MULTI-ELECTRODE COUNTING TUBES*

by

K. Kandiah, M.A., B.Sc.† and D. W. Chambers†

A Paper presented during the Industrial Electronics Convention held in Oxford in July 1954

SUMMARY

The paper considers possible uses of hot and cold cathode decimal counters in systems other than straightforward counting. It deals with their uses for adding and subtracting, for counting a predetermined number, and for dividing by numbers less than ten. The principles of a pulse-amplitude analyser using trochotrons and dekatrons in a matrix system are outlined. References are also made to other possible uses where they are expected to be more reliable than more conventional methods.

1. Introduction

Multi-electrode counting tubes such as the Ericsson Telephones GC10B, the Mullard E1T, and the L.M. Ericsson RYG10, have made it possible to count in decimal figures in a manner which is considerably simpler than in those systems which use a multiplicity of thermionic or cold cathode tubes. It is now possible to use these new tubes in equipment for counting nuclear events and for various counting applications in industrial process control, with the advantage of direct indication of the number stored, high counting speeds, and simple zero resets. The reliability of these tubes has encouraged their use in further applications. It is the purpose of this paper to assess features of these tubes which make them suitable for some unusual applications.

The characteristics of these tubes have been described in detail in the literature.[1, 2, 3, 4, 5]

2. Counting in Decimal Figures

Most of the tubes available at present are designed to count in decimal figures and they are all suitable for connection in a cascade system providing a store of as many digits as desired. The complexity of such a complete unit depends largely on the type of pulses required to drive the tubes. These are single pulses, or pairs of pulses, having fairly wide permissible tolerances for the gas-filled tubes, and pulses of defined amplitude and shape for the E1T and RYG10-type tubes.

* Manuscript first received June 11th, 1954, and in final form on August 3rd, 1954. (Paper No. 310.)

† Atomic Energy Research Establishment, Harwell, Berkshire.

U.D.C. No. 621.387 : 621.374.32.

All tubes available at present in this country provide an output pulse which is of smaller energy content than that required to drive a succeeding counting tube. It is therefore necessary to provide a driving stage, using at least one thermionic valve, or cold cathode trigger tube between the stages of a cascade. A gas-filled counting tube has been described[6] in which the necessary coupling element in the form of a trigger tube is built into the envelope which contains the counting tube.

The Ericsson Telephones GC10B has the advantage of being completely symmetrical, and can therefore be driven in either direction. It is only necessary to reverse the connections to the transfer guides in order to reverse the direction in which the glow transfers. If, however, it is necessary to make the tube add or subtract when an input pulse is applied to one of two alternative points, it is necessary to have independent driving circuits which apply transfer pulses in the correct sequence. When a cascade of GC10B stages is required to add or subtract, the problem becomes more involved, and one method of providing this facility has already been described.[7] A disadvantage of this method is that ambiguity in reading the digits may sometimes be experienced, and it will then be necessary to determine the digit stored by reference to the position of the glow in the previous tube.

An advantage of the method[8] of driving a cascade of GC10B stages by utilizing a combination of a common pulse generator and gating tubes as coupling elements is that it readily lends itself to a reliable method of addition and subtraction. In its simplest form, the circuit of one stage of a cascade is as shown

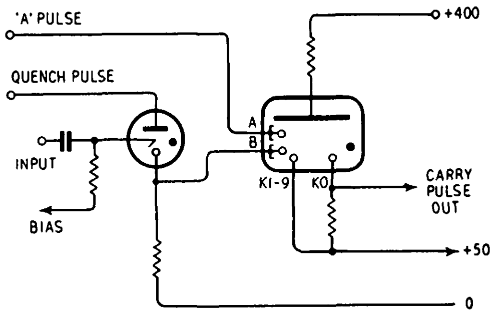


Fig. 1.—One stage of a cascade.

in Fig. 1. In this system, the discharge rests on a "B" cathode of the counting tube and the "A" and "K" cathodes are used as transfer guides. All the stages in the cascade are identical and "A" pulses and "quench" pulses from a common pulse generator are applied to all the stages of the cascade whenever an input pulse is received into the first stage. The waveforms in the first two stages in such a system for addition are shown in Fig. 2. Although pulses are applied to all the "A" transfer guides, the glow will advance by one digit in only those stages which have received a pulse into the trigger tube.

In principle, a cascade of stages using the circuit of Fig. 1 can be made to subtract if the common pulse generator delivers the pulses shown in Fig. 3 which also shows the appropriate waveforms in the first two stages when they count backwards from 10. It should be noted that in this method the first trigger tube receives a pulse which is delayed by about 200 μsec on the input pulse and that all "A" transfer guides receive a negative pulse from the common pulse generator during this delay.

The realization of a practical unit which will add or subtract, working on the principles outlined, will require some changes to the circuit shown in Fig. 1 and to the waveforms from the common pulse generators.

During the period of the negative pulse to all "A" transfer guides, the discharge in the counting tubes will move from the "B" guide to an adjacent "A." This will result in the lowering of the cathode potential of the trigger tube associated with each stage. The tube may therefore fire even in the absence of an input pulse to the trigger electrode and the unit will miscount. It is therefore necessary to modify the cathode circuit of the trigger tubes so that they will fire only when an input pulse is applied to the trigger electrode and not when the associated counting tube momentarily passes current to a guide other than the "B" guide.

Another difficulty arises from the delay between the positive-going back edge of the "A" pulse to a GC10B—which results in that

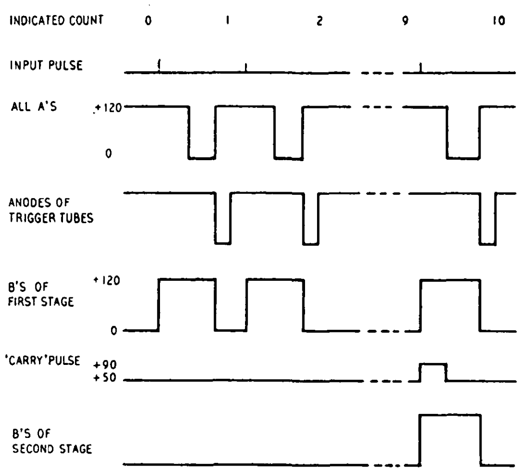


Fig. 2.—Waveforms for addition.

