STEPPING TUBES

COUNTING

The main purpose of stepping tubes such as the types described is to indicate the number of pulses occurring at certain points in electronic circuits. These pulses may be derived from many sources: signals from a photocell counting articles on a conveyor belt, random signals from some nucleonic process, or regular pulses such as from AC mains. They may be widely spaced (one or two a day) or so closely spaced that the glow in the 'units,' 'tens,' and 'hundreds' tubes will be circulating so fast that it will appear as a continuous ring.

Besides simple counting, there are two more complex applications — both of which, however, have *counting* as a basis.

TIMING AND BATCHING

If the input signals being counted are the cycles of the 50 c/s mains, then, when the counters read 5-0-0, ten seconds will have passed. With suitable circuits, the tubes can in fact be made to indicate the time of day. A more important use of timing is in the control of processes such as heating or welding. If the circuit can be arranged to take some *action* after a particular number of input signals, then all sorts of control systems can be devised. Thus an RF heating process can be switched off (or to some other temperature) after exactly so many cycles of the mains (representing, say, five seconds). It is even possible to control action which lasts as little as one or two mains cycles. Thus a spot-welder can be controlled to give, say, two cycles of weld, three cycles of rest, and another two cycles of weld.

If the input signals are provided by the passage of articles in front of a photocell, then some action can be initiated when a certain number of articles have passed. Thus a stream of articles from a production unit can be chopped into batches containing any required number. It does not matter if the articles are spaced unevenly on the conveyor belt, so long as there is a gap between each.

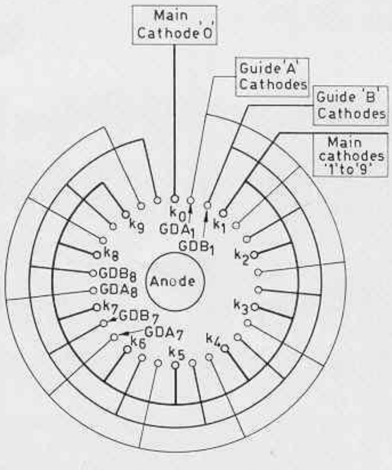
SELECTOR TUBE

How is the glow driven round the stepping tube by the input signals? And how, at any particular point, does the tube initiate external action? The best way to answer these questions is to consider the construction and operation of one type of stepping tube which is know as a *Selector.*

The purpose of a tube such as the Mullard Z502S is to 'select' a particular input signal (say the 3rd, or the 29th) and to provide some external action as soon as that signal has been counted.

DRIVE

The tube contains a circular anode surrounded by a ring of 30 identical rods, which are 'cold' cathodes. The bulb contains a mixture of inert gases. If a DC voltage, greater than a certain value, is applied with positive to the anode, current will flow, and a glow will appear on the cathode. The problem now is to move this round the circle of cathodes in ten distinct steps. Every third rod is a 'main' cathode, and those in between are 'guides,' first a guide 'A' and then a guide 'B'. The cathodes (going clockwise) are GDA$_1$, GDB$_1$, k$_1$, GDA$_2$, GDB$_2$, k$_2$, and so on to GDB$_9$, k$_9$, GDA$_0$, GDB$_0$ and k$_0$. (The diagram, for the sake of simplicity, represents a *Counter* with k$_1$ to k$_9$ taken to a common connection.)



Counter tube electrodes

If any cathode is more negative than any other cathode (that is, if its potential difference from the anode is the greatest in the tube) *this* cathode will be chosen by the glow. If, therefore, the glow is at k$_7$, the obvious way of shifting it to the next cathode (GDA$_8$) is to make GDA$_8$ more negative than k$_7$. Similar means can then shift the glow to GDB$_8$.

In practice, two successive negative pulses are applied, the first to the 'A' guide and the second to the 'B' guide.

These pulses are derived from the input signal. Transfer from the 'B' guide to the main cathode takes place at the end of the second negative pulse, since the guides, when unpulsed, are made to sit at a positive voltage with respect to the main cathodes and the glow will then obviously prefer k$_8$ to GDB$_8$.

It may seem that, as k$_1$ to k$_9$ are all at the same potential, the glow might jump from GDB$_8$ to, say, k$_4$ or k$_9$ instead of to k$_8$. However, k$_8$ has an advantage: it is already in the ionised region which is set up by the glow on GDB$_8$ (it is 'primed'), and for this reason the 'negativeness' which it requires to attract the glow is less than for any other main cathode.

