the

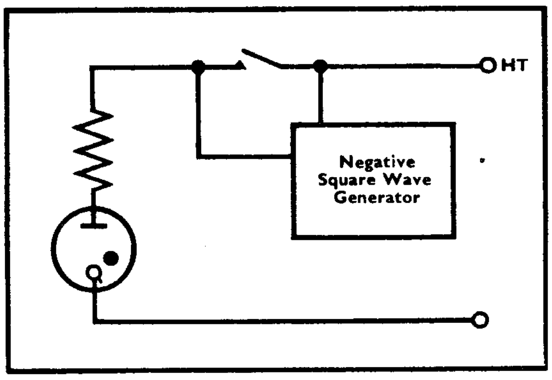


Figure 8

anode voltage being pulsed down to the required figure V_1 for the duration of the pulse.

The duration of this negatively-going pulse is gradually increased until the tube is not able to restrike and at that instant the pulse duration can be regarded as the recovery or extinction time of the tube for the particular set of voltages in use. The voltage V_1 down to which the anode is pulsed is referred to as the 'clip level'.

SECTION III

Characteristics of Triode Cold Cathode Tubes

The triode cold cathode tube consists of three electrodes mounted in a suitable bulb containing inert gas. The arrangement may generally be considered as two diodes having a common cathode. The initiation of a discharge in one diode will influence the characteristics of the second diode because of the ionisation produced. The initiating gap, which usually has a lower striking voltage, is known as the trigger gap to distinguish it from the main gap of the tube. The three electrodes are anode, trigger and cathode, see Fig. 9.

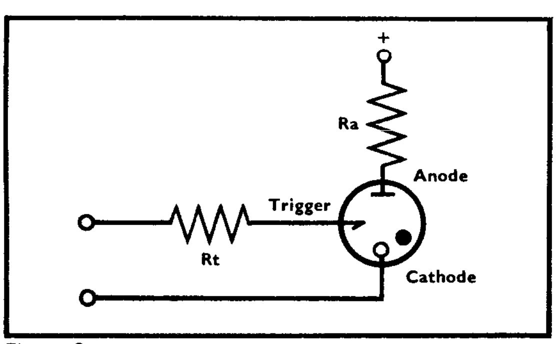


Figure 9

In the normal operation of such a triode a potential lower than the striking voltage of the main gap is applied to the anode through a suitable limiting resistance R_a. Under those conditions the main gap will not strike. If however the trigger gap is then struck (again through an appropriate limiting resistance R_t) the increase in ionisation in the gas will reduce the main gap striking voltage sufficiently to permit breakdown. It can be said that the breakdown has been transferred from the trigger to the anode gap.

This process of inducing the main gap to strike by the application of a suitable signal to the trigger is not reversible and the main gap having once been struck can only be extinguished by the reduction or removal of the voltage between the anode and the cathode.

The principal static characteristics of cold cathode triodes, i.e., the striking voltage and the maintaining voltage of both gaps, are defined and may be measured exactly as with a diode. Similarly the ionisation time of the trigger gap is defined and measured in the same way as that of a diode.

(continued)

There are, however, a number of additional characteristics of cold cathode triodes which are considered below.

(a) **Transfer Current** (I_t)—the minimum current in the trigger gap which will cause a glow discharge to be established between the anode and the cathode when a specified potentials exist between them.

This characteristic may be measured in the circuit shown in Fig. 10. The anode potential is set to the required value. A discharge is established in the trigger gap and the current is raised until transfer occurs.

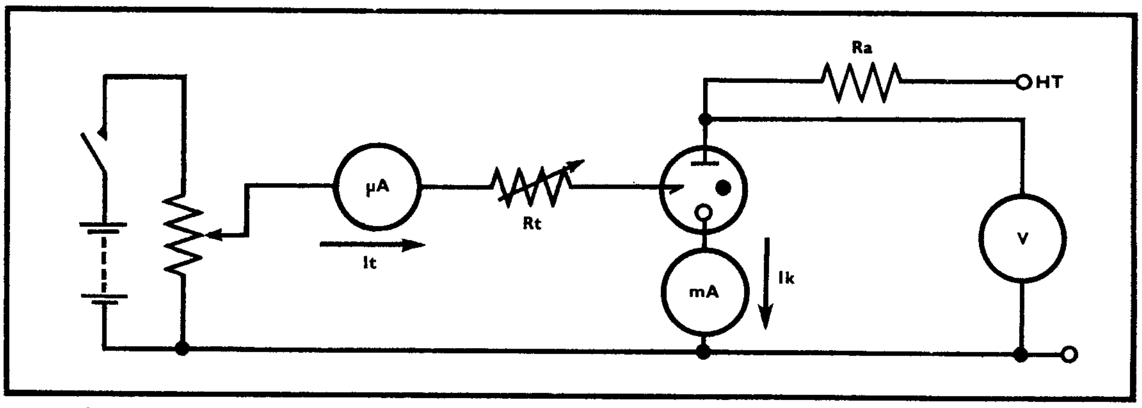


Figure 10

The value of the transfer current varies with the anode voltage and a static transfer characteristic can be drawn as in Fig. 11.

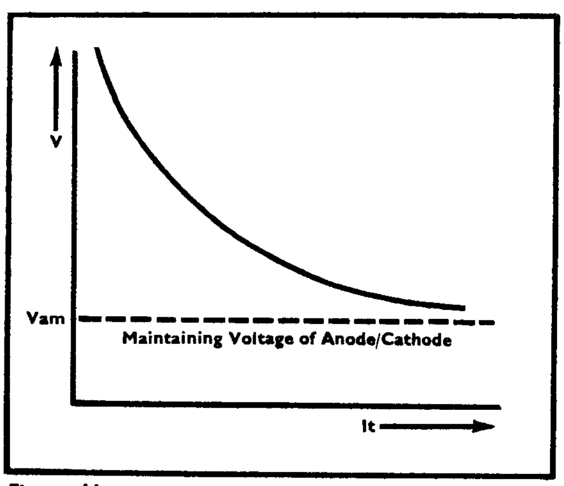


Figure 11

It can be seen that for any value of trigger current there is a corresponding value of anode voltage at which transfer occurs. This voltage is referred to as the transfer voltage or takeover voltage.

