NEW TRIGGER CIRCUITS FOR USE WITH COLD CATHODE COUNTING TUBES*

by

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SUMMARY

The paper describes several new trigger circuits which have been devised for use in conjunction with cold cathode, gas discharge counting tubes. By means of these circuits a scaling unit, which can subtract as well as add, may be constructed. A brief consideration of the counting losses of such a circuit on random input pulses is given.

1. Introduction

The advent of multi-electrode, gas discharge tubes promises new developments in the field of electronic counting. These tubes have been described by Bacon and Pollard[1] and by Hough and Ridler.[2] The cold cathode counting tubes at present available have a lower maximum counting speed than the conventional circuits using thermionic tubes. However, due to the simplification allowed, the new tubes may well replace the conventional circuits, except for applications where minimum resolving time is essential. A recent survey of counting circuits by Cooke-Yarborough[3] pointed out the advantages of the cold cathode counting tube, and also indicated some possible circuit arrangements for straightforward scalers employing them. Barnes, Cooke-Yarborough and Thomas[4] have described an interesting application of these tubes as the storage elements of an electronic digital computor.

The various types of these tubes differ mainly in the method by which the discharge is transferred from one cathode to the next, but this paper is particularly concerned with the one described by Bacon and Pollard,[1] i.e. the "Dekatron," developed and manufactured by Ericsson Telephones, Ltd. This tube contains an anode in the form of a disc around which is an array of thirty similar wires which are at right angles to the plane of the disc. Ten of these wires are used as cathodes while the remaining twenty are transfer electrodes. The arrangement is shown diagrammatically in Fig. 1, where K1, K2—K0 are the cathode wires and the wires labelled A and B are the transfer electrodes. It will be seen that there is one A and one B electrode between each pair of cathodes, and that all the A's are connected together and similarly all the B's. In the quiescent state a discharge passes between the anode and one of the cathodes, e.g. K1, while the transfer electrodes are returned to a potential positive with respect to the cathodes so that very little current flows to them. If now the A transfer electrodes are taken down to a potential more negative than

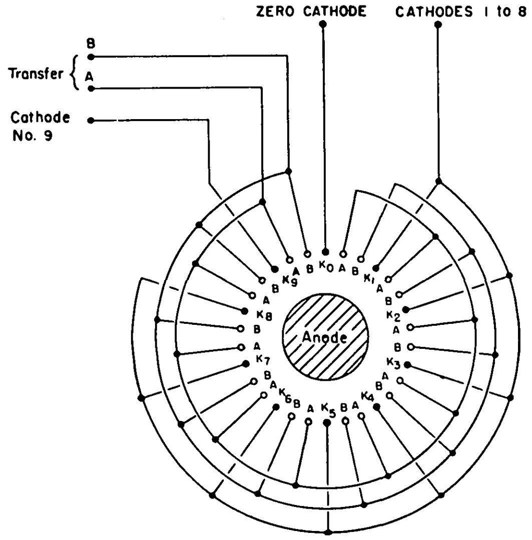

Fig. 1.—Electrode arrangement in the counting tube.

the cathodes, the discharge will leave K1 and pass to the nearest A electrode, and will remain there until this electrode is returned to its positive bias. When this occurs the discharge moves back on to the cathode it has just left, unless the B electrodes are made negative at the same time as the A electrodes become positive, in which case the discharge moves from the A

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on to the nearest B electrode. As before it will remain there until the B electrode is brought back positive again. This time, due to the fact that the A electrodes are more positive than the cathodes, the glow instead of moving back on to the A it has just left moves forward on to the next cathode, i.e. K2. Thus it will be seen that in order to advance the discharge from one cathode to the next, the two sets of transfer electrodes must be driven successively to a potential more negative than the cathodes. By inserting resistances in series with the cathode leads output voltage pulses are developed across them which may be used to operate a coupling circuit to drive the next decade.

Suitable values for the Ericsson tube type GC10A would be a bias of + 60 volts for the transfer electrodes and transfer pulses of 120 volts amplitude and a minimum width of 500 microseconds.

