3

Single Cathode Gas Filled Counting Tubes And Their Circuits

Counting circuits using simple cold cathode gas filled tubes can operate at rates which are at least ten times greater than that of fast electromagnetic counters. Most gas filled tubes have the property of self indication; that is, the number of counts can be read by merely observing which particular tube is glowing in each decade, no additional components being required for readout. This property of self indication also simplifies the servicing of faulty units. Cold cathode tubes are extremely reliable in operation and the absence of heaters simplifies the circuitry, reduces the power consumption and results in less heat being generated than in valve counting circuits. Cold cathode tubes are especially useful in industrial automation for many processes, including counting.

3.1 SIMPLE COLD CATHODE TUBES

Simple cold cathode tubes have two or more electrodes and are normally employed in ring circuits. They have two characteristic stable states, namely conducting and non-conducting. Any number of tubes may be employed in a ring, only one of them conducting at any one time. If the tube which indicates the digit zero is initially passing a current (and therefore glowing), the arrival of an input pulse will cause the next tube, which indicates the digit one, to glow and the zero tube to be extinguished. A second pulse applied at the input will cause the glow to be transferred to the next tube. If the last tube in the ring is glowing, the next pulse will ignite the first tube and the last tube will be extinguished. In addition an output pulse will be passed to the next ring. A counting decade may consist of a vertical row of ten trigger tubes mounted on the front panel of the equipment, each tube being placed behind a small window on which the appropriate digit is marked. Similar decades can be placed side by side. Cold cathode binary counting stages are also used.

The multicathode tubes described in later chapters permit the use of simpler circuitry than is possible when single cathode tubes are used, but the circuits employing simple tubes are more flexible, can easily be adapted for a large variety of particular requirements and can operate from lower H.T. voltages. Cold cathode tubes are very reliable in operation. Most multicathode tubes pass a small current and the output voltage available from them is very limited. Single cathode tubes passing 25 mA or more can be used in counting equipment and fairly high output voltages can be obtained from them; such tubes can be used to operate a relay or electro-magnetic counter directly without any intermediate amplification. On the other hand some trigger tubes can be operated at low currents.

Any desired counting scale can be constructed using single cathode tubes, but this is not usually possible with multicathode tubes. Unsatisfactory operation can occur in gas filled polycathode tubes if the discharge remains at one cathode for a long time owing to sputtering of the cathode material, but trigger tube circuits do not suffer from this effect if they are properly designed.

Cold cathode tubes consist of two or more electrodes placed in a glass envelope which is filled with a suitable gas mixture, usually one or more of the inert gases at a pressure of less than one tenth of an atmosphere. If the voltage applied between the anode and cathode of such a tube is less than a certain value, known as the striking voltage, the current which flows is very small (about 10^{-10} A) and is known as the Townsend current. When the applied voltage reaches the striking voltage, the current suddenly increases and is then usually limited only by the internal resistance of the source of applied voltage. The voltage across the tube falls from the striking voltage to a value which is known as the maintaining or running voltage. This is the normal operating voltage of the tube. Under these conditions the discharge is clearly visible, the colour being determined by the nature and pressure of the gas contained in the tube. The current flowing is given by the equation

$$I_a = \frac{V_b - V_m}{R_a}$$

where V_b is the supply voltage
V_m is the maintaining voltage
R_a is the resistor in series with the tube.

The maintaining voltage remains almost constant over an appreciable range of current and suitably designed cold cathode tubes can, therefore, be used as voltage stabilisers. As the cathode current rises, the discharge covers a larger area of the cathode. If the current is increased beyond the maximum permissible value, the anode to cathode potential will first rise and then fall as an overheated spot on the cathode results in thermal emission. Operation at such currents, however, will normally destroy the tube.

Once the discharge has commenced, it is necessary to reduce the voltage applied to the tube below the maintaining voltage for a time which is not less than the tube deionisation time in order to extinguish the discharge. A voltage at least equal to the striking voltage must then be applied to the tube to cause it to conduct again. If the anode voltage is reduced below the maintaining voltage for a time less than the deionisation time, the tube will ignite again when the maintaining voltage is re-applied. The deionisation time varies somewhat with the anode current and the re-applied voltage, but is normally some milliseconds.

Once a discharge has been initiated in a gas filled tube, the positive ions produced form a space charge extending from the cathode towards the anode. This increases the voltage gradient in the cathode region and results in the maintaining voltage being considerably below the striking voltage.