(b) **Dynamic Transfer Sensitivity**
In very many applications cold cathode triodes are operated by pulse voltages (either alone or in addition to a DC biasing voltage) and it is necessary to assess the sensitivity of the tube under such dynamic conditions.

For this purpose a square wave generator with controllable pulse width and pulse amplitude is necessary and the usual test circuit is as shown in Fig. 12.

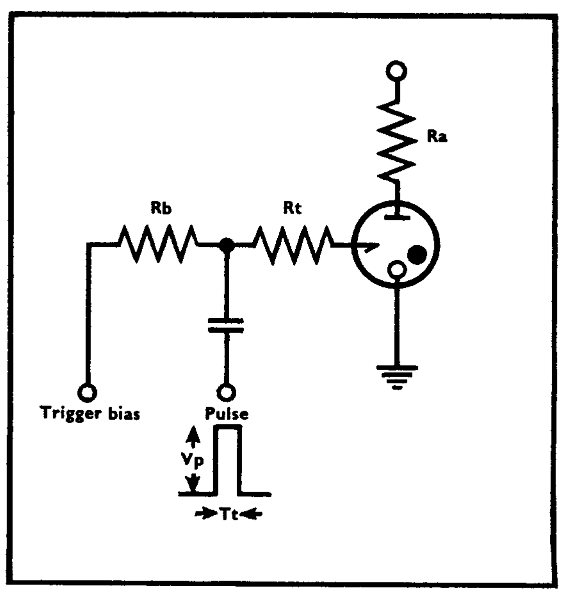


Figure 12

In this circuit R_b must be large compared with R_t to ensure that the full pulse voltage appears on the trigger in addition to the bias voltage.

The anode supply voltage and the DC biasing voltage on the trigger are set to the required values. The pulse duration is set to some predetermined value and the pulse amplitude is increased until the tube strikes. This pulse duration is accordingly the transfer time for the tube corresponding to the pulse amplitude at the preset H.T. voltage. This can be repeated with a range of different pulse durations. The relationship between the transfer time and the pulse amplitude can then be plotted to give a dynamic transfer sensitivity curve as shown in Fig. 13.

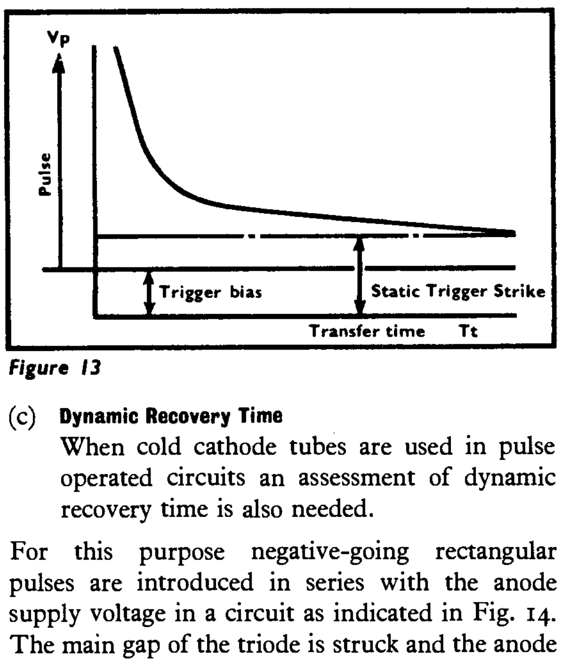


Figure 13

(c) **Dynamic Recovery Time**
When cold cathode tubes are used in pulse operated circuits an assessment of dynamic recovery time is also needed.

For this purpose negative-going rectangular pulses are introduced in series with the anode supply voltage in a circuit as indicated in Fig. 14. The main gap of the triode is struck and the anode current adjusted to the required value. The amplitude of the negatively-going pulse is adjusted so that for the duration of the pulse the anode voltage is reduced to the required clip level. If the pulse duration is sufficiently long the tube will not refire at the end of the pulse when the anode voltage returns to its operating value.

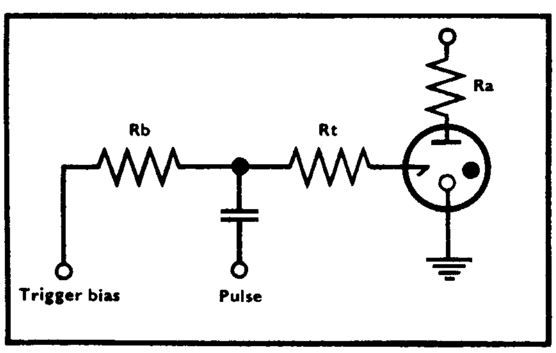


Figure 14

To determine the limiting pulse duration which will just not permit the tube to restrike it is convenient to re-operate the tube by a positive pulse in the trigger circuit after each extinction pulse in the anode circuit. In the circuit shown in Fig. 14 two trains of pulses suitably spaced as shown in Fig. 15 are therefore required.

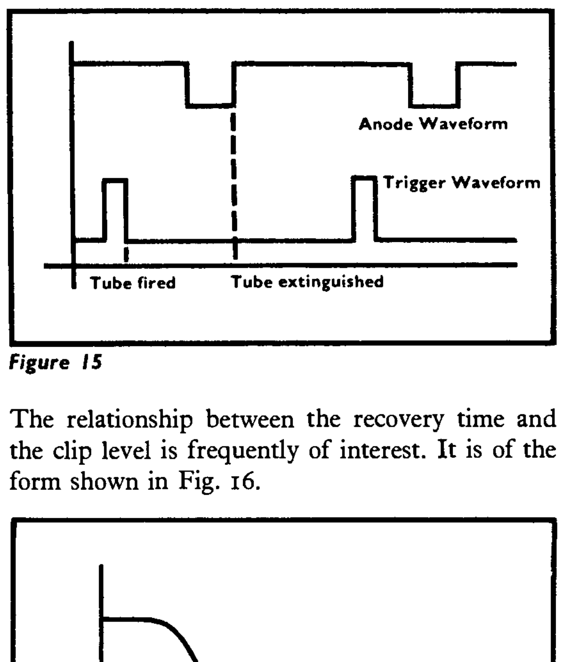


Figure 15

The relationship between the recovery time and the clip level is frequently of interest. It is of the form shown in Fig. 16.