The direction of transfer of the discharge is determined by the order of arrival of the transfer pulses, i.e. the discharge will advance by one cathode if a pulse is applied to transfer electrode A before the pulse on B, and it will move back by one cathode if a pulse is applied to B transfer electrode before the pulse on A. Very little attention appears to have been paid to this reversible property of these counting tubes, but it makes possible a scaling circuit which will subtract as well as add. Such a circuit is of use, for example, in counting the net number of revolutions of a shaft which may reverse as in the case of the velocity servo type of integrator,[5] and possibly for use in electronic digital computors. A third suggested use is in the counting of nuclear disintegrations when the counting rate is very slow and one wishes to subtract the spurious background counts, in which case one would have a Geiger counter registering background counts only, and would wish to subtract its counts from those of another counter which was registering background counts plus required counts.

The trigger circuits now to be described were originally designed for use with cold cathode counting tubes, but they may be of use in other applications.

2. Paired-Pulse Generators

The circuit of Fig. 2 produces two successive square pulses, at separate output points, suitable for driving a cold cathode counting tube.[6] The circuit may be made self-running or triggered and is shown in the latter form. Three pentodes are employed and should preferably be of the short suppressor base variety, e.g. Mazda 6F33, which also has an internal diode which limits positive excursions of the suppressor. Each anode is directly coupled to the suppressor grid of the preceding valve and capacitively coupled to the control grid of the following valve. The screen grids may be connected together and returned to a positive supply.

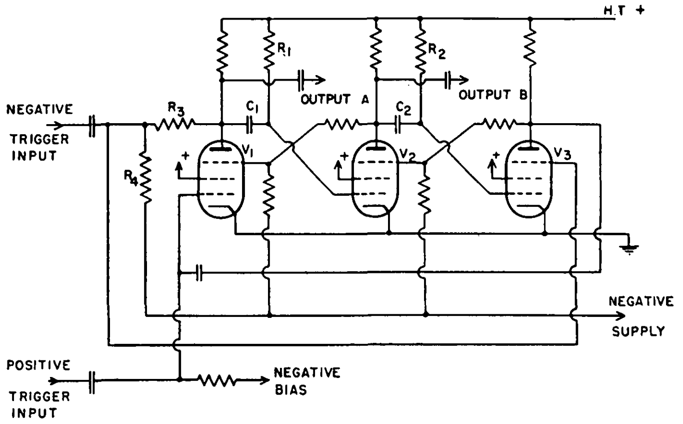


Fig. 2.—Paired pulse generator.

The potential divider formed by resistors R3 R4 is arranged such that when V1 is conducting, the suppressor grid of V3 is held at a potential sufficiently negative to cut off current to the anode of V3, but when V1 is cut off and its anode rises nearly to the H.T. potential, then the suppressor grid of V3 is brought slightly positive with respect to earth potential and allows V3 to conduct. Similarly for the other suppressor grid circuits. In the case of the triggered circuit, V1 is held cut off on its control grid by virtue of its grid leak being returned to a negative supply. Hence V3 is conducting. V2 is conducting to its screen but not to its anode, since its suppressor is cut off by the potential drop across the anode load of V3.

The circuit is triggered by injecting a negative pulse on to the suppressor of V3. The anode of

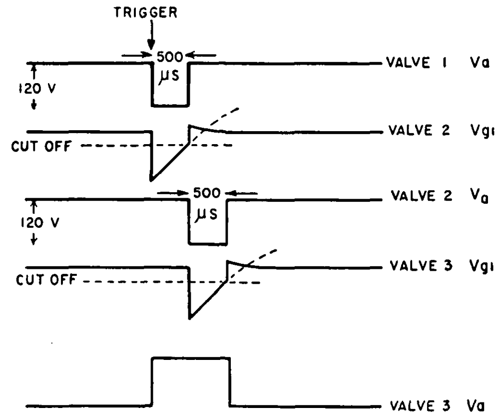


Fig. 3.—Waveforms of the circuit of Fig. 2.