OUTPUT

When the glow has been driven to k$_0$ (or, in the selector tube, to any chosen cathode) an output signal must be obtained. This is arranged by connecting a resistor in series with the output cathode. When the glow reaches this cathode (which has a fixed negative bias) the consequent flow of current generates a voltage pulse across the resistor; and this pulse can be used either to operate the next counter tube or a relay or some other device. The output signal must normally be amplified and shaped before it is suitable for these purposes.

COUNTER TUBE

If a stepping tube is required only for counting, it will have to provide an output signal only once for every revolution of the glow. When the 'units' tube has reached ten it must pass on a signal to the 'tens' tube — which will then indicate '1', while the units tube will go on to count '1, 2, 3, . . .' all over again.

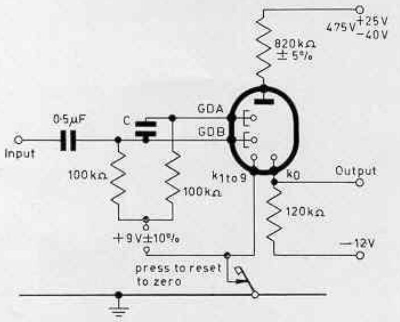
No action is required from any tube anywhere but at its tenth position. Thus the main cathodes '1' to '9' can all be brought out to a single pin. The tenth cathode must still have its own connection. The *internal* structure is the same as that of the *Selector*. The Mullard Z303C is a counter tube of this kind.

INDICATOR TUBE

The indicator tube, such as the Mullard Z503M, is a simpler device. It has only to show what is happening in a counter circuit which otherwise would not have a visual indication. The tube contains an anode and ten cathodes. Each cathode is taken to the appropriate point in the counter, and a glow appears when that particular point is reached by the counting process. The indicator tube can be thought of as ten separate 'neons' in one bulb. The information is visually presented in just the same way as by the counter tubes which may be in the same installation.

DRIVE CIRCUITS

Both the Z303C counter and the Z502S selector need a drive circuit which, from the incoming signal, will produce two successive negative pulses for the guides. Two possible drive circuits are shown.



Sine wave drive

SINE WAVE DRIVE

In this circuit the 'negative pulses' are the negative half-cycle of the mains and a delayed version of it, the delay being produced by a suitable network. This kind of drive is limited to certain applications. If it is used for counter chains, there is a frequency limit below which operation may be unsatisfactory; for, since each stage in a decade chain divides the frequency by ten, the steepness of the leading edge of the input signal is decreased and becomes unsatisfactory for use as a triggering pulse.

INTEGRATOR PULSE DRIVE

The double triode V1a/b, with the diode V2a, amplifies and shapes the input pulse. Its output is fed via C4 to the integrator network R12 C5, which delays the pulse for the 'B' guides. Diode V2b prevents overswing of the guide voltages when the circuit is returning to its standby condition.

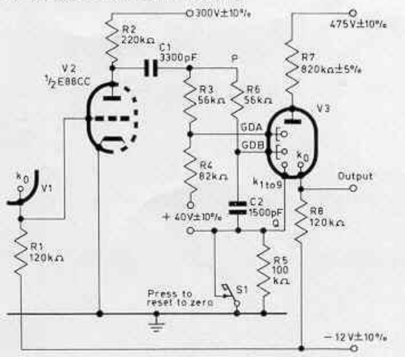
DIRECTION OF ROTATION

There is no reason at all why stepping tubes should not be driven counter-clockwise if this is desired. Guide 'B' is then pulsed negative prior to guide 'A'.

COUPLING CIRCUITS FOR COUNTERS

When it is desired to count to more than ten, it is necessary to use a chain of counter tubes. The output pulse from a Z303C counter tube is the wrong polarity and, besides, its amplitude is too small to drive the next tube. It is therefore necessary to amplify and invert the pulse before it is applied to the integrator network of the next counter.

A suitable circuit is shown. V1 is one counter tube. When the glow in this tube arrives at k_0, a pulse is generated across R1. This pulse is amplified and inverted by V2, and is then fed via C1 to the integrator network R3 R4 R6 C2 and thus to the next counter tube V3. This integrator network must operate under different conditions from those discussed earlier. Whereas the drive circuit for the first counter receives input signals of definite length, the input circuit to the second counter has to accept the output signal as supplied by the first counter. If the glow in V1 is stationary at k_0, V2 will be switched into continuous conduction. The integrator network is designed to facilitate this condition.