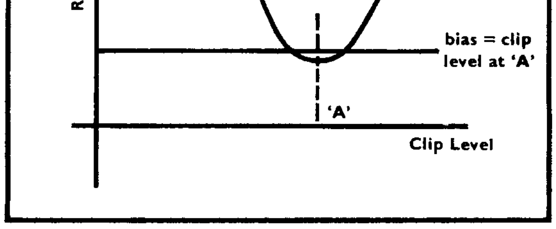


Figure 16

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SECTION IV

Some Typical Applications of Cold Cathode Diodes

1. Indicators

Neon indicator lamps are the simplest form of the cold cathode diode and are very widely used for indicator purposes because of their extremely long life and almost total freedom from sudden failure. Because the maintaining voltage of cold cathode diodes is lower than the strike voltage, these tubes must be operated with a series resistance to limit the current to the desired value. The value of the limiting resistance is calculated to drop the difference between the supply voltage and the maintaining voltage of the indicator at the required operating current. The most widely used type of neon indicator lamp has a maintaining voltage in the neighbourhood of 60V and is operated at a current of approximately 0.5mA. Thus for a 230V AC supply the value of resistance could be 330,000 ohms.

2. Cold Cathode Diodes as Monitors

The monitor application is a special case of the neon indicator in which a cold cathode diode having a relatively stable striking voltage is used to provide visible indication when some voltage reaches a predetermined value. For example a cold cathode diode may be connected to the anode of a thermionic valve in such a way that the normal anode voltage on the valve is insufficient to strike the tube. In the event of a heater failure or any other interruption to the anode current of the valve the voltage on the anode rises, the monitor strikes and gives a visible indication of which valve has failed. Alternatively, the function of the monitor may be to indicate when the anode current of the valve has fallen (due to normal ageing) to some predetermined value representing the end of life.

Applications of this kind call not only for cold cathode diodes of relatively stable characteristics but very frequently they call for tubes which can be relied upon to operate in a wide range of ambient light. It is common practice therefore for such diodes to be of the type referred to earlier in which some radioactive material is introduced to maintain sufficient residual ionisation.

3. Cold Cathode Diodes as Voltage Stabilisers

The use of cold cathode stabiliser tubes is already well known to designers of electrical equipment. The characteristic illustrated in Fig. 4, Section II shows how the voltage across a cold cathode diode remains practically constant over a considerable range of current. Thus by connecting a cold cathode diode in parallel with some load circuit the supply voltage to the load can be kept substantially constant as the current through the load changes. The basic circuit is shown in Fig. 17.

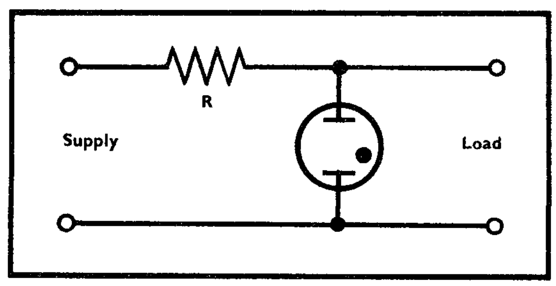

Figure 17

The value of R is chosen so that when the load is open circuited (i.e., when $I_2=0$), the current flowing through the stabiliser is near the maximum permissible for the tube. When the load is connected the voltage across the stabiliser remains practically unchanged. The current through the stabiliser falls as the load current increases so that the total current through R remains the same.

There is a special class of cold cathode stabiliser known as Reference Tubes, having exceptionally stable maintaining voltage characteristics but over a much more restricted current range. Unlike normal stabilisers they are not used to control the voltage applied to a load but exist to provide a stable voltage for comparative or reference purposes.

4. **Cold Cathode Diodes in Relaxation Oscillators**

In circuits such as are shown in Fig. 18a suitable values of resistance and capacity can be chosen to produce relaxation oscillations at a predetermined frequency. The condenser C charges from the voltage source through the series resistance until the striking voltage of the diode is reached. The condenser then discharges through the tube until it extinguishes and the cycle repeats.

In the simple circuit in Fig. 18a the condenser discharges directly through the diode. The peak value of the discharge current may be considerable and for many purposes the introduction of the resistance R_k shown in Fig. 18b will produce more satisfactory results. In such a case the discharge current will have an exponential shape. The further modification to the basic circuit in Fig. 18c will produce negatively-going pulses.

The frequency of oscillation is determined by the striking and maintaining voltages of the tube, the time constant of the condenser and the charging resistance.

The pulse amplitude available from such a relaxation oscillator depends upon the difference between the striking and maintaining voltage of the tube. Special cold cathode diodes are available described as "difference diodes" in which the difference between the striking and maintaining voltage is designed to be substantially larger than in the simplest types of diode. This type of tube is ideal for use in relaxation oscillators.

5. **Cold Cathode Diodes for Pulse Storage**

A cold cathode diode preferably of the difference diode type can be used either for single pulse storage or for coincidence pulse storage.

For storing single negatively-going pulses a circuit similar to Fig. 19a may be used, whilst for storing single positively-going pulses an arrangement as in Fig. 19b as required.

In both cases a DC potential is maintained across the diode which is not sufficient to strike the tube but is sufficient to maintain it after the increased voltage due to the pulse has struck the tube.