V3 rises in potential bringing the grid of V1 with it and causing V1 to conduct. This in turn causes the suppressor of V3 to drop further, giving rise to a regenerative action in which V3 is turned off and V1 turned on.

During this process V2 remains cut off to its anode. When V3 is cut off the potential of the suppressor of V2 is raised, but at the same time the control grid of V2 is cut off by the drop in potential of V1 anode. V2 control grid now starts to leak back towards the positive supply potential at the time constant of R1.C1 and when it rises above cut-off, V2 starts to conduct and a regenerative action similar to that which occurred between V3 and V1 now occurs between V2 and V1. At the end of it V2 is conducting, V3 is cut off on its control grid and V1 is cut off on its suppressor.

The grid of V3 now leaks back with a time constant C2.R2 until V3 starts to conduct and the regenerative action takes place once more, leaving V3 conducting. Here the process stops, since the grid of V1 is held below cut-off by the negative bias supply. The circuit may also be triggered by a positive pulse on the control grid of V1 and may be made self-running by returning the grid leak of V1 to the same positive supply as those of V2 and V3. The relevant waveforms are shown in Fig. 3.

An alternative method of generating these successive pulses is to employ two flip-flop circuits coupled together, such that the second one is triggered over when the first one triggers back into its stable state. When counting random events, however, the circuit of Fig. 2 is preferable, since it has a known dead time. A second trigger pulse, which arrives before the circuit has completed its cycle of operation, has no effect, since V3 is cut off until the cycle is complete. In the case of the double flip-flop arrangement a second trigger pulse could trigger the first flip-flop over again before the second one had resumed its stable state. This would lead to uncertain operation when used to drive a counting tube.

In order to exploit the reversible nature of the counting tube it is necessary to be able to reverse the order of arrival of the pulses at the transfer electrodes. The simplest way, of course, is to reverse the connections to the transfer electrodes

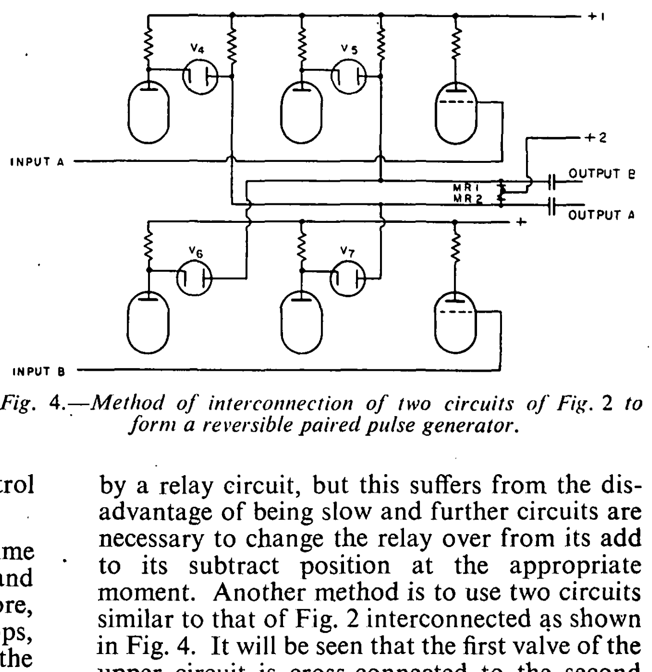


Fig. 4.—Method of interconnection of two circuits of Fig. 2 to form a reversible paired pulse generator.

by a relay circuit, but this suffers from the disadvantage of being slow and further circuits are necessary to change the relay over from its add to its subtract position at the appropriate moment. Another method is to use two circuits similar to that of Fig. 2 interconnected as shown in Fig. 4. It will be seen that the first valve of the upper circuit is cross-connected to the second valve of the lower circuit and vice-versa. The diodes V4, 5, 6, 7 are incorporated to prevent the operation of one circuit triggering the other and the germanium rectifiers MR1 and MR2 limit the pulse amplitude in the event of both circuits being triggered together. Then a trigger pulse at input A produces an output pulse at output A followed by a pulse at output B, while a trigger at input B produces a pulse first at output B and then one at output A.