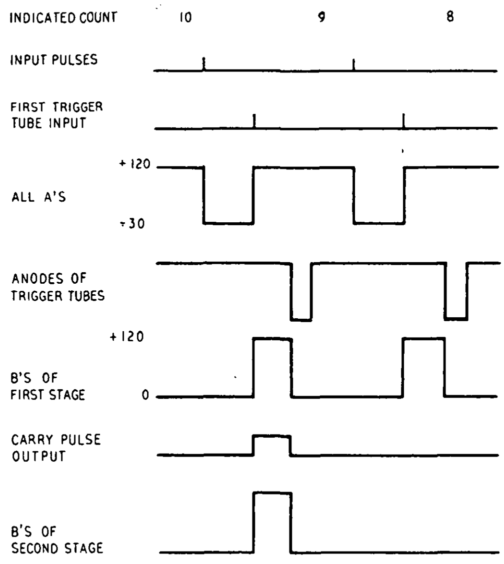


Fig. 3.—Waveforms for subtraction.

particular stage counting to 10, and the firing of the subsequent trigger tube. This delay is partly due to the trigger tube, and in the case of a fast trigger tube, mainly due to the rate of rise of the GC10B anode voltage and the rate of transfer of glow to the output guide Ko. It is possible to keep this delay down to about 10 μsec per stage of the cascade. In a 5-stage unit the delay may therefore be 40 μsec. The resulting waveforms on the 1st and 5th stages during addition and subtraction are shown in Fig. 4. In the case of addition the effect of the delay can be completely overcome by increasing the delay between the input pulse and the negative-going front edge of the "A" pulse. For subtraction, however, it is necessary to ensure that the back edge of the "A" pulse is returned to the + 120V line only when the trigger tube of that particular stage has fired. If the trigger tube does not receive an input pulse, the "A" guides are returned to + 120V when the quench pulse is applied to all the trigger tubes.

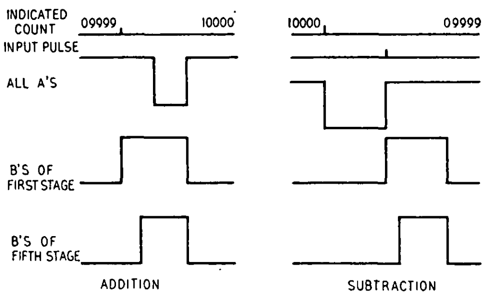


Fig. 4.—Effect of cumulative delay in five stages of a cascade.

The circuit diagram of a typical stage of a cascade capable of adding and subtracting, with the modifications necessitated by the above considerations, is given in Fig. 5. The waveforms for addition and subtraction are given in Fig. 6. Let us first consider the quiescent state of the typical stage shown in Fig. 5. The trigger tube V1 is not conducting and the anode voltage on this tube is at the recommended value for the tube. The cathode of V1 is held at earth potential by the rectifier MR1, there being a small current through R1 to − 20V. The GC10B is passing current to a guide "B" which is held at the potential of the cathode of V1 by rectifier MR2, the current through R2 being slightly greater than the current through the GC10B. Guides "A" and "K" of the GC10B are at + 60V.

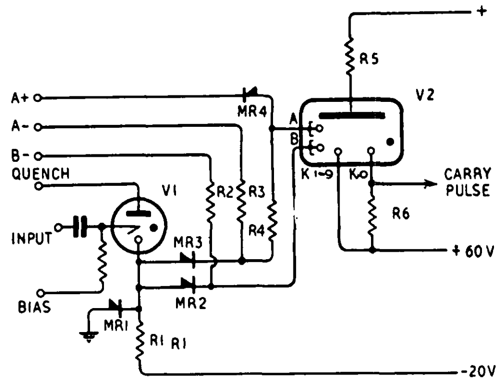


Fig. 5.—Typical stage of cascade for addition or subtraction.

When the unit is required to add, a trigger pulse is applied to V1 and after about 200 μsec, the common "A" pulse is applied to the A + line as shown in Fig. 6. At the end of this pulse, the quench pulse is applied to the anodes of all the trigger tubes. The GC10B then transfers forward via a guide "K" and a guide "A" to the following guide "B." The waveforms in the 5th stage of the cascade are shown in Fig. 6, where it is seen that the positive-going front edges of the pulses on guides "A" and "B" of this stage have the cumulative delay through the four preceding stages. This does not result in erratic counting provided that the delay between the positive-going edge of the "B" pulse and the negative-going edge of the "A" pulse in this stage is greater than 80 μsec. It should be noted that, when V1 is fired, current flows through R2 and R3 to the B − and A − lines respectively. Since the number of trigger tubes that are fired by a pulse at the input to the cascade can vary from 1 to 5, it is important to ensure that the A − and B − lines do not change their potentials by more than about 5V as a result of this, since it may lead to erratic counting. It is also necessary to ensure that the pulse applied to the A + line from the common pulse generator is capable of taking this line to 0V notwithstanding the current that will flow through the resistors R4 of each stage in which V1 has fired.

When the unit is required to subtract, pulses from the common pulse generator are applied to the A —, B —, and quench lines as shown in Fig. 6. Also, the pulse that is applied to the first trigger tube is delayed by about 100 μsec on the input pulse. The sequence of events in the various stages will now be described. On receipt of the input pulse, the glow is made to transfer to the guides "A" immediately preceding the guides "B" that were glowing. When the delayed input pulse fires the first trigger tube, the guides "A" and "B" are taken to + 120V with the result that the guide "K" immediately preceding will now glow. When the quench pulse is applied, the glow will rest on guide "B" which is one digit earlier than it was at the beginning of the cycle. If the glow passed to a Ko guide during the above sequence a "carry" pulse will have been produced which will have fired the succeeding trigger tube, and the associated GC10B will have moved back one digit. In the case of those stages where a "carry" pulse is not received from the previous stage, the glow will return to the original guide "B" at the end of the cycle. It can be seen from Fig. 6 that the effect of the time delays due to the trigger tube and the rate of rise of the output pulse from the GC10B tube will result in a shortening of the duration of the glow on a guide "K" in the later stages of the cascade. The duration of the common A — and B — pulses and hence the delay to the front edge of the quench pulse from the input pulse must be made long enough to avoid erratic counting. It should be noted that, as in the case of addition, the common pulse generator should be capable of maintaining the correct potential at the A —, B — and A + lines irrespective of the number of trigger tubes in the cascade that happens to fire for an input pulse.