The initiation of the gas discharge when a voltage is applied to any cold cathode tube is dependent on the presence of some ions in the gas. Once the discharge has commenced, the bombardment of the cathode by the positively charged ions formed in the discharge causes electrons to be emitted from the surface of the cathode and these electrons produce more ions as they pass through the gas.

The cathodes used in cold cathode tubes may be divided into two main types. The first type of cathode is coated with a material of low work function which emits electrons easily; materials with a work function of about 2.5 V such as barium or potassium are used. Tubes in which this type of cathode is used have relatively low maintaining voltages of about 60 to 100 V, but the cathodes are subject to deterioration in use. The second type of cathode has a higher work function (about 5 V) and the tubes in which they are used normally have a higher maintaining voltage. Cathodes of the second type usually consist of pure molybdenum or nickel. During the manufacture of tubes employing this type of cathode, material is sputtered from the cathode by heavy ionic bombardment so that the cathode surface is very pure. In addition the sputtered material on the glass envelope binds any impurities in the gas to the wall of the tube. Such tubes are extremely reliable when operated within their ratings, but cannot be used at low anode to cathode voltages.

3.1.1 Priming

If a discharge is to be rapidly initiated when the appropriate voltage is applied to the tube, a limited number of ions must be present in the tube at all times. A few ions per minute are formed in a trigger tube by cosmic rays and by the radiation from stray radioactive atoms which are present in all materials, but more ions are needed if the discharge must always be initiated rapidly. On the other hand, the presence of an excessive number of ions in the gas before ignition will lower the striking voltage and affect the functioning of the tube. Artificial methods for increasing the number of ions present in cold cathode tubes are known as priming.

If a coated cathode of low work function is employed (such as in the Z701U tube), priming may take place by means of light shining on the cathode. This photoemission can occur at wavelengths less than about 5,000 Å, but the glass used in the manufacture of the tubes does not cut off much of the light with a wavelength above 2,900 Å. Such tubes may take a long time to ignite (up to ten minutes) if they are operated in a completely dark room and if no other form of priming is employed. Tubes which have a cathode of low work function should not be operated in bright sunlight or so many ions may be formed that the striking voltage is considerably lowered. Some tubes employing coated cathodes contain a little tritium gas or other radioactive material which provides the ionising particles required for rapid striking even in complete darkness. The amount of radioactive material used is so small that there is no danger even if the bulb of the tube is broken.

Photoemission will not occur from cathodes of the second type which have a high work function unless ultra-violet light of wavelength less than about 2,500 Å falls on them[1], but light of such a wavelength cannot pass through the glass of a normal tube. Such tubes are quite unaffected by bright sunlight, but some method of priming must be employed if the initiation of the discharge is to take place almost immediately after the application of a potential greater than the striking voltage.

One of the most common methods of priming involves the use of an auxiliary anode or cathode. A constant current of a few microamps flows through the gas between the auxiliary electrode and one of the other electrodes so that ions are always present in suitable numbers. If a priming cathode is used, the tube can be extinguished by raising the cathode potential without the priming discharge being affected, but a negative supply line is required. Tubes with a priming anode can be extinguished by lowering the main anode voltage without the priming discharge being affected. In some tubes a priming anode and a priming cathode are used, the auxiliary discharge taking place between these two electrodes. The ionisation time is affected by the magnitude of the priming current, but the maintaining voltage is independent of this current. Primed tubes which use pure metal cathodes have a very constant striking potential and are unaffected by the ambient lighting.

3.2 COLD CATHODE DIODE COUNTING CIRCUITS

One of the simplest cold cathode diode circuits is shown in Fig. 3.1[2]. Let us assume that the left-hand tube, *V*1, is conducting and the right-hand tube, *V*2, is cut off. The voltage developed across R_1 (due to the current flowing through this resistor to *V*1) is such that the voltage across *V*2 is less than the striking voltage of this tube. Thus the system is stable. The capacitor C_2 is charged so that the anode of *V*2 is positive with respect to the anode of *V*1 by an amount equal to the potential difference across R_2.