For coincidence storage a combination of those two circuits may be used. By a suitable choice of pulse amplitude and circuit values it can be arranged that the tube will fire only when a positive

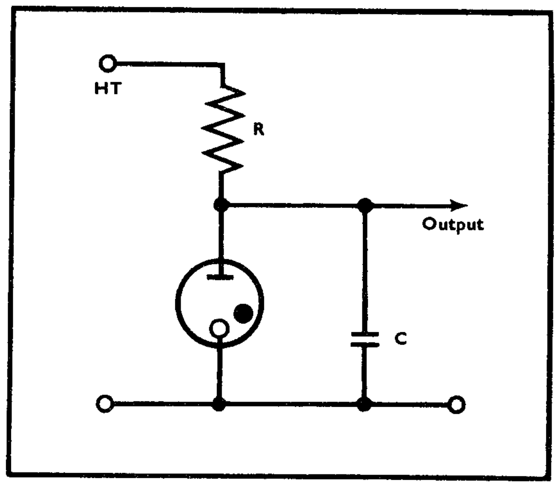

Figure 18a

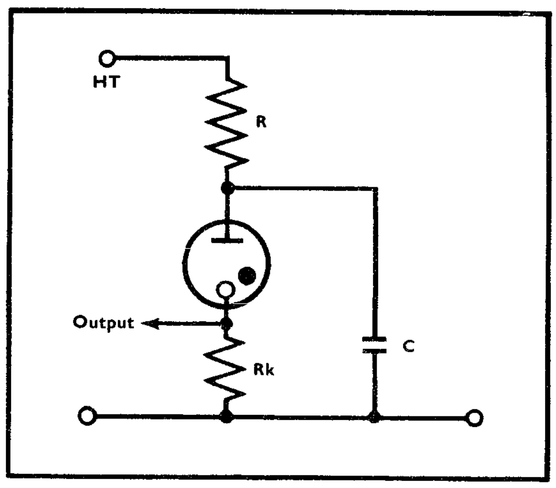

Figure 18b

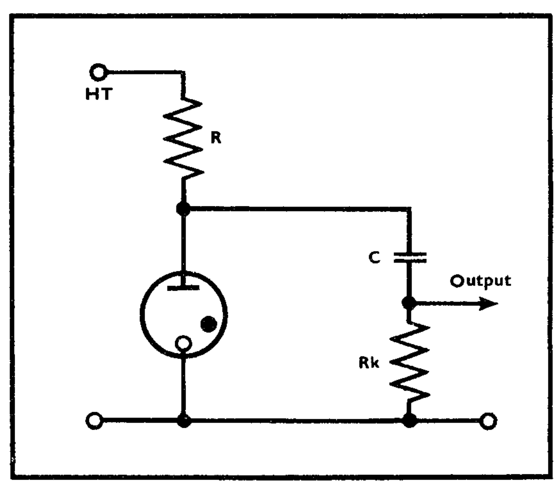

Figure 18c

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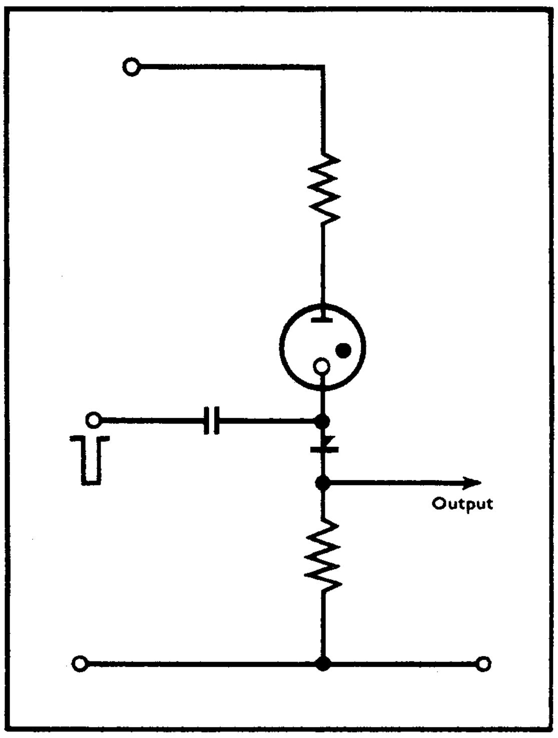

Figure 19a

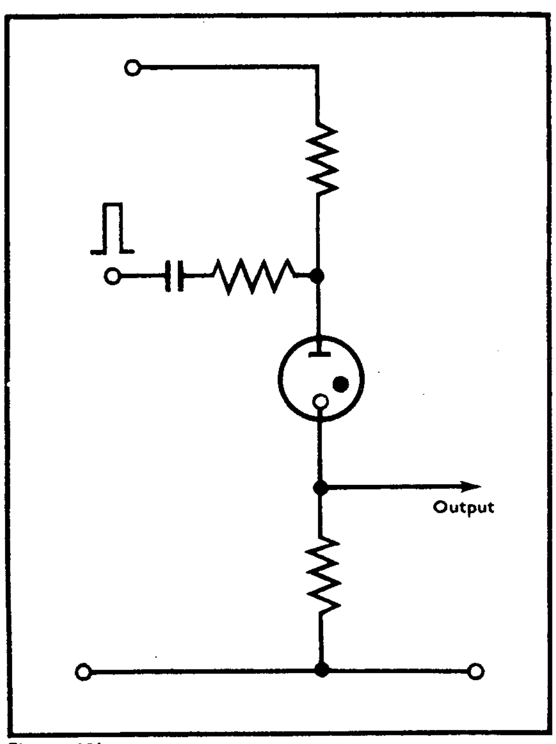

Figure 19b

pulse is applied to the anode of the tube and a negative pulse to the cathode simultaneously and circuits of this kind have very wide application in computing techniques.

The merit of the difference diode type of tube for these applications is that the applied DC voltage or bias across the tube can be high enough to ensure satisfactory maintaining without introducing any risk of spurious firing. The cathode resistor shown in both Figs. 19a and 19b can of course be replaced if required by a relay which will operate when the tube fires and will then hold for as long as the tube is maintained.

6. Cold Cathode Diodes as A.F. Transmission Switches

The DC current in a cold cathode diode can be modulated at audio frequency so that the tube will transmit audio frequency signals or speech currents.