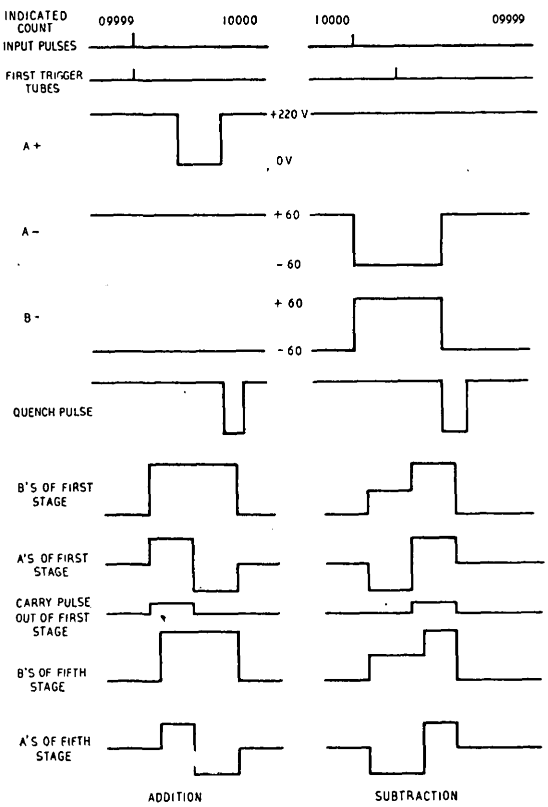


Fig. 6.—Waveforms for addition and subtraction using circuit of Fig. 5.

3. Frequency Division and Counting a Predetermined Number

The use of the new counting tubes for dividing the repetition frequency of a train of pulses by factors of 10 is a further application of their normal scaling circuits. Some important industrial uses are: the accurate measurement of an unknown frequency using standard timing pulses as a reference; measuring the time between two events; and the provision of frequency signals which are sub-multiples of a standard frequency.[9, 10] In general, the total number of components for each divider using one of the new counting tubes will be greater than that needed by one of the monostable trigger circuits which are normally used where the pulse spacing is fixed. However, one important advantage of the circuits using the new tube is that the number of close tolerance components in each dividing stage can be smaller, and further, the dividing factor is completely independent of pulse spacing. It is expected that the circuits using these tubes will give long periods of trouble-free operation.

One advantage of the monostable trigger circuits is the ease with which the dividing factor can be changed from 1 up to about 10. Provided that the input repetition frequency does not vary by more than say 5 per cent., this method of frequency division is probably the simplest. Where, however, the dividing factor has to be independent of the input frequency, it is necessary to use a counting circuit. It is possible to alter the dividing factor in a circuit using the E1T counting tube from 1 to 10 in a relatively simple way. It is seen from the characteristics of the E1T shown in Fig. 7 that the 10 stable positions of the beam correspond to 10 voltage levels at the right-hand

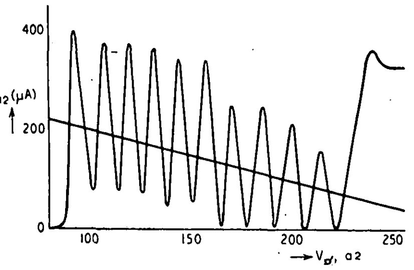


Fig. 7.—Typical characteristic of the E1T.

deflector, with a mean separation of about 14V between two adjacent points. The "0" position corresponds to about 240V and the "9" position about 100V. When pulses are applied to the left-hand deflector, the beam moves from one stable position to the next, and after passing position "9," the beam is normally reset to the "0" position by momentarily cutting off the beam current. This makes the right-hand deflector return to the highest potential which gives a stable beam position. If the right-hand deflector is caught at an intermediate potential by a diode, then the beam can be made to reset to any one of the other stable positions. This reduces the number of stable positions available and consequently allows division by any number up to 10. The use of the E1T in a counting unit to provide an output at the end of a pre-determined number of counts, N follows from the above method of setting the beam to any one of the 10 stable positions. If a cascade of say five stages is used, then the stages are initially set up to the number 100,000 $- N$ by momentarily arranging to "catch" the right-hand deflectors at suitable potentials whilst cutting off the beam currents. If, now, N pulses are applied at the input, the unit counts in the normal manner and the last stage will give an output pulse at the Nth input pulse. It can then be again set to the original 100,000 $- N$ position by resetting as above.

It is also possible to arrange for the trochotron RYG10 to divide by any number less than 10. Let us first consider the normal operation of the trochotron in the arrangement which allows division by 10. The basic circuit diagram is given in Fig. 8, and the waveforms in Fig. 9. Normally the spade resistors R1, R2 – R10 are all equal, and so are all the spade capacitors C1, C2 – C10. A negative pulse whose duration is approximately $0{\cdot}8\ CV/I$ (where C is the total capacitance at the spade, V is the spade voltage, and I is the cathode current) is applied to the anode in order to shift the beam from one stable position to the next. If the negative input pulse on the anode moves the beam from spade one to spade two, the voltage on spade one rises with the time constant C1R1 whereas the voltage on spade two falls much more rapidly since the current flowing to this spade during the input pulse is the full cathode current of about 10 mA. The quiescent current on the spade which passes current is usually less than 1 mA. The waveforms for this condition are as in Fig. 9a. If the duration of the negative pulse