Coupling circuit

RESETTING

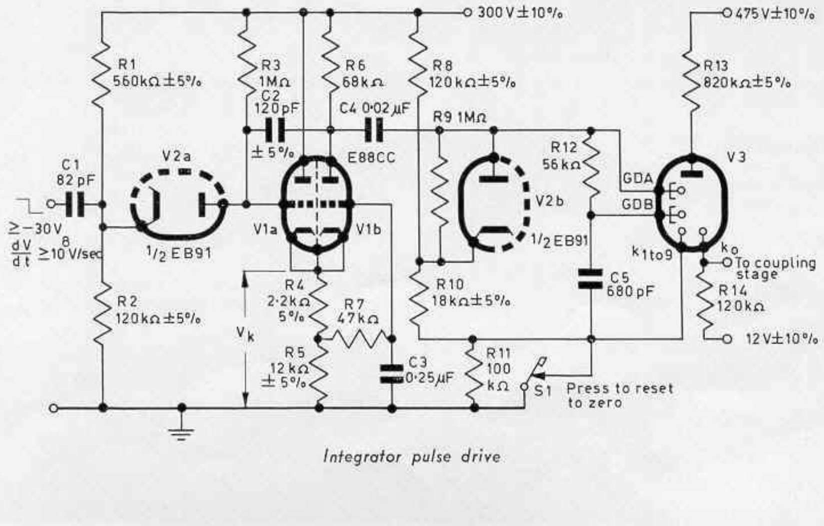
When starting a count, or any other stepping tube operation, it is obviously desirable to reset the glow in the tubes to zero. This can be done either by the push-button S1 shown in the drive and coupling circuits, or by a pulse. In both methods the zero cathode k_0 is taken more negative than any other electrode, and it is held negative until the glow steps to this position. The negative voltage must be greater than used in normal transfer, since k_0 will not necessarily be primed (the glow might be at k_5 on the other side of the tube). An unprimed electrode always needs a greater potential difference from the anode before it will start to conduct.

DIRECT COUPLING

A recently developed counter, the Z302C, operates in chains without interstage amplifiers. It has the advantages of circuit simplification and low equipment cost. However, these advantages are gained at the expense of the maximum counting speed, which is 1000 pulses per second instead of the 4000 PPS possible with the Z303C and Z502S.

CIRCUIT DESIGN

All the tubes discussed require careful circuit design. In particular, the pulse amplitudes and durations must be within the limits given in the data sheets, otherwise the glow may not be transferred at all, may step in the wrong direction or, alternatively, the required counting speed may not be attainable. It is important to use the correct voltages, since potential differences underline every aspect of circuit operation.



Integrator pulse drive

Chapter 3

COUNTING and NUMBER systems

Counting and scaling — two general types of counting circuitry — the gas-filled counter tube — the vacuum counter tube or "trochotron" — numerical notation systems the binary system — BCD codes — fixed and variable weighting — the reflected binary code — redundancy and error detection.

In a great many applications of digital techniques, circuitry is required to perform the operation of counting—usually, counting a series of electrical pulses. The pulses may be occurring randomly as in cases where they originate from a radiation detector such as a Geiger-Muller tube or where they correspond to physical articles on a conveyor belt interrupting a light beam; or, alternatively, they may be occurring periodically, as from an electronic or other oscillator.

The operation "counting" as used in electronics should be carefully differentiated from "addition," although quite often in digital equipment the circuitry used to perform these two operations may be somewhat similar.

Whereas **counting** is the operation of responding to a series of pulses and registering the number of these received, **addition** is the operation where the digital representations of two numbers are used to produce the representation of their arithmetical sum. Addition is one of a number of digital operations normally called "arithmetic," and as such is rather outside the scope of the present series of articles.

Another operation which should be differentiated from counting as such as "scaling." Here the connection between the two is much closer than between counting and addition, because in general exactly the same circuitry is used for scaling as for counting. The difference between scaling and counting is in terms of the interpretation placed on circuit operation.

In counting, the "output" of the circuitry is understood to be continuously available as a registration of the number of input pulses which have occurred up to the time concerned. In **scaling**, the circuitry is arranged to deliver an output pulse only after each successive occurrence of a given number of input pulses; it may be arranged to deliver an output pulse for every 5 input pulses, every 16 input pulses, or so on.

Where the input pulses are derived from an oscillator and are periodic in nature, scaling amounts to **frequency division** because the output of the scaler will also be periodic and will have a period corresponding to the designated number of input periods. Thus for periodic signals a scale-of-16 scaler becomes a $\times$ 16 frequency divider, etc.