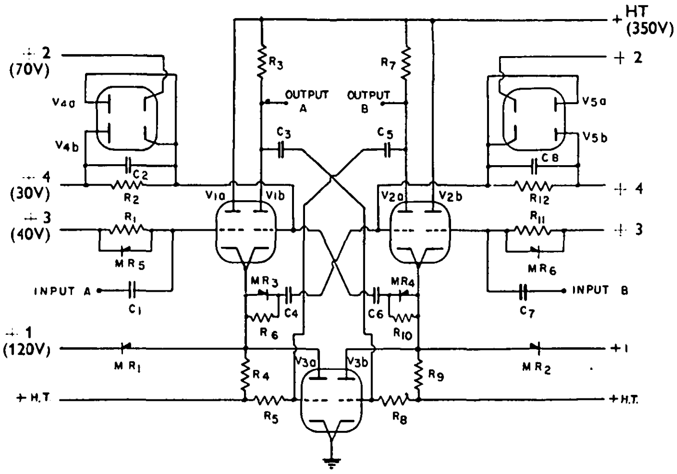
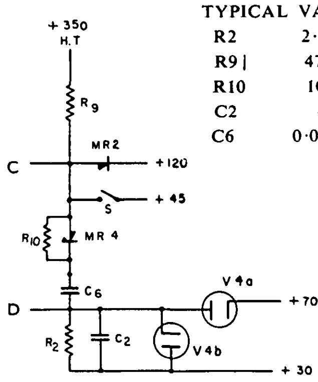


Fig. 5.—Reversible paired pulse generator.



TYPICAL VALUES	
R2	2·2MΩ
R9	470kΩ
R10	100kΩ
C2	47pF
C6	0·005μF

Fig. 6.—Detail of Fig. 5.

A more elegant method of performing this operation is by means of the circuit of Fig. 5.[7] Here again, there are two input points and two output points, and the order in which the pulses are generated at the output points depends on which input point receives the trigger pulse.

The waveforms relevant to the circuit of Fig. 5 are shown in Fig. 7, but before going into the details of the circuit a brief description of the mode of operation is worth while.

The circuit starts with V1a, V3a, V2b and V3b all conducting. A trigger pulse at input A causes the anode current of V1a to be diverted through V1b and the potential drop at its anode cuts off V3b. The grid of V3b leaks back and, when the valve conducts, its anode current passes through V2a and the drop in potential at the anode of the latter cuts off V3a. Its grid then leaks back and when V3a conducts again its anode current passes through V1a and at the same time V2a is cut off, causing V2b to conduct. The circuit is then back in its original state.

In the description to follow, reference is made to various clamping potentials, and for clarity the actual values used in a design are quoted. These values are by no means critical and may vary between one design and another.

In more detail the circuit operation is as follows:—

The grid of V1a is returned to a more positive potential than the grid of V1b so that when the circuit is in its normal state V1a conducts and V1b is cut off. Hence current flows through V1a and V3a in series. Similarly, current flows through V2b and V3b in series. The operation of the circuit will be described for the case of a trigger pulse applied to input A, but the circuit