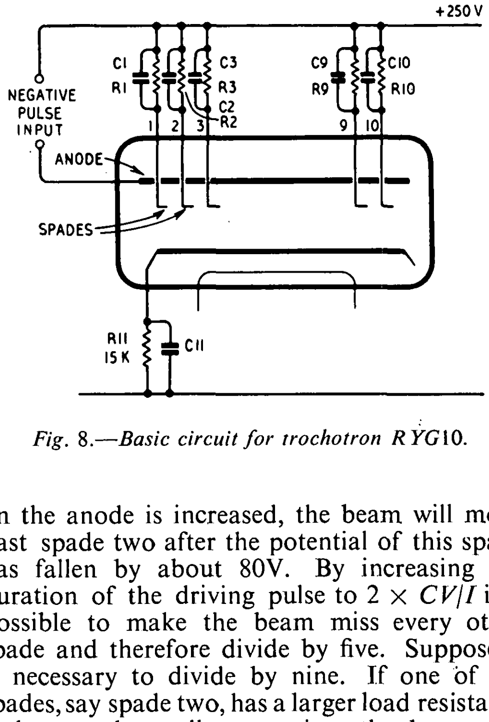


Fig. 8.—Basic circuit for trochotron RYG10.

on the anode is increased, the beam will move past spade two after the potential of this spade has fallen by about 80V. By increasing the duration of the driving pulse to $2 \times CV/I$ it is possible to make the beam miss every other spade and therefore divide by five. Suppose it is necessary to divide by nine. If one of the spades, say spade two, has a larger load resistance and a much smaller capacitor the beam will always miss spade two, and the waveforms will be as shown in Fig. 9b. If this technique is used on many spades, the value of the cathode

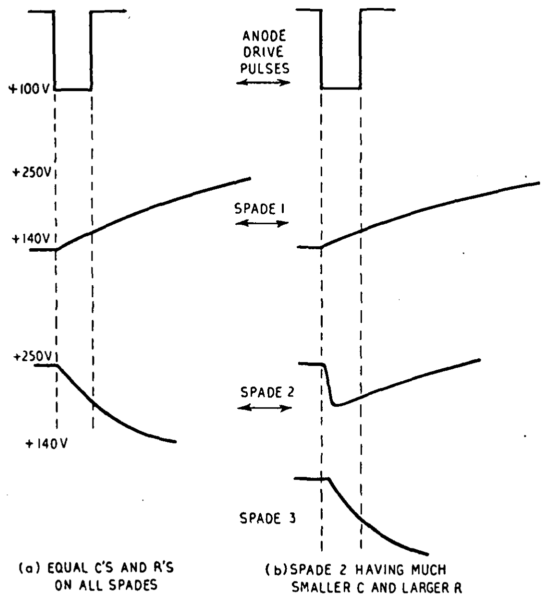


Fig. 9.—Waveforms in trochotrons.

resistor R11 will become critical at high repetition frequencies. An alternative method of making the trochotron divide by a number less than 10 is to join the requisite number of spades together, and connect them to a common load resistor and capacitor. If more than three spades are joined together for this application the anode and spade supply voltages will require re-adjustment.

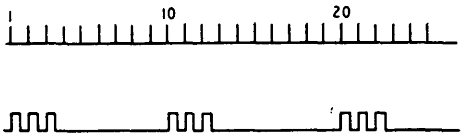
In the gas-filled counting tubes, the digit stored in the tube can be identified by the guide to which current is passing. In order to be able to set the tubes to any required number, it is necessary to bring the 10 guides corresponding to the numbers to separate connections outside the tube. By then applying suitable initial potentials to these guides, these tubes can also be used in a predetermined counter. These tubes require a large negative pulse to a guide in order to bring the glow to that guide. In the case of the GC10B, a negative rectangular pulse of at least 200V amplitude with a duration of a few milliseconds is necessary to reset the glow to an arbitrary guide. A pulse with an exponential decay is also effective provided that the time constant is more than 10 milliseconds. The faster gas-filled tubes can be reset with slightly shorter pulses, but it is generally true that the time necessary to reset in this manner is much greater than the resolving time of the tubes.

It will be seen from the preceding statements that the use of tubes other than the E1T or the RYG10 for frequency division by a factor other than 10 will result in more complicated circuits associated with each tube. There are two exceptions corresponding to division by 2 or 5. If we connect together K0, K2, K4, K6 and K8 of a GS10B, in which all cathodes K are brought out to separate leads, and derive the "carry" pulse from this common point, it will be seen that this stage will divide by 2. Similarly, if we take the "carry" pulse from K0 and K5 connected together then we can divide by 5. In general, by connecting together any number N of cathodes K in a 10-position tube, we can divide by the number $10/N$, but the output pulses from such a stage will not be equally spaced except in the cases of division by 2, 5 or 10. Where regular pulse spacing is unnecessary, for instance, when calibrating ratemeters, then the circuit of Fig. 10, giving a variable dividing factor from 1 to 10, is very economical in components.

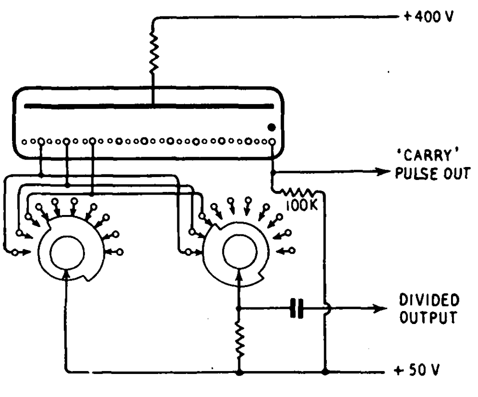
In certain cases of frequency division such as in the generation of standard time signals from a quartz crystal oscillator,[11] it is necessary to maintain the least possible time delay between the output pulse and the associated input pulse. In the case of the trochotron RYG10 and the E1T this time delay can be made less than 1 μsec per stage, using the circuits recommended for those tubes. With slight modifications to the circuits, this delay can be made less than 0·3 μsec, but this will in general lead to closer tolerance for some of the component values. Using negative-driving pulses, the time delay between input and output pulses for the GC10D and the G10/241E will be 20 μsec or more, and for the GC10B it will be more than 160 μsec per stage. By driving the gas-filled tubes with positive pulses as in the system using a common pulse generator, this time delay can be made less than 2 μsec per stage for the GC10D and 10 μsec per stage for the GC10B.