The normal cold cathode diodes introduce some attentuation of the audio frequency signal and also an increase in noise level. Special types of cold cathode diodes have been developed which are commonly known as "speech tubes" in which these undesirable effects are very greatly reduced.

Cold cathode diodes used in this way can be controlled by the applied DC voltages or struck by single or double pulses as described in the preceding section and in this way the diode can replace electro-mechanical relays or switches in A.F. transmission systems.

SECTION V

Some Typical Application for Cold Cathode Triodes

1. General

The operating circuit on the trigger of a cold cathode triode can be separated electrically from the main gap circuit and this considerably widens the scope of cold cathode triodes as compared with diodes.

This factor and the availability of very small and economical tubes has greatly encouraged the use of cold cathode triodes which for many purposes have replaced the diode.

2. Cold Cathode Triodes for Sensitive Relay Operation

The introduction of an electro-mechanical relay in either the anode or the cathode circuit of a cold cathode triode as in Fig. 20 permits the relay to be operated by the very low trigger currents or if required from pulses applied to the trigger circuit. Once the trigger has fired it will maintain and the relay will remain operated as required.

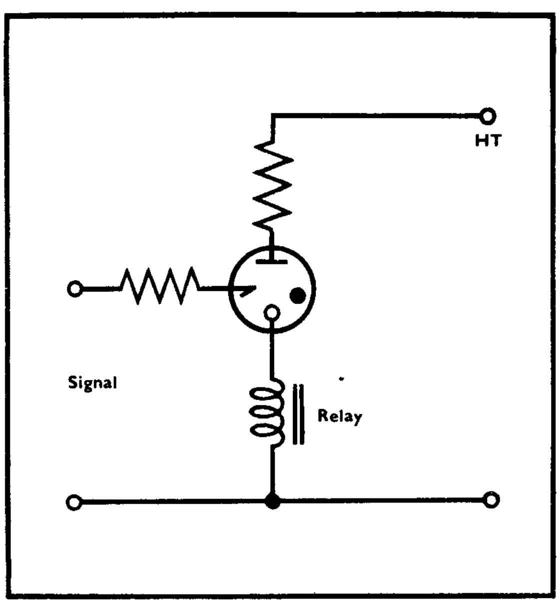

Figure 20

Apart from the sensitivity of this arrangement simple modifications can be made to introduce time delays or to operate the device from an AC source and so on.

Arrangements of this kind have very wide application in telephone switching techniques and in automation systems for the control of machinery and plant.

3. Cold Cathode Triodes as Relaxation Oscillators

The main gap of a cold cathode triode normally has characteristics rather similar to those of a difference diode, i.e., the strike voltage is substantially in excess of the maintaining voltage. For this reason the main gap can be used in a relaxation oscillator circuit similar to that already described in Section IV, No. 4.

Used in this way the triode has certain advantages. Fig. 21a shows a typical circuit in which a potential divider provides a voltage sufficient to fire the trigger. The trigger current is adjusted by R_t and fulfils two functions. In the first place the trigger gap operates as a "keep alive" and in the second place it provides a ready means of adjusting the frequency of oscillation in the main gap.

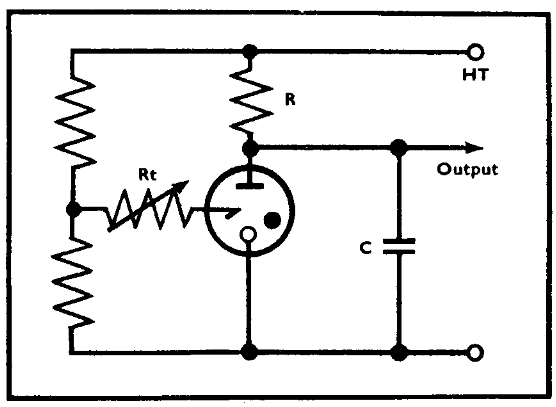

Figure 21a

As already explained in Section III (a) the strike voltage of the main gap is a function of the trigger current. Accordingly, by adjusting R_t the main gap strike voltage can be controlled and the relaxation frequency adjusted.

Figs. 21b and 21c show variations of the simple circuit in which either positively-going or negatively-going output pulses can be obtained.

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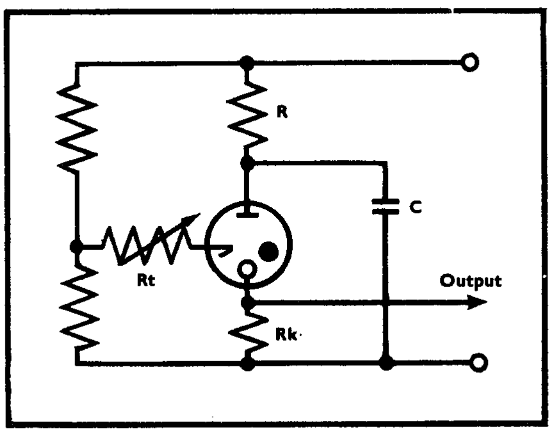

Figure 21b

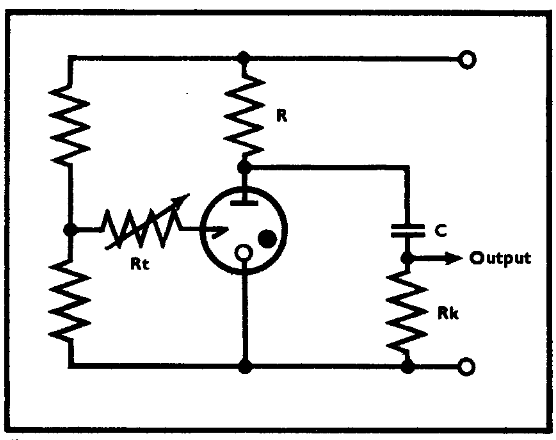

Figure 21c

4. **Cold Cathode Triodes for Coincidence Storage**

Storage of either single pulses or double pulses can be effected by the trigger circuit of a cold cathode triode in exactly the same way as has already been described in Section IV under Diodes. In the triode case, however, the "work circuit" is entirely separate from the trigger circuit which receives the pulses and for many applications this is a significant advantage. Alternatively, coincidence storage can be achieved with cold cathode triodes by arranging that one pulse is received on the trigger and the other on the anode and by a suitable choice of circuit values the tube can be arranged to fire only when the two pulses are received simultaneously.

