

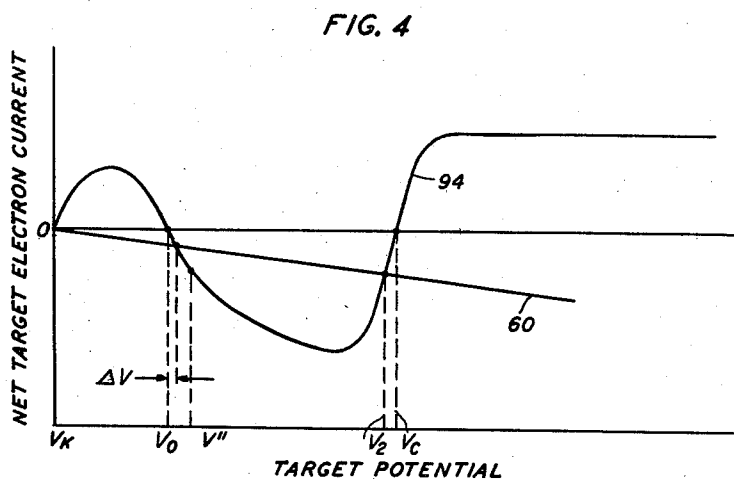
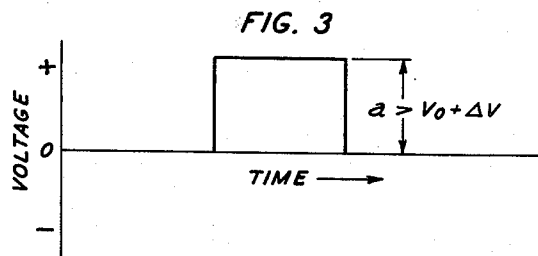
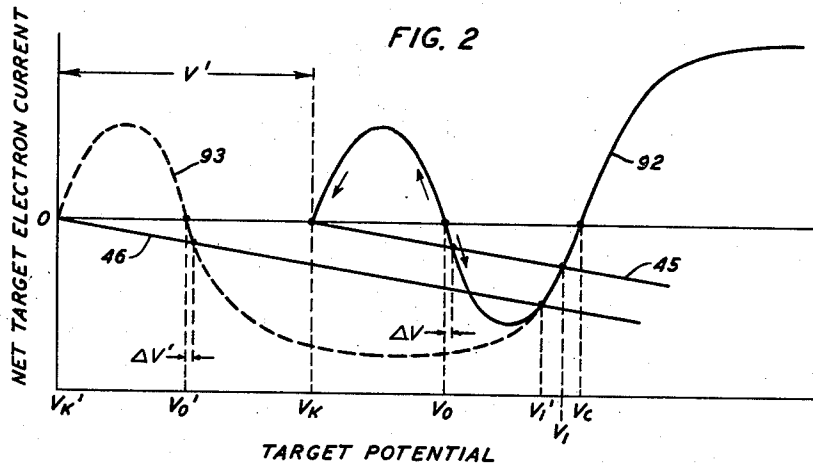
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ELECTRON DISCHARGE DEVICE

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ELECTRON DISCHARGE DEVICE

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This invention relates to electron discharge devices, and more particularly to such devices and circuits for counting electrical pulses.

Multielement vacuum type counting tubes to enable counting or stepping at high rates are known. However, the pulse lengths required to insure correct operation of such tubes are often critical. It therefore would be desirable to provide a simple tube structure and circuit which would obviate the disadvantage heretofore encountered in multielement counting devices.

It is accordingly an object of the present invention to provide improved means for rapidly counting electrical pulses.

Another object of the invention is to improve the performance characteristics of multielement electron discharge devices such as high speed electronic counting tubes.

A further object of the invention is to provide a multielement discharge device and an associated circuit capable of yielding one output pulse in response to the accumulation of a predetermined number of input pulses.