The many applications of counting circuitry **as such** include digital-analog and analog-digital information conversion, sequential control of digital computer operations as directed by a 'program," and such digital instruments as voltmeters, frequency- and time period-meters, thermometers and frequency synthesisers. Some of these may be discussed in a later article of this series.

Counting circuits can be divided conveniently into two general types; those whose operation is based upon the use of circuit elements of a bi-stable nature, such as valve or transistor "flip-flops," and those whose operation is **not** based upon such elements. The latter type of counting circuitry is usually arranged to count directly in familiar decimal numeral notation, whereas special arrangements are often required if the former type is to count in this fashion. Usually it is arranged to perform the basic counting operation in binary notation, as will be discussed later in this article and in the following article.

Two examples of counting circuitry which do not depend upon bi-stable circuit elements will now be discussed. These are the circuits associated with the multi-cathode gas-filled counter tube or **"Dekatron"** (this word is actually a registered trade-mark of Ericsson Telephones Limited, but is commonly used to describe any tube of this general type) and those associated with the vacuum-type counter tube or **trochotron.**

Gas-filled counter tubes usually have a construction as shown in figure 1. A central disc anode is surrounded by some 30 rod electrodes spaced equidistantly around its periphery. Every third rod electrode is termed a "cathode," and all but one of these cathodes are connected together (K_{1-9}). The remaining cathode is brought out to a separate electrode (K_0).

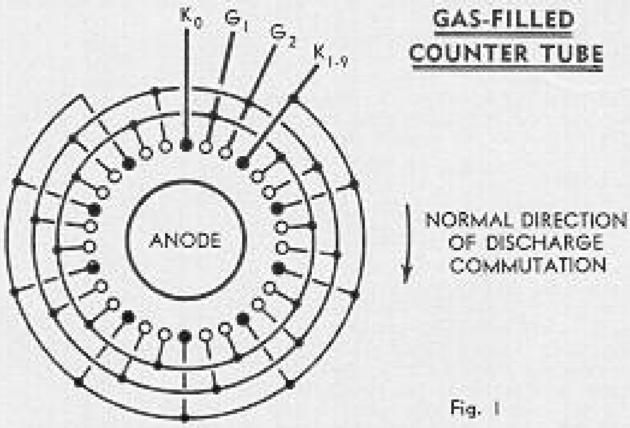
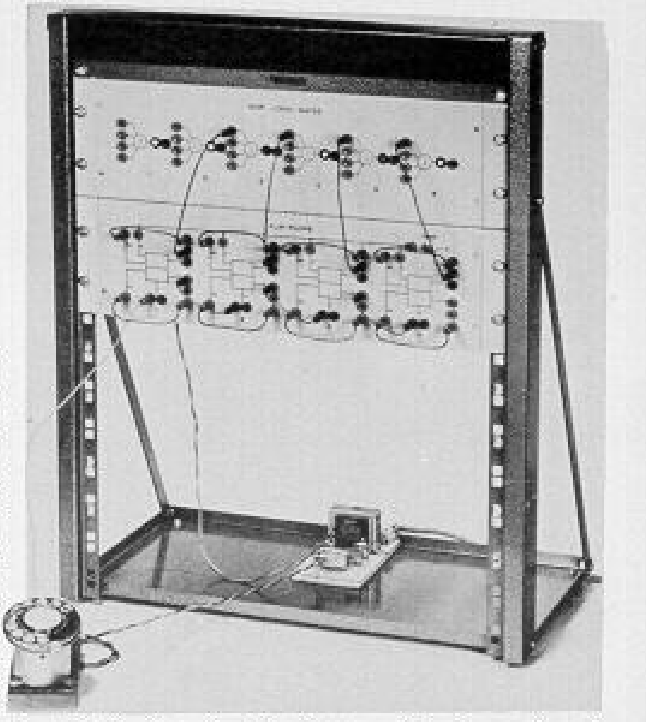


Fig. 1

The larger of the two "Dekatron" gas-filled tubes shown at left is a counter tube; the smaller is a selector tube. (Both courtesy Ducon Division, Plessey Components Group. "Dekatron" is a registered trade mark.)

In this chapter the author introduces the basic concepts of counting and number systems, and discusses decimal stepping tubes. The discussion is continued in chapter 4, which looks at counting techniques employing bi-stable circuit elements. Many of the concepts involved in counting are illustrated by the author's digital demonstrator unit, shown here partly complete. The unit is described in detail in chapters 12 and 13.