5. **Cold Cathode Triodes as A.F. Transmission Switches**

The main gap of a cold cathode triode can be used as a transmission path for A.F. signals or for speech in the same way as has been described already in Section V in the case of Diodes.

The trigger cathode gap provides an independent and sometimes easier means of operating the tube and so connecting the A.F. path.

Similar problems of attenuation and noise arise in the design of cold cathode triodes for this purpose but special types of "speech tube" have been evolved in which the unwanted noise level and the attenuation in the anode cathode gap are very low.

Fig. 22 illustrates a typical balanced audio frequency transmission circuit.

6. **Cold Cathode Triodes as Counting Devices**

Individual small cold cathode triodes provide the flexibility to enable circuit designers to make up counting circuits from the simplest two-tube type (e.g., multi vibrator or toggle circuits) to ring counters of 10 or any other required scale.

The two-tube circuits form the basis of counting systems of the binary type. They may be divided broadly into mono-stable or bi-stable circuits and these are illustrated in Figs. 23 and 24.

In the mono-stable circuit shown in Fig. 23 tube T2 is struck initially by some suitable means such as a negative cathode pulse. The arrival of a positively-going pulse on the trigger of T1 causes it to strike. The resulting drop in the voltage on the anode, which is connected to the anode of T2, will cause the latter to extinguish. At the same time the voltage across R1 rises at a rate determined by R1 and C1. When the voltage from R1 added to the bias already existing on C2 is sufficient, T2 restrikes and T1 is then extinguished by the same mechanism as already described. This process, of course, repeats for each incoming pulse.

The bi-stable circuit in Fig. 24 differs from the preceding circuit in that it is stable on either tube, i.e., whichever tube is struck remains operated until an incoming pulse causes changeover from one to the other.

In practice it is normal to make provision to prime one of the two tubes by dropping the cathode potential by some suitable pulse. If it is assumed in Fig. 24 that tube T2 has been struck in this way then the arrival of a positively-going pulse on the two triggers in parallel will have no effect on T2