A still further object of the invention is to insure reliable high speed counting of electrical signals of noncritical pulse lengths.

These and other objects of the invention are achieved by positioning in an evacuated envelope a cathode, a control grid, a plurality of secondarily emissive target electrodes arranged around the cathode, a plurality of grids associated with each target electrode, and collector electrodes compartmentalizing the target electrodes and their associated grids. Associated circuitry cooperates with the novel tube to cause the target electrodes to conduct one at a time in sequence in response to electrical pulses.

A counting tube in accordance with the invention may have any number of compartments but for clarity of presentation a decimal or ten compartment tube will be assumed. In such a tube a register or counter in a target electrode circuit may advantageously be actuated or energized once in response to each ten input pulses. Negative input pulses of any length which it is desired to count are applied to the cathode, the control grid, to one of the grids associated with each target electrode, and to a flip-flop or switching device. If the input pulses are of positive polarity, such pulses are applied to the target electrodes and to the flip-flop. An output of the flip-flop is applied to a grid in each of the odd-numbered compartments and the other flip-flop output, of opposite polarity, is applied to a grid in each of the even-numbered compartments. Each input pulse causes the tube to step or count one position. Thus, if counting is commenced with compartment 1, every tenth input pulse will cause the register in the circuit of compartment 10 to register or count. Since compartment 1 is initially pulsed and energized by a starting circuit, it is to be noted that the first nine input pulses may cause the register to count one step. However, in subsequent

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counting cycles ten input pulses are required to actuate the register.

The target electrodes are made of secondarily emissive material with a secondary emission ratio greater than unity in the tube operating range and consequently, as explained in fuller detail hereinafter, each target has two stable equilibrium points of operation. One stable point corresponds to the off condition and occurs when the potential difference between the cathode and a target electrode is zero. The second or higher stable point corresponds to the on condition and occurs when a target electrode is positive with respect to the cathode.

The target of compartment 1, for example, is initially pulsed to or about the higher stable point by the starting circuit. This target stabilizes at the higher point and in so doing primes compartment 2, through an impedance network, for conduction in response to an input pulse. Then, the application of an input pulse to the tube does in effect three things: Compartment 1 is turned off, compartment 2 is turned on, and compartment 3 is readied or primed for conduction in response to the next input pulse.

Thus, a feature of this invention resides in an improved unitized counting tube structure and novel circuit associated therewith which use secondary emission effects of bombarded metal targets to count pulses of noncritical lengths at megacycle rates.

It is a further feature of this invention that a high speed electron discharge counting device is provided having a cathode, a control grid surrounding the cathode, a plurality of radially positioned collector electrodes, and a secondarily emissive target electrode between each two collector electrodes.

A further feature of this invention resides in an electron discharge device having a cathode, an array of secondarily emissive targets, an electrode between adjacent targets and defining distinct compartments for the targets, and a first and a second control electrode in each of the compartments. Further in accordance with a feature of this invention a first group of alternate first control electrodes connected together and a second group of alternate first control electrodes are connected together, and an impedance network connects each second control electrode to its associated target and to the target of the prior compartment in the array.

A still further feature of this invention resides in an electron discharge device having a cathode, a control electrode, an array of secondarily emissive targets opposite the cathode, a first and a second electrode between each target, and the control electrode, and circuitry for applying an input pulse to the cathode, control electrode, and the first and second electrodes, whereby an input pulse extinguishes the discharge to a first conducting target, initiates a discharge to a previously primed second target, and primes a third target for conduction in response to a next input pulse.

A complete understanding of the invention and of this and other features and advantages thereof may be gained from consideration of the following detailed description in conjunction with the accompanying drawing, in which:

Fig. 1 is a schematic representation of an electron discharge device illustrative of this invention with appropriate circuit elements connected thereto to form a pulse counting circuit;

Fig. 2 is a plot of the current-voltage characteristic of each of the target electrodes employed in the electron discharge device and circuit of Fig. 1;

Fig. 3 is a plot of the output voltage of the starting pulse source as a function of time; and

Fig. 4 is a plot of the current-voltage characteristic.

of each of the target electrodes employed in an electron discharge device and circuit similar to that shown in Fig. 1 but wherein the input pulses are applied to the target electrodes.