4. Switching Applications

All of the counting tubes discussed earlier with the exception of the E1T are capable of being used as 10-way switches. A modified version of a tube similar to the E1T, and other switching tubes of the trochotron type have been described[10] recently. One possible application



(*a*)



(*b*)

Fig. 10.—*Method of obtaining calibrating frequencies.*
(*a*) *Waveforms with* $K1$, $K2$, $K3$ *connected together.*
(*b*) *Switching arrangement.*

of switching tubes is in communications where normal audio or radio frequency signals are used. A prime requirement for such applications is that the switch should not introduce spurious signals or distort or attenuate the signal being transmitted through the switch. The gas-filled tubes have the disadvantages of being able to switch only at relatively low speeds and transmitting satisfactory signals only at audio frequencies. If the signal is fed into the anode of a gas-filled tube and taken out of one of the guides the voltage and current gains are equal to 1. The signal can therefore be transmitted through a number of tubes without appreciable attenuation. The noise in the tubes is generally not greater than a few millivolts r.m.s. between anode and guide, and in the case of good tubes may be as small as a few hundred microvolts. The maximum signal that can be transmitted through the tubes is about 10V r.m.s. with the current being limited to about 100 μA r.m.s.

At the other extreme of switching speeds the trochotron of the RYG10 type can change over from one spade to the next in about 0·3 μsec. Signals applied to the cathode can be switched to one of the 10 spades. The voltage gain of the tube is slightly less than 1, and the current gain is less than 0·05 for the RYG10. In the case of the tubes with separate collectors[10] such as the TR-SR-11, the current gain is about 0·2 and the voltage gain can exceed unity. It is seen that these tubes attenuate the signal considerably and the use of tubes in cascade for switching purposes involves amplification of the signal and will result in additional valve circuits in series with each signal. The greatest disadvantage of these tubes lies in the high noise level which can be as high as 10 μA r.m.s. for a mean spade current of 1 mA. It should be observed that the complete shot noise given by

$$\bar{I}^2 = 2eI\,\delta F$$

for a current of 1 mA is 0·018 μA assuming δf to be 10^6 c/s. In tubes such as the TR-SR-11 where the collectors are not in any way connected to the spades, the noise current is expected to be a smaller fraction of the mean collector current although it will still be considerably higher than the true shot noise.

The use of various counting tubes as coders and decoders in pulse code modulation systems and as decimal-to-binary converters is expected to lead to a reduction of the total number of valve elements in such systems. An interesting immediate application is in a system where information is converted from an analogue to a digital system. One particular case is the pulse-amplitude analyser. In this instrument the pulses in the amplitude range $0 - E$ volts are counted in n channels each of which accepts pulses in the range 0 to $\frac{E}{n}$, $\frac{E}{n}$ to $2\frac{E}{n}$, $2\frac{E}{n}$ to $3\frac{E}{n}$, . . . and $(n-1)\,\frac{E}{n}$ to E respectively. In one method, a capacitor is charged to the peak voltage of each signal pulse as it arrives, and at the same time an accurate linearly increasing voltage and a pulse train of fixed spacing is generated. The first pulse of the train opens the first channel, the second pulse closes the first channel and opens the second channel, the third pulse closes the second channel and opens the third channel and so on. When the linearly increasing voltage reaches the voltage of the capacitor, which remains constant at the peak signal pulse voltage, a pulse is applied to all the channels and only the channel which is open at that instant will register this pulse. Some form of digital counting system is used in each channel and the number of pulses of a particular amplitude range is therefore counted in one channel. As soon as the pulse is counted in a channel the capacitor is discharged and the system is ready to accept another pulse.

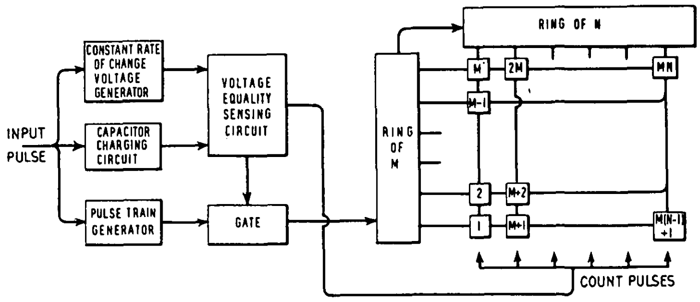


Fig. 11.—Block schematic of analyser.

A novel method[14] of reducing the total number of valves in a multi-channel pulse analyser of the above type is to use two counting circuits consisting of a ring of m and a ring of n respectively and to connect them in a matrix as in Fig. 11. Every complete circulation in the ring of m moves the ring of n by one stage. There are mn combinations of states in the two ring circuits in which one stage of each ring circuit is in an odd state. In order to use this in a pulse-amplitude analyser of the type just described, the pulse train is applied to the input of the ring of m. Each channel of the analyser consists of a triple coincidence arrangement which receives an input from one stage of the ring of m, an input from one stage of the ring of n, and a counting pulse, which is common to all channels. The pulse train, which starts when the capacitor is being charged to the peak input pulse, is counted in the ring circuits until the linearly increasing voltage reaches the voltage on the capacitor. When this state is reached the pulse train is interrupted and the counting pulse is applied to all channels. Only that channel which is connected to the odd stage in the ring of m and the odd stage in the ring of n will register the pulse. This is therefore a pulse-amplitude analyser with mn channels, where the mnth channel counts all pulses above a certain level.

An interesting system has been worked out on the above general principles but using RYG10-type tubes in place of the ring counters and using GC10B tubes to perform the combined functions of the coincidence unit and the digital counter of each channel. In the proposed system there are no components in each channel other than one GC10B, the anode load of the GC10B and the output cathode resistor. The pulses out of the GC10B in each channel can be counted in further counting stages of any desired type.