The rod electrodes immediately clockwise from each of the cathodes are all connected together, being called the "first guide electrodes" (G1). Similarly, the remaining electrodes are connected together to form the "second guide electrodes" (G2). The complete electrode assembly is mounted in a neon-filled glass bulb which is arranged so that any discharge between the anode and other electrodes may be observed visually.

The operation of this tube as a counter may be explained by reference to figure 2. The anode is connected to a positive supply voltage Vbb (usually about 400V) via a load resistor R1, while the cathodes are taken to earth—via a normally closed push button in the case of K_{1-9}, and either directly or via a small resistor in the case of K_0.

The guide electrodes G1 and G2 are connected to a source of positive voltage Vc (usually about 40V) to ensure that under steady-state conditions they do not act as cathodes. They are also inter-connected and AC coupled to the input terminal—G1 directly via a DC blocking capacitor only, and G2 via an integrating network formed by resistor R and capacitor C.

When voltage is applied to the circuit, pushing the reset button disconnects cathodes 1-9 from earth, leaving K_0 as the most negative of all the rod electrodes. A discharge thus occurs between this cathode and the anode, the current drawn lowering the anode voltage to a value determined by the **maintaining** voltage of the discharge. As this is lower than the **ignition** voltage of the remaining cathodes, the button may then be released without transferring the discharge away from K_0.

Consider now what happens when a **negative - going** pulse is applied to the input terminal, with an amplitude sufficient to temporarily cancel the positive bias on the G1 electrodes and drive them negative with respect to earth. When this occurs the A-G1 voltage will approach the ignition voltage; and as the G1 electrode nearest K_0 is in a region which is partially ionised, its ignition level will be least negative with respect to the anode. Thus, as soon as this voltage is reached the tube discharge will transfer from K_0 to this G1 electrode.

Now the input pulse lasts for only a short time, and when it ceases the G1 electrodes return to the positive potential Vc. If there were no G2 electrodes the discharge would simply return to K_0 when this occurred. However, there are G2 electrodes, and the integrating circuit formed by R and C has the effect of supplying these electrodes with a delayed version of the input pluse.

The integrating constants R and C are, in fact, so arranged that, at the very instant that the G1 electrodes return to the positive bias voltage, the G2 electrodes have just reached the voltage where the G2 electrode nearest the conducting G1 electrode is at its ignition voltage. Again, this G2 electrode will have the least negative ignition of all G2 electrodes because it is in a region of partial ionisation. Thus, the discharge will not return to K_0 but will transfer from G1 to G2.

When, in turn, the pulse on the G2 electrodes decays, the discharge cannot return to the G1 electrode from whence it came because this has returned to the positive voltage Vc. Instead, it transfers to the most negative electrode in the vicinity, which is also the electrode with the least negative ignition voltage—K_1. And it will remain on this cathode until another pulse appears at the input to initiate a second transfer cycle.

It may be seen that the single negative input pulse has resulted in a stable transfer of the tube discharge from one cathode to the next. In identical fashion, further input pulses will transfer the discharge around to the other cathodes in turn.

The tenth pulse will return the discharge to K_0: and if a resistor (shown

THE TROCHOTRON

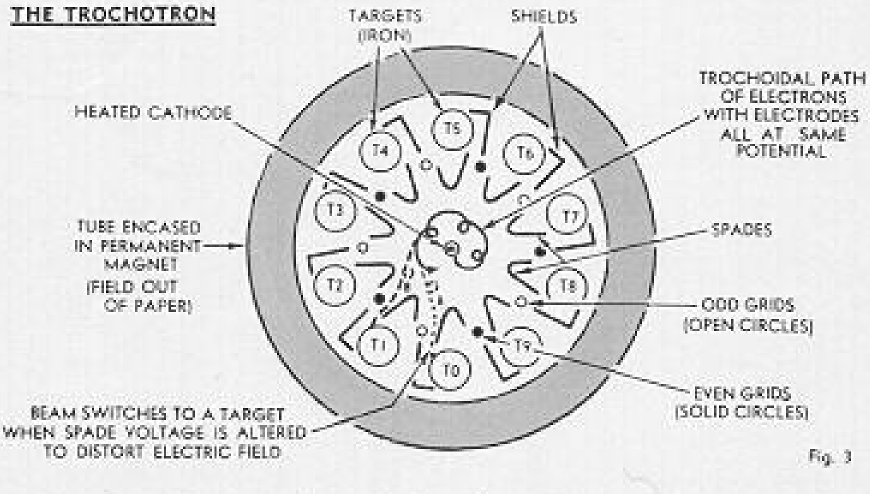


Fig. 3

The tube at right is a trochotron high-speed vacuum counting tube, capable of operating at counting speeds up to 1MHz. (Courtesy Mullard-Australia Ltd.)

dashed) is fitted in series with this cathode a positive pulse wll be generated for possible use in feeding a "tens" counting circuit. As far as this stage is concerned, however, the discharge will continue to commutate from one cathode to another for each successive input pulse.