Referring now to the drawing, Fig. 1 illustrates an electron discharge device or counting tube 20 comprising an evacuated envelope or enclosure 21, for example, of glass or other suitable material, having therein a centrally positioned cylindrical cathode 22 which may be of the indirectly heated type, the heater not being shown in the drawing. The cathode 22 carries on its outer cylindrical surface a coating of emissive material which may be of any conventional type. Surrounding the cathode 22 and spaced equidistantly therefrom at all points is a cylindrical control grid 23.

Annularly positioned around the cathode 22 and the control grid 23 are radially extending collector electrodes 24, a plurality of grids 25, hereinafter referred to as A grids, a second plurality of grids 26, hereinafter designated as B grids, and target electrodes 27. Interposed between each target electrode 27 and its associated A grid 25 or B grid 26 is a grid 28 designated as a G grid.

The collector electrodes 24 serve to compartmentalize the counting tube 20 and, thus, the tube may be considered as comprising within a single envelope 21 a plurality of discharge devices which can be interconnected with external circuitry for high speed counting. For counting in the decimal system, for example, the counting tube 20 may comprise ten compartments, each including a target electrode 27 and associated grids. The various electrodes are held in proper spaced relation to one another by supports, not shown, made of electrically nonconducting material, such as mica.

Fig. 1 illustrates a ten compartment tube wherein the target, G grid and A grid elements of compartment 1 are respectively designated 27-1, 28-1, and 25-1. The target, G grid, and B grid elements of compartment 2 are respectively designated 27-2, 28-2, and 26-2. The elements in the other compartments are similarly numbered, with the dash number associated with each element indicating its compartment location.

In actual embodiments of counting tubes according to this invention an individual lead extends through the envelope 21 from each target electrode 27, from each G grid 28, from the cathode 22, and from the control grid 23 to appropriate external terminals, not shown. A single lead extends through the envelope to an appropriate external terminal, also not shown, from the A grids 25 which are all electrically interconnected within the tube and, similarly, one lead extends to a suitable external terminal, not shown, from the B grids 26 which are also all electrically interconnected within the tube. Further, all the collector electrodes 24 are internally connected together and a lead 50 connects them to an external source of positive potential V_0 . In other specific embodiments according to the invention some of the circuit elements may be placed within the counting tube and the number of individual leads extending through the envelope thereby reduced.

Fig. 1 also shows the counting tube 20 connected into a suitable counting circuit. Each G grid 28 is connected through a resistor 30 and a capacitor 31 in parallel via lead 56 to the negative terminal of a D.C. source such as the battery 32, hereinafter referred to as E_G . A capacitor 18 is connected in parallel with E_G . The positive terminal of E_G is connected through an input resistor 33 to ground. The cathode 22 is connected to the positive side of E_G by leads 53 and 54, and is also connected to the positive terminal of a D.C. source such as the battery 34. The negative terminal of the battery 34 is connected to the control grid 23 by lead 55, and a capacitor 35 is connected in parallel with the battery 34.

The target electrodes 27 are each connected through a resistor 29, hereinafter referred to as the target resistor, to ground, and each target electrode is connected to its

associated G grid through a resistor 36. Further, a resistor 37 connects the ungrounded side of each target resistor 29 to the G grid 28 of the adjacent clockwise compartment.

The external terminal, not shown, for the A grids is connected to one output terminal 38 of a flip-flop or switching device 80, and the other output terminal 39 of the flip-flop 80 is connected to the external terminal, not shown, of the B grids. At any one time flip-flop 80 supplies a bias voltage of one polarity, with respect to the cathode 22, to the A grids and a bias voltage of the opposite polarity to the B grids.