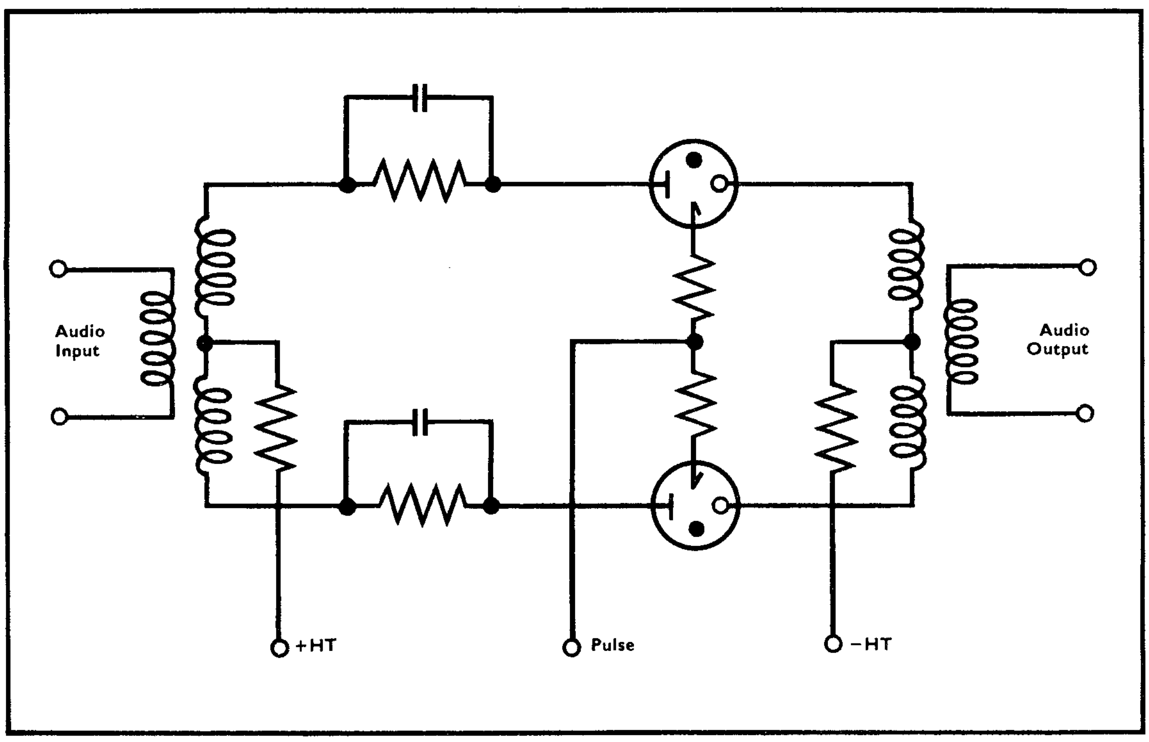

Figure 22

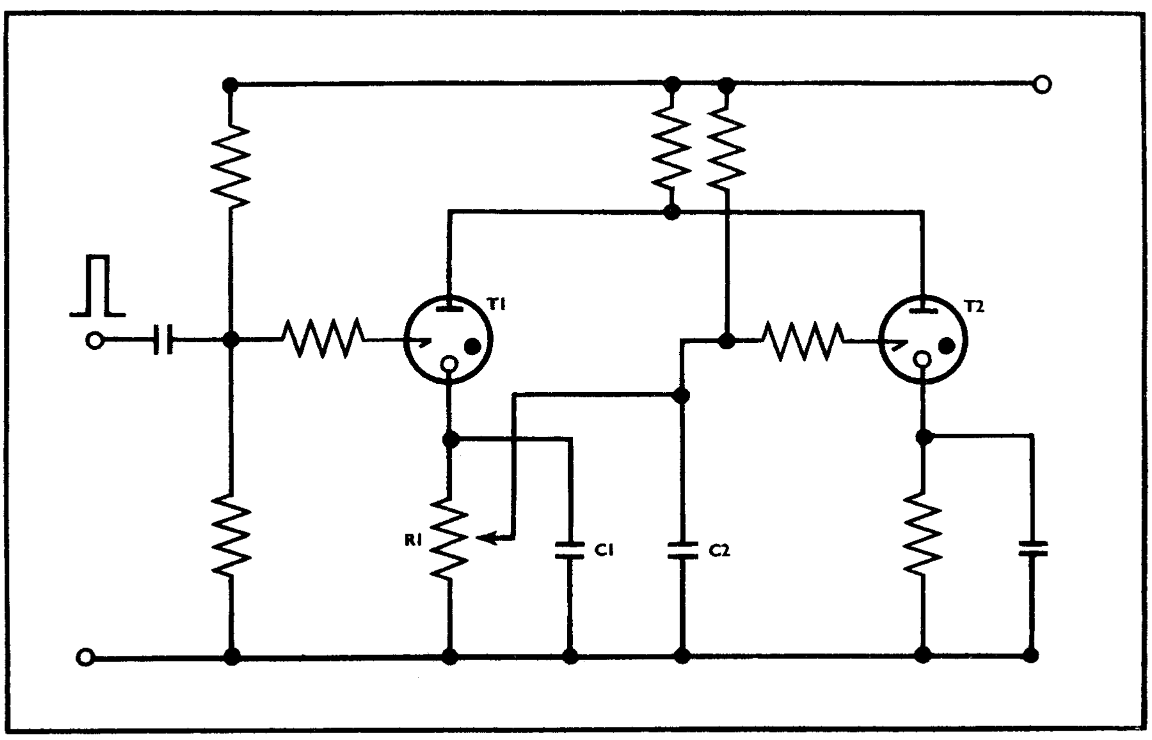

Figure 23

(continued)

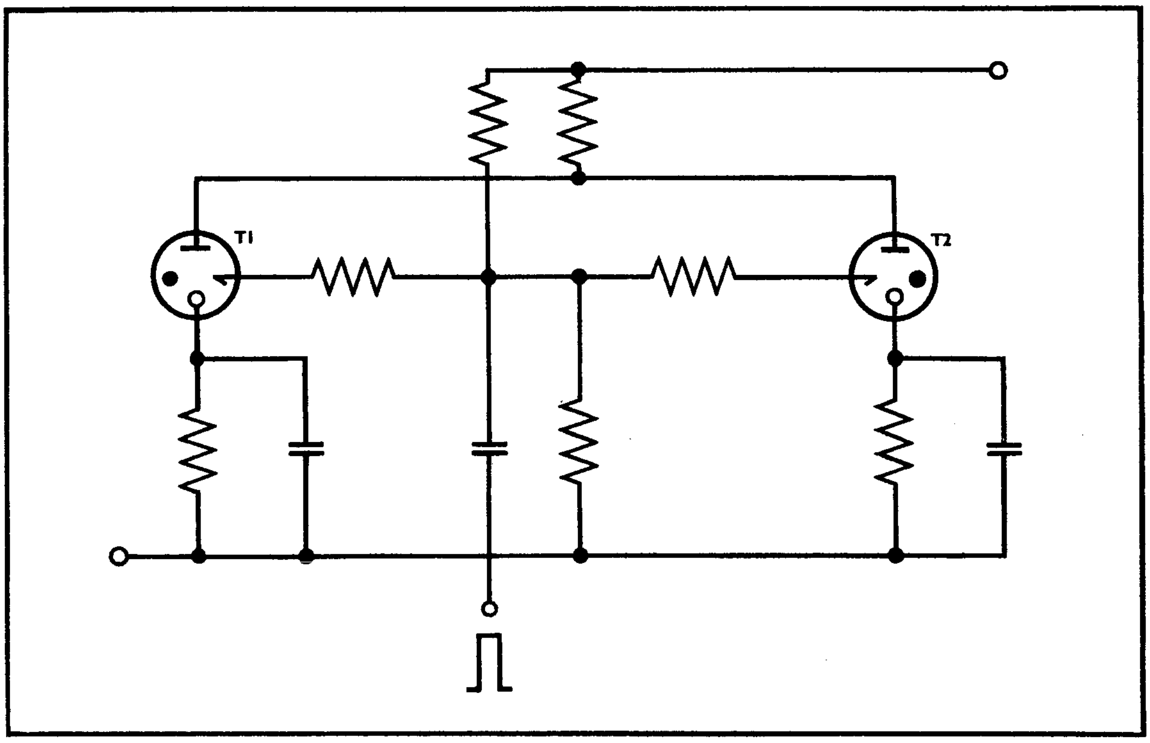

Figure 24

but will strike T1. The operation of T1 will extinguish T2 by the resultant drop in anode voltage and the circuit will remain stable in that condition until the arrival of a further pulse restores the previous situation by striking T2.

Fig. 25 shows the arrangement of a multi tube ring counter in which the H.T. supply to all tubes is connected through a common resistor R_a.

The supply voltage V_b is lower than the main gap striking voltage of the tubes used but higher than the main gap maintaining voltage. If it is assumed that the first tube in the ring is conducting the voltage drop across the cathode resistor R_k operates as a positive bias voltage on the second tube. The circuit values are chosen so that this voltage is insufficient to strike that tube. The remaining tubes in the ring counter are not biased in this way.

Thus the arrival of a positively-going pulse on all the triggers simultaneously will fire the second tube alone.

At the instant of firing, the cathode of the second tube is at earth potential and the anode potential therefore drops to the maintaining voltage of the tube. The cathode of the first tube meanwhile remains above earth for a period determined by the time constant of its cathode circuit. The available voltage between the common anode line and the cathode of the first tube is insufficient to maintain it and the tube extinguishes.

In this way the counter steps on successively from tube to tube as each pulse appears.