Read-out of the count registered by the tube may be performed at any time simply by looking into the tube to see which cathode is currently associated with the discharge—or, at least, this can be done when the tube is counting fairly slowly. When rapid counting is occurring it may not be possible to see which cathode is associated with the discharge glow.

And although the gas-filled counter tube is not capable of counting at particularly high speeds, the maximum speed is about 20KHz—rather too high for visual read-out while in operation! As with all counters, however, the read-out may be made whenever the input pulses slow down or cease temporarily.

The gas-filled counter tube may be used for scaling, as one might imagine. Even the tube shown in figures 1 and 2 may be used in this fashion, as the resistor from K_0 to earth provides an output for every 10 input pulses. However, for scaling purposes it is usual to employ a variation of the basic tube design in which other cathodes besides K_0 are brought out to separate connections. In some cases all 10 of the cathodes are given separate connections, in which case the tube is called a "selector" tube.

Finally, it may be noted that the gas-filled tube may be made to count in reverse simply by interchanging the connections to the G1 and G2 electrodes.

The major disadvantage of the gas-filled counter tube is that its counting speed is limited. Where counting must be performed at speeds higher than about 20KHz the de-ionisation time of the gas filling makes operation unreliable.

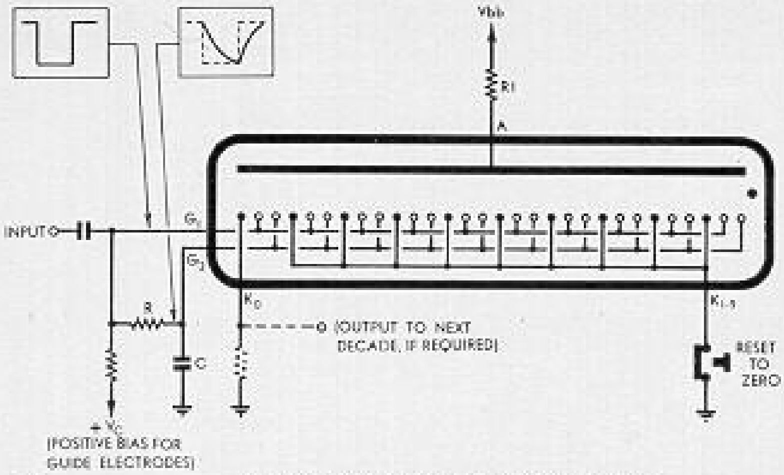


Fig. 3

OPERATION OF GAS-FILLED COUNTER TUBE

The basic circuit of a pulse-counting stage using a gas-filled counting tube of the type shown on page 44. By feeding each input pulse sequentially to the two guide electrode systems, the cathode discharge is switched.

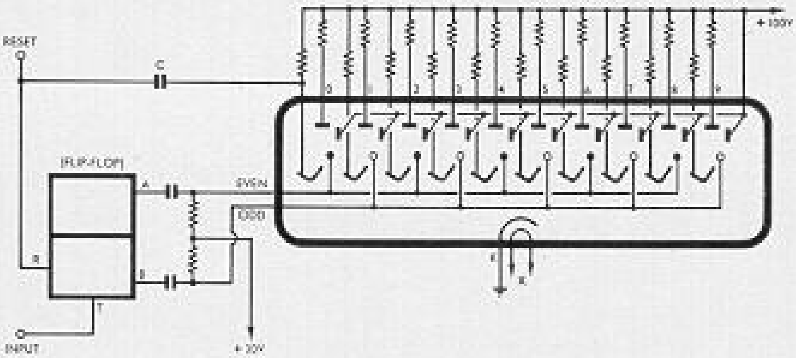


Fig. 4

OPERATION OF THE TROCHOTRON

The basic circuit of a counting stage using the trochotron vacuum counting tube. Input pulses initiate negative-going pulses alternatively at the "even" and "odd" grid electrodes, switching the electron beam.