The input terminal 40 of the counting circuit of Fig. 1 is directly connected by lead 57 to a source 90 of input pulses by lead 53 to the counting tube cathode 22, and by lead 52 to the input of the flip-flop 80. Capacitors 41, 42 are connected respectively between the flip-flop input lead 52 and its output terminals 38, 39.

A starting pulse source 75 is connected to one terminal of a normally open switch 43 and the other terminal of the switch 43 is connected through a capacitor 44 to the ungrounded side of the target resistor 29 of, for example, compartment 1.

A register or counting device 70 having approximately the resistance of a target resistor 29 may be inserted in place of such a resistor in any target electrode 27 circuit. Such a counting device 70 is shown in Fig. 1 in the target electrode circuit of compartment 10.

In Fig. 2, the net target electron current is shown plotted as a function of the target potential for the case where the targets 27 are made of a material in which the secondary emission ratio exceeds unity within the counting tube 20 operating range. For the solid line curve 92, V_k is the potential of the electron source or cathode 22, V_0 is the value of bombarding or target potential at which the secondary emission ratio of the target material is equal to unity, and V_c is the potential of the collector electrodes 24. V_0 of Fig. 2 may be about 50 volts in a specific embodiment of this invention. A load line 45 represents a target resistor 29, and intersects the plotted curve at two stable values of target potential. These values are V_k , the cathode potential, and the potential V_1 . If the cathode potential is dropped by some voltage V' to V_k' then the target current-voltage characteristic will change to the dashed curve 93 of Fig. 2 and the stable potential values will then be V_k' and V_1' , as indicated by the load line 46.

If a target potential is not at one of the two stable values and if the target is being bombarded by electrons from a cathode at potential V_k , the target will charge to potential V_k if the target potential is below $V_0 + \Delta V$ or the target will charge to potential V_1 if the target potential is above $V_0 + \Delta V$. This same type of action applies to the dashed curve with respect to the potential $V_0' + \Delta V'$ when the cathode is at potential V_k' .

This action of charging to one of the two stable potential values may be seen from the following consideration. At low primary energies or target potentials, the secondary emission ratio is less than unity, indicating that the net target electron current is positive, and the target being bombarded is assuming a negative charge from the acquisition of electrons. The bombarded target will accumulate negative charges until it finally reaches the cathode potential, a stable point.

When the target potential is increased to a critical voltage V_0 , the secondary emission ratio of the target material becomes equal to unity, and the net current to the target would be zero if the impedance in the target circuit were infinite. The presence of a finite load impedance in the target circuit provides an additional path for electron flow so that the potential at which the effective target secondary emission ratio becomes equal to unity is increased by ΔV . ΔV is the potential difference between V_0 and the potential at which the load line intersects the curve of Fig. 2 immediately above V_0 . At po-

tentials slightly higher than $V_0 + \Delta V$, the effective target secondary emission ratio exceeds unity and the net electron current to the target is negative. The target accumulates positive charges until it reaches an equilibrium potential determined by the intersection of the target resistor load line and the target characteristic. Thus, the cathode potential and the intersection potential are the two stable points of operation for a bombarded secondarily emissive target element.

With a particular target, for example 27-1, at potential V_1 and all other targets at potential V_k , an electrical pulse, whose length, amplitude and shape characteristics are discussed below, applied at the input terminal 40 will cause the target electrode of the compartment one position clockwise of the one at V_1 , e.g. that of compartment 2, to charge to V_1 while all other targets stabilize at potential V_k . Thus, the application of a pulse to the input resistor 33 will cause the tube 20 to count, or step, one position clockwise.