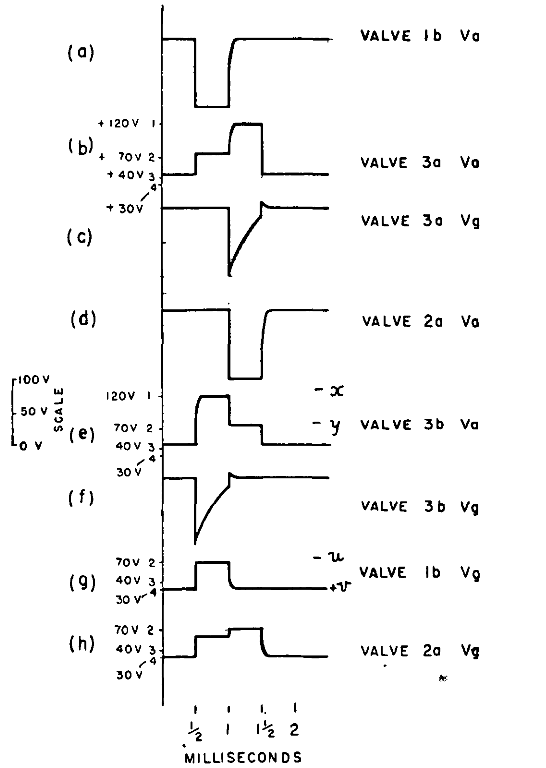


Fig. 7.—Waveforms of the circuit of Fig. 5.

is perfectly symmetrical and the operation is similar for input B with the functions of V1 and V2 and of V3a and V3b interchanged.

When a negative pulse is applied to the grid of V1a this valve is cut off and its anode current diverted through V1b, producing a drop in the potential of its anode. This drop is coupled via C3 to the grid of V3b causing this valve to cut off. The anode of V3b is connected via R9 to the H.T. line so its potential tends to rise towards the H.T. potential. In order to ascertain the nature of this rise, the relevant part of Fig. 5 has been separated for clarity and is shown in Fig. 6. The switch S represents the valve V3b and while it is conducting the point C is held at a few volts above the grid potential of V2b. When the switch S is opened the potential of points C and D would, in the absence of C2, rise instantaneously to potentials determined by the relative values of R9 and R2 and, with the values shown in Fig. 6, point D would rise from 30 volts to approximately 280 volts. During this phase the germanium crystal rectifier MR4 is conducting in its forward direction and can be regarded as a short circuit. However, the presence of C2 (which is much smaller than C6) delays this initial rise slightly and, in fact, this rise has a time constant given by C2 and R9 and R2 in parallel. When point D reaches a potential of +70 volts it is caught by the diode V4a and from then on the potential of point C rises with a time constant of R9 C6 towards the H.T. potential until it is caught by the germanium crystal MR2 at +120 volts. The potential of point D then starts to decay exponentially towards +30 volts with a time constant given by R2 C6 but this is chosen to be large compared with the period of operation of the whole trigger circuit. These rises in potentials of the anode of V3b and the grid of V1b are shown in Fig. 7e and g.

This rise in the grid potential of V1b to above the +40 bias potential of the grid of V1a gives the necessary trigger action. Further, the cathodes of V1, and therefore the anode of V3a, rise to a potential a volt or two above the +70 clamping potential of the grid of V1b. This rise is transmitted via C4 to the grid of V2a, bringing it up to a potential decidedly more positive than the +40 grid return of V2b.

The grid potential of V3b rises exponentially towards H.T. potential with a time constant of R8.C3, and this is the time constant which determines the width of the pulse from output A. When V3b starts to conduct, its anode drops from its clamping potential of +120 volts to a volt or two above the grid potential of V2a. It is essential to the operation of the circuit that this drop is not transmitted instantaneously to the grid of V1b and thence back via C4 to the grid of V2a, otherwise a trigger back action occurs and the grid of V2a is brought down below the grid of V2b. To obviate this, capacitor C2 and germanium crystal rectifier MR4 have been included. The drop in potential of the anode of V3b cuts off MR4 so that there is now the resistance of R10 in series with C6. Hence the grid of V1b drops with a time constant of R2, R10 and C2 in parallel. This gives time for V2a to conduct and the drop of potential at its anode to cut off V3a and V1b. The anode potential of V3a rises, rapidly at first until the grid of V2a has been carried up to its clamping potential of +70, and then more slowly until it is caught by MR1 at +120 volts (see Fig. 7b). Meanwhile, the potential of the grid of V1b has dropped to its lower clamping potential of +30 volts and has been caught there by diode V4b. Hence, when V3a starts to conduct again its anode current will pass through V1a.