The block schematic of the new 100-channel pulse analyser is shown in Fig. 12 and one of the two ring circuits and gates is shown in Fig. 13. The ring circuits are identical to each other. The main differences in function are that ring A receives its drive pulses directly from the pulse-train generator, and the pulses through the gating valves V2, V4 . . . V20 are fed to the "A" guides of the GC10B tubes; whereas the ring B receives its drive pulses from the "carry" pulses out of ring A, and the pulses through the gating valves are connected to the "B" guides of the GC10B tubes. The RYG10 has the usual cathode resistor R4 and spade resistors R5, R8 . . . R32. The nine spades that are not passing current are caught by the corresponding diodes V1, V3 . . . V19 at + 250V. The spade that is conducting will be at about 10V below the potential of the cathode of the RYG10. The grids of the left-hand sections of the gating valves V2, V4 . . . V20 are connected to spades 1, 2 . . . 10 respectively of the RYG10. The grids of the right-hand sections of the valves are connected together and returned to the junction of R2 and R3 which is about 20V above the potential of the cathode of the RYG10. The anodes of the right-hand sections are connected to the GC10B's, those from ring A being connected to the "A" guides and those from ring B to the "B" guides as shown in Fig. 12.

In Fig. 13, the valves V22 and V24 are normally cut-off. Hence the cathodes of V1, V3 . . . V19 are held by diode V23 at + 250V and the cathodes of the gating valves V2, V4 . . . V20 are at about + 275V, there being no current through any of the gating valves. One of the gating valves, corresponding to the spade of the RYG10 that is conducting, has its left-hand

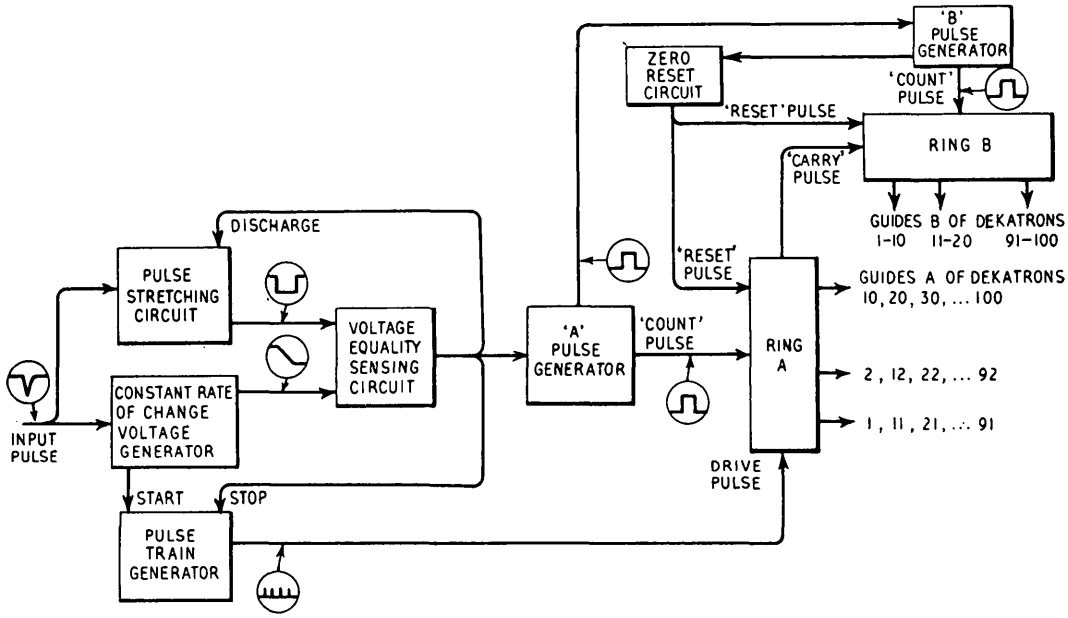


Fig. 12.—*Block schematic of pulse analyser using trochotrons and dekatrons.*

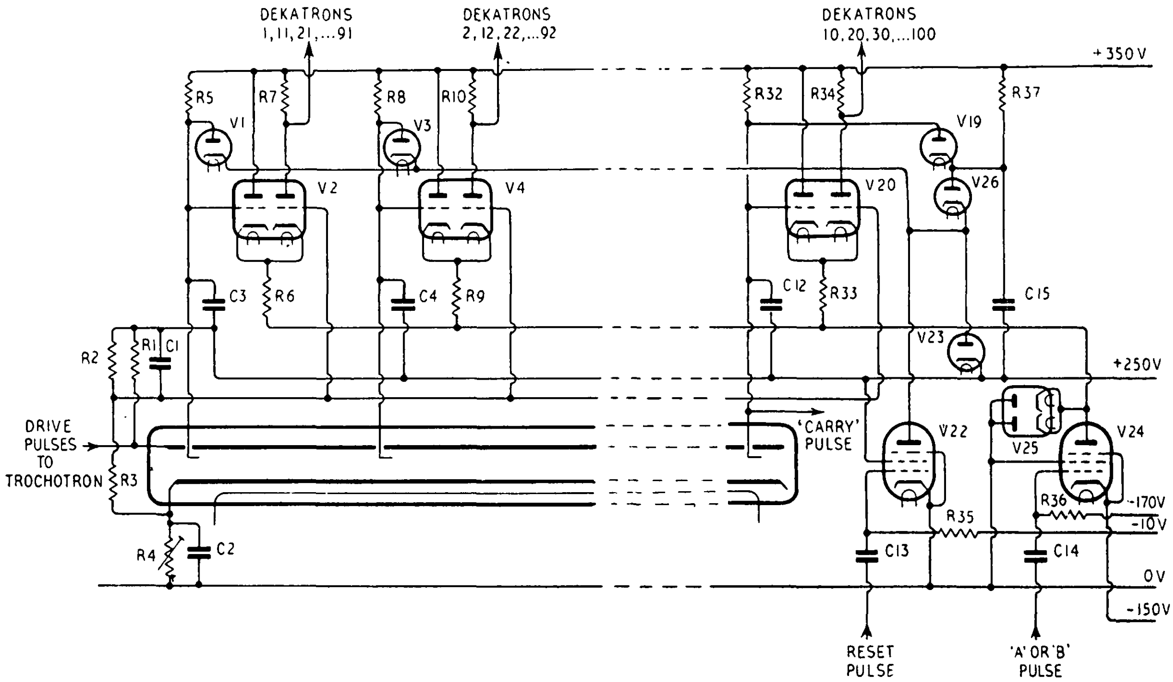


Fig. 13.—*Ring circuit and gates for pulse analyser using trochotron RYG*10.

grid at about + 120V, whereas the left-hand grids of all the remaining gating valves are at + 250V. The right-hand grids of all valves are at about + 150V. If the valve V24 is now brought into conduction there will be a negative pulse out of the right-hand anode of that gating valve which is connected to the conducting spade.