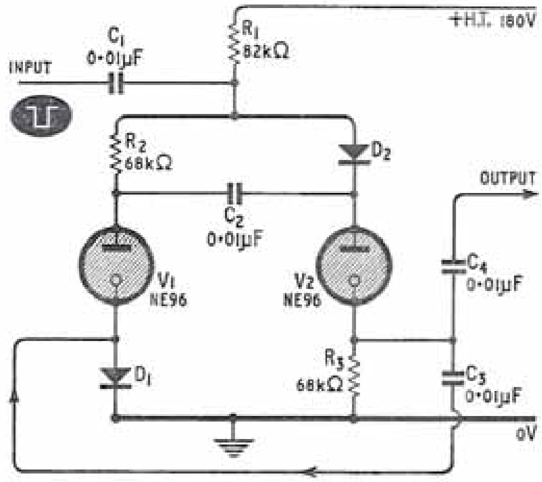

Fig. 3.1 A simple binary counter using cold cathode diodes

If a negative going pulse is now applied at the input, the anode voltage of *V*1 falls below the maintaining voltage and the tube is extinguished. The current through R_1, therefore, decreases and the anode voltages of both tubes will tend to rise. In addition, a sudden rise of anode voltage will occur at

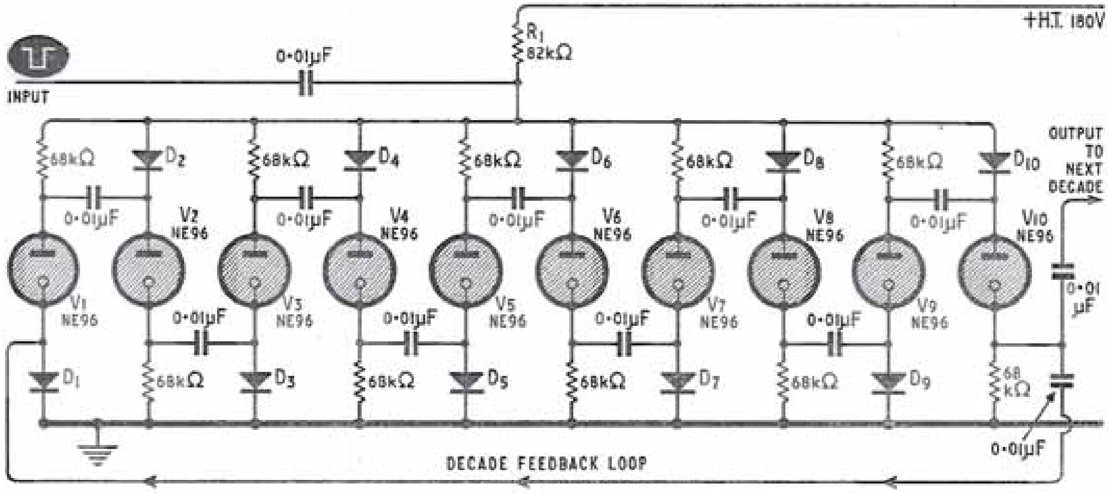

Fig. 3.2 A ring of ten cold cathode diodes for decade counting

the end of the input pulse. C_2 is prevented from discharging rapidly by the reverse resistance of D_2 and, therefore, it holds the anode of *V*2 at a positive potential with respect to the anode of *V*1. *V*2 will, therefore, strike preferentially to *V*1 as the anode voltage rises. When *V*2 commences to conduct, the voltage across *V*1 is kept below the striking voltage by the voltage drop across R_1. The glow is thus transferred from *V*1 to *V*2 and a count is registered.

When *V*2 is conducting, no current flows through R_2 and hence the voltage across C_2 equals the voltage across the diode D_2 – which is small, since the current passes through this diode in the forward or low resistance direction. The capacitor C_3 is charged owing to the flow of current through R_3. The polarity of this charge is such that the cathode of *V*1 is negative with respect to the cathode of *V*2. If a second negative going pulse is now applied at the input, the anode voltages are reduced as before and *V*2 is extinguished. C_3 is prevented from discharging quickly by the high reverse resistance of D_1 and, therefore, the cathode of *V*1 is held at a negative potential with respect to the cathode of *V*2. *V*1 will, therefore, strike preferentially to *V*2, as the anode to cathode voltage is greater. The second pulse thus resets the binary circuit to its initial or zero state in which *V*1 is glowing. The capacitors C_2 and C_3 must be large enough to hold most of their charge during the switching operation, but should not be so large that the maximum counting speed is appreciably reduced.

A number of binary circuits can be cascaded as discussed in Chapter 1 but, when cold cathode tubes are used, it is normally much more convenient to construct a ring counter such as that shown in Fig. 3.2. One common anode resistor, R_1, is employed and the coupling capacitors are placed alternately in between the cathodes and anodes of successive stages as shown. The principle of operation of this circuit is exactly the same as that of Fig. 3.1, but there are ten tubes in the ring instead of two. Any even number of tubes, however, could be used in the ring.