A vacuum-type counter tube which is capable of operating to about 2MHz is the **trochotron,** also called the "beam-switching tube" or the "beam-X switch." Although this tube is somewhat different from and more complex in its operation than the gas-filled counter tube, there are certain similarities which should become apparent from the following description.

Figure 3 shows the construction of a typical trochotron. In an evacuated envelope which is surrounded by an annular permanent magnet are ten cylindrical iron electrodes which act both as guides for the magnetic field and as "target" electrodes. The magnetic field within the tube may be visualised as parallel to the axis of the tube and emerging perpendicularly from the plane of the diagram. (In some versions of the trochotron there is no external magnet, but the target electrodes are themselves magnets.)

At the centre of the tube axis is a conventional heated cathode. Interposed between this cathode and each target electrode are ten "J"-shaped electrodes termed "spades," and adjacent to the spades wire electrodes termed "grids." Finally a set of "L"-shaped electrodes are included between the targets to act as electrical shields.

The shield electrodes are all connected together; while alternate grids are connected together to form two groups of five (shown as open and solid circles on the diagram, for clarity) termed the "odd" and "even" grids. All spades and targets are given individual connections.

In operation the shield electrodes are connected to a positive voltage supply (usually about 100V). The targets are connected to the same supply via low-value resistors, while the spades also connect to the supply via high-value resistors. The cathode is earthed, and the grid systems connected to a positive bias supply (about 30V) via suitable resistors. Figure 4 shows the general circuit configuration.

The tube is arranged so that with the correct operating voltages applied to the electrodes at switch-on, the magnetic and electric fields adjacent to the cathode are such that on leaving the cathode electrons do not move to any of the positive electrodes but spiral around the cathode in paths corresponding to the mathematical **trochoid** curve.

They do not proceed to the positive electrodes because the latter are all at the same voltage, resulting in a completely uniform radial electric field: the electrons are "trapped" into rotating around the cathode under the influence of the magnetic field, oscillating away from and toward the cathode under the combined influence of both fields.

To cause the tube to register "0" the electron beam must be guided into moving to Target T_0. This is done by applying a negative-going pulse to the "reset" terminal in figure 4, the pulse having an amplitude of approximately 35V. One of the effects of this is to apply the pulse to the "0" spade electrode, temporarily lowering the voltage on this electrode to earth potential or beyond.

With spade "0" at earth potential the electric field within the tube is distorted in such a way that the electron beam is deflected from its circular path to glance past spade 0 and be collected by target T_0. Although most of the electrons are collected by T_0, sufficient are collected by spade 0 to maintain the low voltage on this electrode due to voltage drop in the supply resistor. When the reset pulse ends, the beam thus remains in its new position, virtually "locking" itself to T_0 by maintaining the low voltage on spade 0.

To explain how the tube performs counting, reference must be made to the flip-flop unit shown capacitively coupled to the two grid systems and connected to the reset terminal.

The flip-flop will be discussed in some detail in the next article in this series and it is not proposed to explain its operation here. For the present, it will be sufficient to regard it as a device which responds to pulses applied to the input terminal by providing negative pulses alternatively to outputs A and B. The application of the reset pulse to the flip-flop "R" terminal can be visualised as adjusting it so that the **first** input pulse will result in a negative pulse appearing at A.

When the first input pulse occurs, then, a negative pulse will be applied via the appropriate coupling capacitor to the trochotron "even" grids. As one of these is immediately adjacent to the electron beam currently switched to target T_0, this will cause the beam to be repelled from T_0; and the tube geometry and fields are so arranged that it is in fact deflected toward spade 1 and target T_1. As soon as some of the electrons are collected by spade 1, its voltage falls, and the beam is thence locked to target T_1 in the same manner as before.

When the second input pulse arrives it causes a negative pulse to be produced by the flip-flop, not at A but at B—and thence to the trochotron "odd" grids. And since one of **these** is adjacent to the beam in its new position, the beam will again be repelled and directed to spade 2 and target T_2. Fairly obviously, each input pulse will cause the beam to transfer to a new spade and target, while between pulses it will remain stably associated with the last spade and target to which it was switched.

And because the switching is being performed by a beam of electrons moving in a vacuum, the counting can occur at quite high speeds—up to about 2MHz, as mentioned before.

Note that there is no provision for direct visual read-out of the count; however, the targets are all brought out to separate connections to allow use to be made of the fact that there will be a voltage drop across the load resistor of the target currently associated with the electron beam. By suitable circuitry connected to the targets, the voltage drop at this target can be made to produce an indication.