The grid potential of V3a rises exponentially towards H.T. potential with a time constant of R5.C5, which is the one which governs the width of the pulse from output B. When V3a starts to conduct its anode potential drops from +120 volts to a volt or two above the +40 return of the grid of V1a. This drop is transmitted to the grid of V2a, causing V2a to cut off. Its anode current is diverted through V2b and the grid of V2a is caught at its initial potential of +30 by V5b diode.

The circuit is now back in its original condition, having delivered a negative-going square pulse from output A, followed by a similar pulse from output B. A trigger pulse on input B would, by a similar process, produce a pulse at output B, followed by one at output A.

The germanium crystal rectifiers MR5 and MR6 are included to prevent positive overshoot in the triggering waveform triggering the circuit back prematurely.

The choice of values for the clamping potentials +1, +2, +3 and +4 is governed by the following considerations: +3 should be sufficiently positive with respect to +4 that valves V1b and

V2a are completely cut off when the circuit is in its quiescent state. Potentials +1 and +2 are so chosen that the drop x→y in the anode potential of V3b (see Fig. 7e) is more than sufficient to carry the grid of V1b from its upper clamping potential +2 to its lower clamping potential +4, i.e. u→v in Fig. 7g.

When the two inputs to the circuit are trains of randomly occurring pulses, then some counting losses are involved, due to the dead time of the circuit. The magnitude of these losses cannot be estimated unless one has a knowledge of the sum of the mean pulse rates of the two inputs, as will be seen from the following argument.

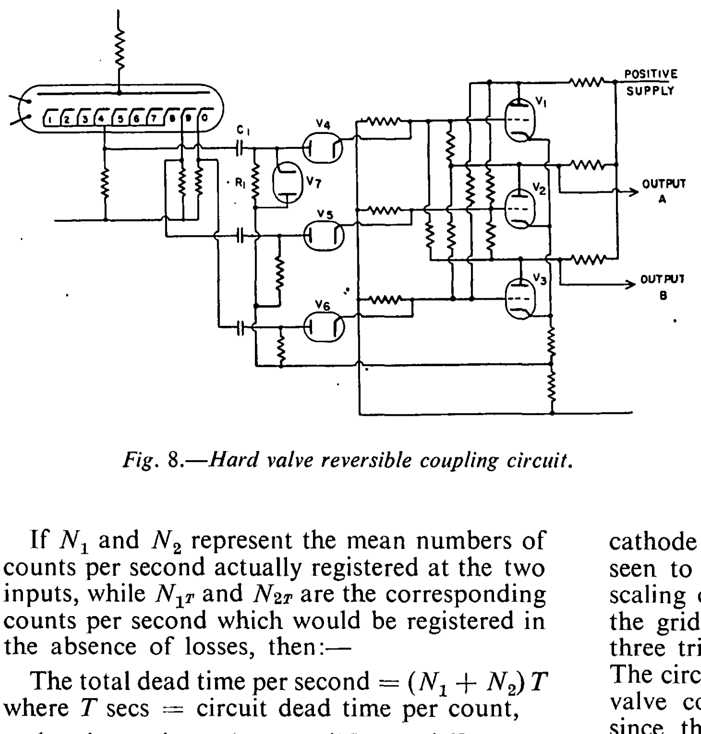


Fig. 8.—Hard valve reversible coupling circuit.

If N_1 and N_2 represent the mean numbers of counts per second actually registered at the two inputs, while N_{1T} and N_{2T} are the corresponding counts per second which would be registered in the absence of losses, then:—

The total dead time per second $= (N_1 + N_2)T$ where T secs = circuit dead time per count,

then loss at input 1 $= N_{1T}(N_1 + N_2)T$ per sec ....(1)

and loss at input 2 $= N_{2T}(N_1 + N_2)T$ per sec ....(2)

whence $N_1 = N_{1T}[1 - (N_1 + N_2)T]$ ....(3)

and $N_2 = N_{2T}[1 - (N_1 + N_2)T]$ ....(4)

From equations (1) and (2) it follows that the error in the difference is $(N_{1T} - N_{2T})(N_1 + N_2)T$. Then substituting for N_{1T} and N_{2T} from equations (3) and (4) we obtain:—

The error in the difference =

$$(N_1 - N_2)\frac{(N_1 + N_2)T}{1-(N_1 + N_2)T}\ \text{counts per sec.} \quad \ldots\ldots(5)$$

For slow counting rates when $(N_1 + N_2)T \ll 1$, equation (5) reduces to:—

Error $= (N_1 - N_2)(N_1 + N_2)T$ counts per sec.