If *V*10 is glowing when an input pulse is received, a positive going output pulse will be produced which may be used to operate a ring of ten similar tubes, in which case the arrangement will count up to one hundred. Alternatively the ouput pulses (after amplification and phase inversion) may be used to operate an electro-magnetic counter.

If the position of the coupling capacitors are altered in Fig. 3.2 so that there is cathode coupling between *V*1 and *V*2, anode coupling between *V*2 and *V*3, cathode coupling between *V*3 and *V*4, etc., the circuit will count backwards as the glow is transferred from the right-hand tube in the circuit towards the left-hand tube.

A very similar cold cathode diode ring circuit is shown in Fig. 3.3 in which all of the capacitors are placed in the cathode circuits of the tubes. Any number of tubes may be used in this type of circuit. When $V1$ is conducting, the right-hand side of C_2 is negative with respect to its left-hand side. If a negative going pulse is now applied to all of the anodes, $V1$ is extinguished and the junction of D_1 and R_2 becomes more negative as the current through R_2 declines. C_2 cannot discharge rapidly through the high reverse resistance of the diode D_2 and the negative pulse from the junction of D_1 and R_2 is applied to the cathode of $V2$. This results in $V2$ striking preferentially to other tubes when the common anode voltage rises at the end of the input pulse.

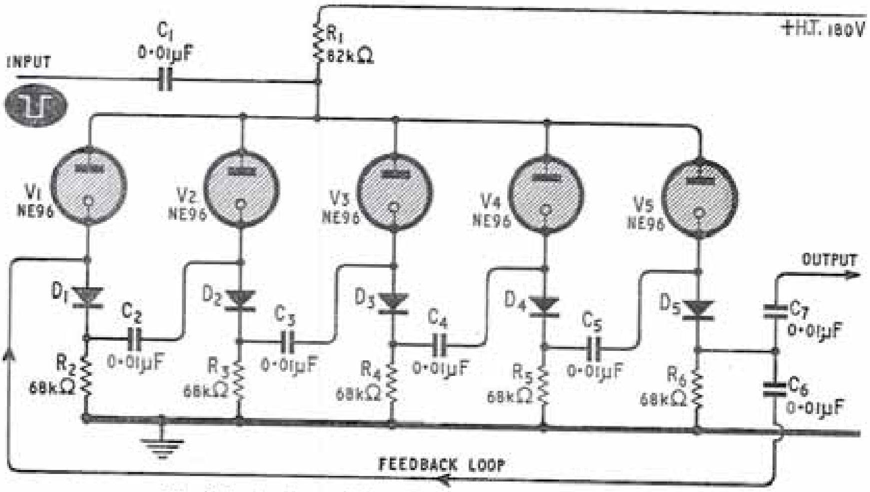

Fig. 3.3 A ring of five diodes with cathode coupling

Cold cathode diodes are not used as counting elements in modern equipment, since similar circuits can be constructed using the more versatile trigger tubes or PNPN semiconductor devices. The maximum speed of cold cathode diode ring circuits is usually of the order of 1 kc/s. Changes in the striking voltage of the diodes during life tends to reduce reliability and the amplitude and duration of the input pulses are quite critical.

3.3 TRIGGER TUBES

A trigger or relay tube is very similar to a cold cathode diode but, in addition to the anode and cathode, it possesses at least one additional electrode known as the trigger or starter. This electrode may normally be considered as an additional anode, although in a few tubes (such as the Z804U) the trigger has a negative potential and acts as an additional cathode. The trigger is normally placed near to the cathode and either in or near to the main anode to cathode gap. The voltage which must be applied to the trigger electrode to initiate a discharge is much less than that required by the main anode. In normal operation the potential applied between the main anode and the cathode of a trigger tube is less than the striking voltage but is greater than the maintaining voltage of the tube. If a suitable positive pulse is applied to the trigger electrode, a current will flow between this electrode and the cathode and the gas between the electrodes will be ionised. Enough ions will be formed for the striking voltage of the main gap to be lowered almost to the maintaining voltage. The greater the trigger current, the greater the amount by which the striking voltage is lowered. Thus the trigger pulse can initiate conduction in the main anode to cathode gap and it can be said that the discharge has been transferred from the trigger gap to the main gap. For a given value of anode—cathode voltage, a certain minimum trigger current is required to enable the main gap to take over the discharge. This is known as the transfer current.