The operation of the complete pulse analyser can now be described with reference to Fig. 12 and the waveforms as shown in Fig. 14. The waveforms refer to a signal pulse of an amplitude corresponding to channel 25. The signal pulse is fed through a diode to a capacitor which is therefore charged to the peak value of the signal. The capacitor remains charged to this voltage until the information corresponding to this signal is stored in the appropriate channel. When the capacitor is charged, the constant rate voltage and pulse-train generators are started simultaneously. The pulse train which can have a spacing of about 2 μsec is fed to ring A and the carry pulse from ring A is fed to ring B. When the constant rate voltage reaches the voltage stored on the capacitor the level-sensing circuit stops the pulse train. Immediately after this a positive rectangular pulse of about 100 μsec duration is fed to V24 of ring A which therefore applies negative transfer pulses of about 120V to the "A" guides of the GC10B's 5, 15 . . . 95 in the case of this particular pulse amplitude since ring A will be stopped on position 5. Immediately after the "A" pulse, a similar positive "B" pulse is applied to the corresponding point in ring B which will therefore apply a negative transfer pulse to the "B" guides of GC10B's 21 to 30. Since the only GC10B which received both an "A" and a "B" pulse is tube 25, this tube and no other will transfer by one digit. At the end of the "B" pulse a positive reset pulse is applied to the grids of the resetting valves V22 in the two-ring circuits. This causes the cathodes of the diodes V1, V3 . . . V19 to come down to nearly earth potential and recover slowly to the normal potential of + 250. Spades 1 to 9 will recover faster than spade 10, as shown in Fig. 14, since the recovery of spade 10 will be determined by R37 and C15, which is made longer than the recovery of the normal spade circuits.

In a complete analyser it is necessary to have certain ancillary circuits in order to avoid errors. It will be appreciated that in the system described above, any pulse larger than E volts in amplitude will be counted in one of the channels as if it was a pulse of amplitude less than E volts. It is therefore necessary to have a circuit which

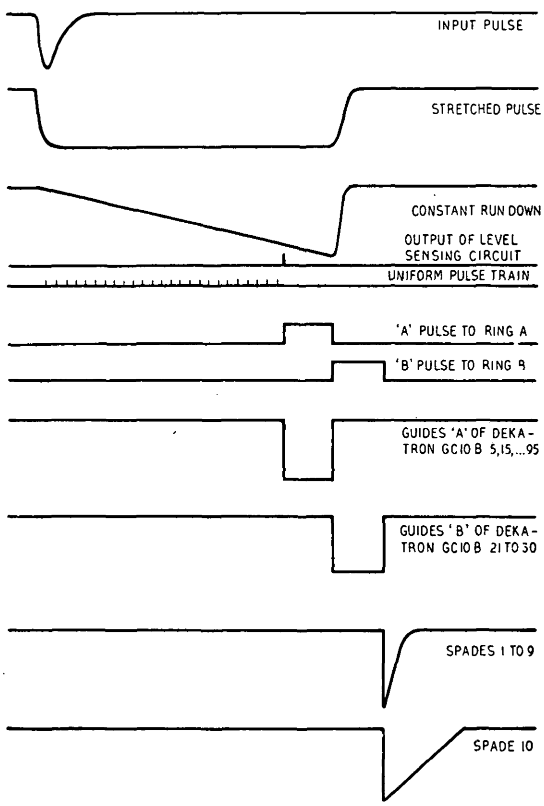


Fig. 14.—The waveforms in the pulse analyser of Fig. 12.

ensures that each gate shall be open once only during each cycle. It is also necessary to introduce a gate which prevents pulses entering the stretching circuits while a previous pulse is being analysed by the unit.

The simplicity of the above system can be appreciated by comparing the total number of components in the circuits associated with the sorting of the pulses into the various channels in different types of analysers. In one of the earlier types of analyser[13] there are approximately 80 valves and 400 components in the sorting circuits for a 30-channel unit. For the purposes of this estimate, double valves in one envelope have been counted as two valves and the valves and components which perform functions common to many units are not included. The scaling and counting circuits in the individual channels are not included in the above estimate. On the same basis the analyser described in this paper uses 72 valves and 100 components in the two ring circuits and 100 GC10B dekatrons and 200 resistors in the 100 channels. It will accept signal pulses with a resolving time of about 500 μsec, whereas the 30-channel analyser referred to will resolve signal pulses which are 150 μsec apart. It can be said that the new analyser provides 100 channels with fewer valves and much fewer components than the 30-channel analyser.

Another comparison can be made with the slow analyser[14] working on similar principles. In this unit, which will resolve signal pulses 100 msec apart, there are approximately 160 valves and over 200 components. It should be noted, however, that no further components are necessary to store the number of pulses in each channel since mechanical registers which can store four digits are used. In the unit described in this paper it will be necessary to use 100 valves in order to work the registers following the dekatrons, and there will be five components associated with each valve. The main improvement that has been obtained is the resolving time of 500 μsec as opposed to 100 msec in the slow analyser.

Another important instrument for the study of the interaction of neutrons with nuclei is the time-of-flight spectrometer.[12] In this instrument a pulse of neutrons of short duration but of varying energies is allowed to travel a known distance, and the time delay in the arrival of the neutrons at the detector is measured in order to give information on the energy of the neutron.

The number of neutrons arriving with time delays of 0 to t, t to $2t$, $2t$ to $3t$ . . . $99t$ to $100t$ are counted in 100 separate channels. It is seen that the ring circuits and associated GC10B's in the analyser described above, can be used directly for this purpose. It is only necessary to use the pulse-train generator which is started when the neutrons leave the source, and stopped when a neutron is received at the detector. This system will only permit the recording of one neutron during each complete cycle; but in those instances where the neutron source transmits one neutron in the direction of the detector for every few pulses at the source this does not lead to serious error in the measurement.