3. Reversible Coupling Circuits

A complete scaling circuit normally consists of more than one decade, which means that if it is required to subtract as well as to add, then an interstage coupling circuit is necessary, which will transfer the sense of the arithmetical operation from the preceding decade to the following one. A circuit which achieves this is shown in Fig. 8. It is shown as used in conjunction with a cold cathode counting tube in which cathodes 1 to 8 are connected together internally and brought out to a common base pin and cathodes 9 and 0 each have their own pin. Signals are taken from all three cathode pins. The nature of the output signals during addition will be a succession of eight positive-going pulses from cathodes 1 to 8, followed by one pulse from cathode 9, and then one from cathode 0. During subtraction the pulse from cathode 0 will precede that from cathode 9. The coupling circuit of Fig. 8 will be seen to be a modified form of a ring-of-three scaling circuit. Every anode is d.c.-coupled to the grids of both of the other valves, and the three triodes have a common cathode resistor. The circuit is in a stable condition with any one valve conducting and the other two cut off, since the conducting valve has its grid d.c.-coupled to the anodes of two cut-off valves and it is, therefore, more positive than the grid of a cut-off valve which is d.c.-coupled to the anode of one conducting valve and one cut-off valve.

If the circuit starts with V1 conducting, either of the other two valves may be made to conduct by momentarily raising its grid to a potential more positive than the grid of V1. A cumulative action takes place and the change-over is rapid. The diodes V4, V5 and V6 are inserted to

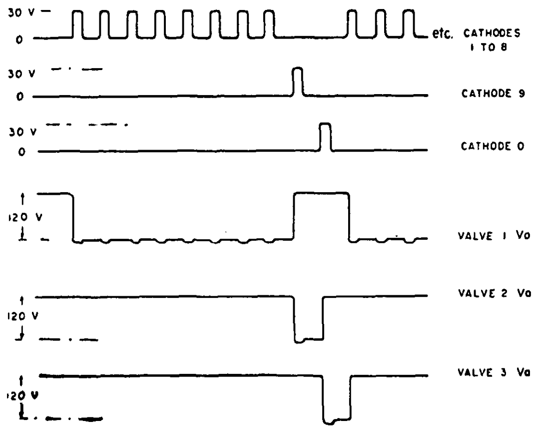


Fig. 9.—Waveforms of the circuit of Fig. 8.

prevent the trailing edges of the triggering pulses from triggering the circuit in the reverse direction. The anodes of these diodes are returned to a potential below the grid cut-off potential of valves V1, V2 and V3.

Diode V7 is to provide d.c. restoration on the rapidly occurring pulses at that input.

The transfer electrodes of the following counting tube are d.c. coupled to the anodes of V2 and V3. It will be noticed that, while a count of 9 is registered on the first decade, the glow of the second will rest on transfer electrode 1. Similarly, the glow of the second will rest on transfer electrode 2 when a count of 0 is registered on the first decade, and the glow comes to rest on a cathode in the second decade when the count has reached 1 or 8 in the first, depending on whether the circuit is adding or subtracting. This, however, does not lead to any ambiguity in reading the count. The relevant waveforms are shown in Fig. 9.

Another circuit which fulfils the same function as the one of Fig. 8 is shown in Fig. 10.[8] Of the two, the latter is to be preferred, since apart from being simpler the values of its circuit components are far less critical. The valves V1, V2 and V3 are gas-filled cold-cathode trigger valves. For clarity the connections to the priming gaps and shield electrodes have been omitted from the figure.