In practice provision is frequently made for the first tube of the ring to be self-starting. This is effected by a condenser between the H.T. supply and the trigger of the first tube.

The commonest application for such counters is for decade purposes in which the appropriate number of rings of 10 tubes are employed.

It is arranged as indicated in Fig. 26 that as transfer occurs from the tenth to the first tube a pulse is also passed to the successive ring producing one step. This ring may in turn be connected to a further ring, thus enabling a counter containing any number of digits to be designed.

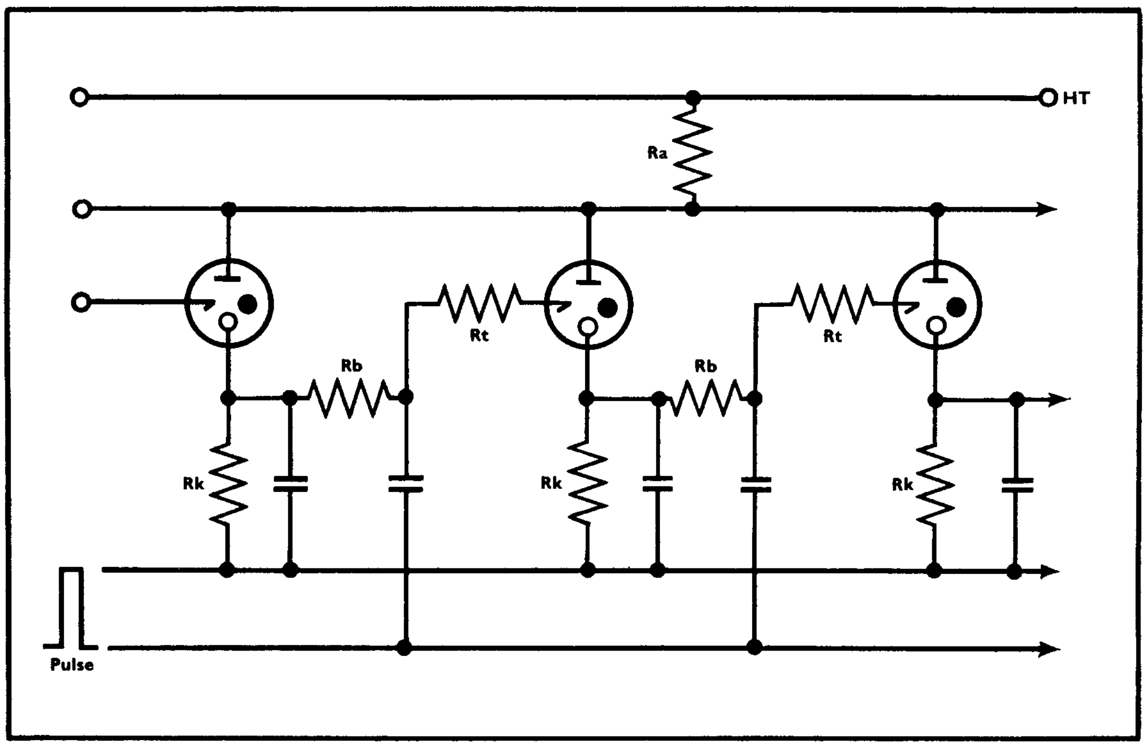

Figure 25

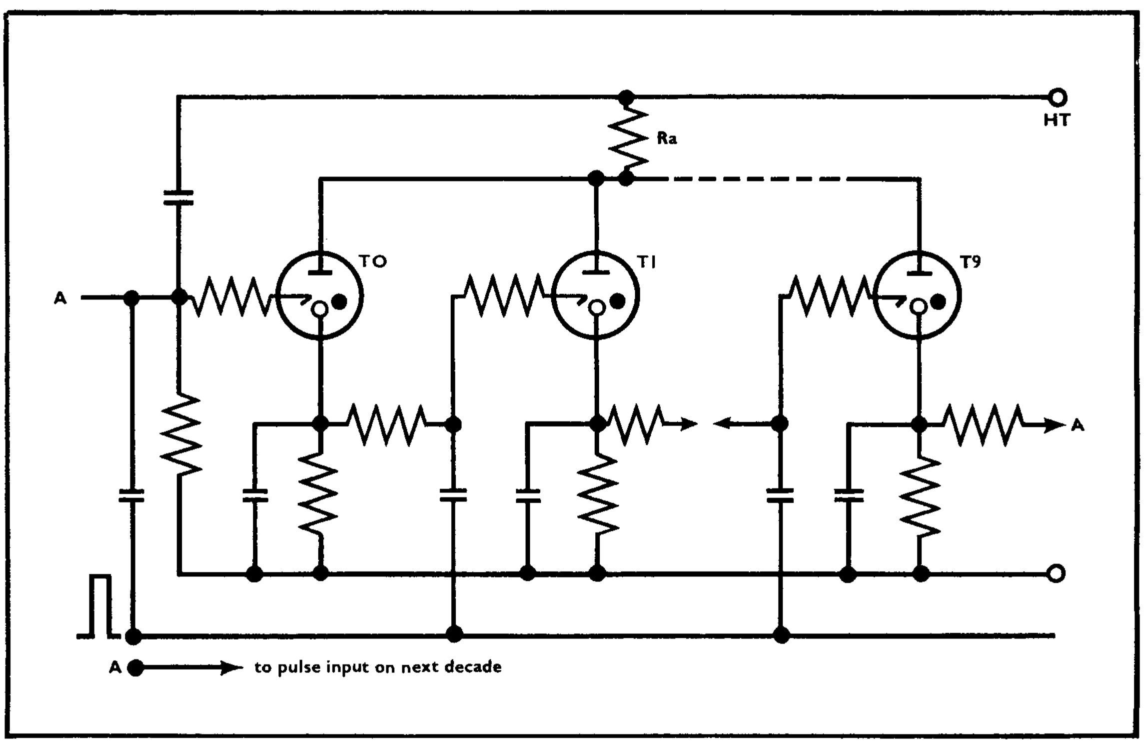

Figure 26