The above instrument can be used for any application in which a delayed signal is generated from some main event and where the exact time delay is not known and where there is a fluctuation in the time delay. A simple decimal counting unit with two decades is sufficient to measure a time delay of up to 100 units only where there is one time delay involved.

5. Conclusions

The counting tubes discussed have shown great promise not only in simple circuits where the total number of events of one type is to be counted, but also in complex equipment such as pulse-amplitude analysers and time-of-flight spectrometers. In every application where information in a digit form has to be analysed or stored, these tubes provide a means of obtaining accurate information of a complex nature in relatively small and simple equipment. The life of these tubes has been found to be comparable to normal valves and since one of these tubes performs the functions of many valves the ultimate reliability of equipment is expected to be improved considerably. This should lead to the use of these tubes in industrial measurements and process control of complex types in which combinations of valve circuits have lacked the necessary simplicity and reliability.

6. References

1. J. R. Acton, "The single-pulse dekatron," *Electronic Engineering*, **24**, p. 48, 1952.
2. R. C. Bacon and J. R. Pollard, "The dekatron—a new cold-cathode counting tube," *Electronic Engineering*, **22**, p. 173, 1950.
3. G. H. Hough and D. S. Ridler, "Multi-cathode gas-tube counters," *Electrical Communication*, **27**, p. 214, 1950.
4. A. J. W. M. Van Overbeek, J. L. H. Jonker and K. Rodenhuis, "A decade counter tube for high-counting rates," *Philips Technical Review*, **14**, p. 313, 1953.
5. H. Alfven and L. Lindberg, "Theory and application of trochotrons," *Acta Polytech. Elect. Eng. Ser.*, **2**, No. 2, p. 106, 1949.
6. P. S. Peck, "A ten-stage cold-cathode stepping tube," *Electrical Engineering, N.Y.*, **76**, p. 1136, 1952.
7. J. L. W. Churchill, "New trigger circuits for use with cold-cathode counting tubes," *J. Brit.I.R.E.*, **11**, p. 497, 1952.

8. K. Kandiah, "A scaling unit employing multi-electrode cold-cathode tubes," *Proc. Instn Elect. Engrs*, **101**, Part II, p. 237, June 1954.
9. W. R. Bland and B. J. Cooper, "A high-speed precision tachometer," *Electronic Engineering*, **26**, p. 2, 1954.
10. S. Kuchinsky, "Multi-output beam-switching tubes for computers and general-purpose use," *Record of National Convention of the I.R.E.* 1953, Part 6, p. 43.
11. H. M. Smith, "Quartz clocks of the Greenwich time service," *Monthly Notices of the Royal Astronomical Socy*, **113**, No. 1, 1953.
12. F. S. Goulding and others, "The development of a neutron spectrometer for the intermediate energies," *Proc. Instn Elect. Engrs*, **101**, Part II, p. 248, June 1954.
13. E. H. Cooke-Yarborough and others, "A pulse-amplitude analyser of improved design," *Proc. Instn Elect. Engrs*, **97**, Part III, p. 108, March 1950.
14. D. H. Wilkinson, "A stable ninety-nine channel pulse-amplitude analyser for slo- counting," *Proc. Cambridge Phil. Soc.*, **46**, Part 3, p. 508, July 1950.

DISCUSSION*

N. Armitage: I am interested in protection problems on power lines and in these circumstances reliability is most important. We have begun experiments with cold cathode tubes for various switching relay circuits. We have no operating experience of the life of these tubes and I would therefore like to ask if Dr. Taylor can give us actual figures of their life? We have been unable to get any information from the manufacturers apart from "several thousand hours."

I would also like to ask a question of Mr. Kandiah. We may use cold cathode tubes for counting fault incidence. When the tube comes to and end of its useful life, is that end indicated rapidly; or does the valve gradually become unreliable, and, if so, in what manner?

Dr. D. Taylor (*in reply*): I do give one figure in the paper† for the life of cold cathode tubes. Replying to the question further, the type of trigger tube used in the monitor described by Stephens‡ has a failure rate of the order of ¼ per cent. per annum. We have used the multi-electrode tube that Mr. Kandiah describes in one of our digital computers, and the life figures are of the same general order as the better-type thermionic valves.

K. Kandiah (*in reply*): I would like to make one further comment in addition to what Dr. Taylor has said about cold cathode switching tubes. I feel that there has been some conflict in the general opinion on the life of cold cathode trigger tubes. When it is stated that reliability is poor, I am certain that this is due to lack of appreciation of the limitations of these tubes, which are of quite a different character to thermionic valves. Taking those limitations into mind there is no doubt that the life of these tubes is very long.

Multi-electrode tubes and switching tubes do not fail catastrophically. If a particular characteristic is measured, it is extremely unlikely that this will have changed appreciably in the next few days except in a few special cases. The few special cases are those in which the characteristic is a function of the nature of the surface inside the tube, such as in some types of activated tubes or when the tube contains hydrogen or similar gases. Some of those tubes can change their characteristics in a few hours, but in general it is a very slow process and this sort of defect can very easily be overcome by marginal test before the tubes are put into use.

W. Nock: We have been using switching tubes of the type described by Mr. Kandiah since their introduction in 1950; our primary use is in time measurements, although in recent years we have used them for batching and control purposes. We have had very reliable results except for the first version of the GC10D (20 kc/s tube) which became "sticky" after a short time in use. We have recently obtained a modified version of this tube and this is giving very promising results. We have had a timer using one in use for four months.

Mr. Kandiah mentions the use of selector tubes with ten cathodes, GS10B, to give fixed counts of 2 and 5. Using the GS12B with 12 cathodes, it is also possible to produce stages with counts of 2, 3, 4, 6 and 12. In addition we have used a GS10B with forced reset to give stages counting in any number up to 10 at speeds up to 2 kc/s.

*Part of this Discussion has already been published in the November 1954 issue of the *Journal*, following the paper by Dr. Taylor. It is repeated here for the sake of completeness.

†*J.Brit.I.R.E.*, 14, p. 568, November, 1954.

‡*J.Brit.I.R.E.*, 14, p. 377, August, 1954.