The mode of operation of the circuit may be best followed by starting with the assumption that V1 is glowing and that V2 and V3 are extinguished. Then V2 may be struck by applying a positive pulse to its trigger electrode. When this occurs the anode of V2 is held instantaneously at H.T. potential by the action of the capacitor C2 and hence the potential of the common cathode line rises in order to maintain the volt drop across the valve at the value for glow conditions. This raising by V2 of the cathode potential of V1 causes the latter to extinguish since the anode of V1 cannot rise instantaneously because of the presence of C1 and the anode-cathode voltage of V1 is brought below its glow maintaining value. The anode potential of V2 then falls exponentially with a time constant determined by C2 and the parallel combination of R2 and R4. The cathode line potential drops at the same rate to its original value.* In a similar way a pulse on the trigger electrode of V3 will cause it to strike and in doing so to extinguish V2. When a valve is extinguished its anode potential rises exponentially to H.T. potential with the time constant of the anode circuit (R1.C1 in the case of V1).

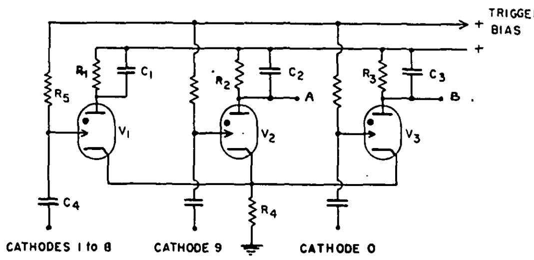


Fig. 10.—Reversible coupling circuit employing gas discharge trigger valves.

The diodes V4, V5 and V6 shown in Fig. 8 are not necessary in this circuit, since the gas filled trigger valves cannot be quenched by a negative pulse on the trigger electrode. In this case, in order to employ a diode across R5 for d.c. restoration, a resistance must be inserted between the trigger electrode and the junction of R5 and C4, since without it, once the trigger gap has struck, sufficient current to maintain it will then pass through the diode from the trigger bias supply and the result is that V1 cannot be quenched. However, with this circuit it is quite adequate simply to choose the time constant of the coupling circuit C4.R5 to be about equal to the period between output pulses generated by

*Only if R1 = R3 = R2.

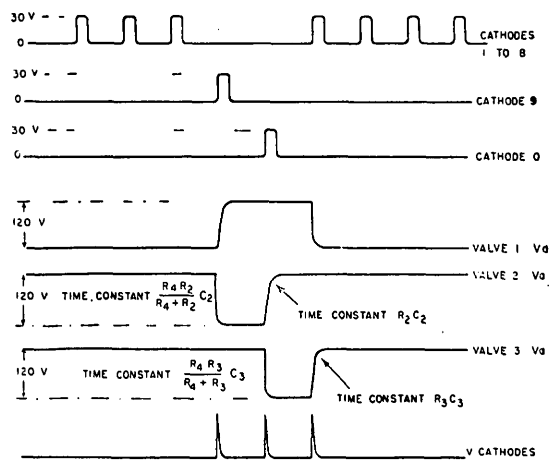


Fig. 11.—Waveforms of the circuit of Fig. 10.

the preceeding counting tube. With this value the leading edge of the first pulse of the train is transmitted to the trigger electrode with negligible attenuation and further the coupling capacitor C4 will discharge substantially during the period in which the glow of the counting tube is on cathode 9 or 0. The relevant waveforms are shown in Fig. 11.

This circuit could be extended for other applications to include any number of valves any one of which could be made to conduct, at the same time extinguishing a valve which is already glowing.

4. Conclusions

Trigger circuits have been described which can be used to drive multi-electrode cold cathode counting tubes of the variety which have two transfer electrodes between successive cathodes. These circuit arrangements have the special property of being able to drive the counting tube both in the forward and in the reverse direction, allowing for the construction of a scaling circuit which can both add and subtract and some applications of such a circuit are suggested.

5. Acknowledgments

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