Often a cold-cathode numerical indicator tube is used for this purpose; details of such indication devices will be given in a later chapter.

The fact that all 10 targets are brought out separately also makes the trochotron highly suitable for scaling. However, note that, due to the geometry of the tube and to the fixed magnetic field, it can switch only in one direction. It cannot be used for reverse counting and is, therefore, at a disadvantage compared with the gas-filled tube.

As mentioned earlier, the other main type of counting circuitry is that which is based upon bi-stable circuit elements. Nowadays this type of circuitry is actually in far more common use than the type which we have just been discussing; accordingly it will be discussed at somewhat greater length.

However, in order that the reader may be helped to a greater understanding than otherwise of the principles involved in such circuitry, it will be worthwhile at this point to re-examine our concepts of digital information and numerical notation.

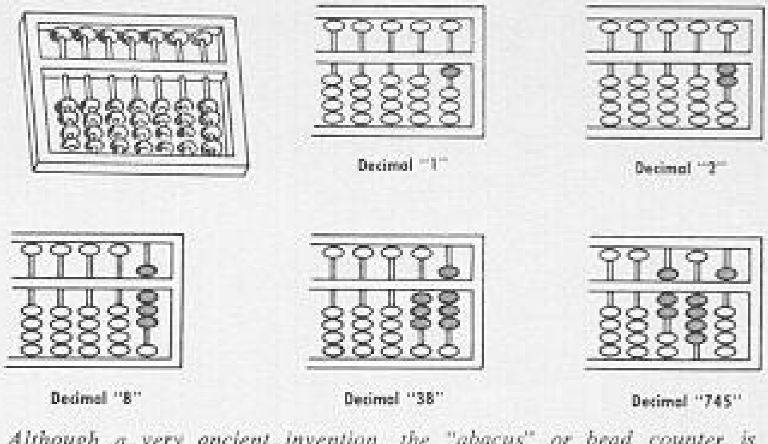
Thus far in the discussion of digital circuitry given in these articles we have regarded the digital information processed by the circuitry from a logical viewpoint—i.e., as **statements which** may take either of the two values "true" (1) or "false" (0). And this relatively simple conception of digital information is, in general, quite adequate for a consideration of the basic logical circuit functions.

However, it becomes necessary to analyse and expand this concept if one is to understand fully the operation of the digital circuitry involved in storage of information, counting, and "arithmetic." In the present chapter we will be concerned with the concepts involved in counting and information storage, while some of the concepts involved in "arithmetic" will be discussed in chapter 11.

In most cases the content of digital information statements is numerical: i.e., the information is in the form of numerical statements or numbers. And for a digital system having only two possible value-states to easily handle such statements, they should ideally be in the form of dyadic or "two-valued" numerical notation—**binary numbers.**

In order to be reasonably clear in one's conception of digital counting and storage it is, therefore, necessary to become familiar with the general concepts

The ABACUS: an early BCD counter



Although a very ancient invention, the "abacus" or bead counter is still very widely and effectively used for rapid addition and subtraction. A typical abacus employs "bi-quinary" notation, a system in which each decade is counted in two groups of five. The diagrams above should help in understanding how the abacus operates.

GLOSSARY OF IMPORTANT TERMS

Addition: A digital arithmetic operation in which the electrical representations of two (usually binary) numbers are used to produce the representation of their arithmetic sum. Circuit configurations involved in addition are discussed in chapter 11.

Base or Radix: That parameter of a numerical notation system which describes the number of values which may be taken in any given digital position. The base of the decimal system is 10, while that of the binary system used by most computers is 2.

BCD Codes: Numerical codes which employ the two binary digit values 1 and 0 in arbitrary combinations to represent the ten decimal digits. Theoretically there are more than seven million such binary-coded-decimal codes, but not all are used.

Bit: A convenient contraction of "binary digit." Having only two possible values (1 or 0), a single bit may be regarded as the smallest possible quantum of information.

Counting: A digital operation in which a configuration of circuit elements is arranged to produce an electrical representation of the number of pulses applied to their input. Counting plays an important part in the operation of most digital instruments.

Redundancy: An information theory parameter describing the efficiency of a symbolic information transfer system. Defined as the ratio of the unused information potential of the symbols being used to the information capacity actually being utilised.

Scaling: An operation in which a group of circuit elements are arranged to produce an output pulse after each successive occurrence of a given number of input pulses. When the input pulses are periodic in nature, scaling becomes **frequency division.**