The operation of this specific illustrative embodiment of a counting tube 20 and circuit in accordance with my invention is as follows:

The tube, even when its heater is energized, is initially in the off condition, i.e., all of the target electrodes are at potential V_k , the lower of the two stable potential values referred to above. The readying or starting circuit comprises the starting pulse source 75, the switch 43, and the capacitor 44. When the switch 43 is closed, the starting pulse source 75 applies a positive pulse, like that shown in Fig. 3, through the capacitor 44 to the target resistor 29 of compartment 1. The amplitude a of this pulse must be greater than $V_0 + \Delta V$. The flip-flop 80 is so arranged that in the absence of an input pulse the A grids 25 are positive and the B grids 26 are negative with respect to the cathode 22. Electrons cannot pass the negative B grids 26 and, thus, only the odd numbered target compartments are capable of being triggered. The resistors 29, 30, 36 and 37 are so chosen that the starting pulse voltage appearing at the target electrodes of compartments 3 and 9 is substantially less than $V_0 + \Delta V$, and the target electrodes of odd-numbered compartments more remotely positioned from compartment 1 than compartments 3 and 9 are at still lower potentials. Thus, only the target of compartment 1 charges to potential V_1 while the remaining targets 27 remain at or near potential V_k . Also, the resistance values 29, 30, 36 and 37 are so chosen that only the G grids 28 of compartments 1 and 2 are substantially positive with respect to the cathode 22 when the target of compartment 1 is at potential V_1 . The slight positive bias on the other G grids is removed by battery 32. Although the G grid 28-2 of compartment 2 is positive, no electrons reach the target electrode 27-2 of that compartment because, as noted above, its B grid 26-2 is negative with respect to the cathode 22.

The counting device having been started or readied, assume now that a negative pulse, for example, is applied to the input terminal 40. The pulse amplitude V' must be greater than $V_0' + \Delta V' - V_k$, and further, it is necessary that the applied pulse rise fast enough for the target potential to rise above $V_0' + \Delta V'$ against the negative charging action below $V_0' + \Delta V'$. Also, the pulse length should at least be such that before the removal of the pulse the target electrode has charged to a point on the dashed curve of Fig. 2 corresponding to a target potential greater than $V_0 + \Delta V$. Then, at the pulse removal, when the operation changes back to the solid curve of Fig. 2, the target, being at a potential greater than $V_0 + \Delta V$, will stabilize at V_1 . Otherwise, neither pulse length nor pulse shape has any adverse effect on reliable high speed counting action.

The cathode 22, the control grid 23, and the G grids 28 are all pulsed negative by a negative input pulse. This causes the operating characteristic shown in Fig. 2 to change from the solid to the dashed curve. Just

before the application of the above assumed input pulse, the target of compartment 2 was at potential V_k . V_k target potential with respect to the dashed curve is, as Fig. 2 clearly shows, a value of target voltage greater than $V_0' + \Delta V'$ and so the target of compartment 2 will charge to the higher stable target voltage V_1' upon the application of the input pulse. Electrons reach only the target electrode 27-2 of compartment 2 upon the application of the pulse because, as explained above, conduction in the target electrode circuit of compartment 1 maintained only the G grids of compartments 1 and 2 at positive potentials with respect to the cathode 22. Further, the input pulse to the flip-flop 80 reverses the potentials on the A 25-1 and B 26-2 grids so that conduction in the target electrode circuit of compartment 1 is cut off at approximately the same time that compartment 2 is rendered able to conduct.

When the negative input counting pulse, i.e. the voltage V' , is removed, the operating curve once more becomes the solid curve of Fig. 2 and the target electrode 27-2 of compartment 2 then charges from potential V_1' to V_1 . Conditions at compartment 2 are then as they were at compartment 1 previous to the application of the input pulse, and the target electrode 27-2 of compartment 2 remains at potential V_1 while all other target electrodes are at potential V_k .

In the specific embodiment of the invention shown in Fig. 1, every tenth input pulse with, as noted above, the exception of the first counting cycle, causes the target electrode circuit of compartment 10 to conduct and its counting device 70 to register. This invention is, of course, not intended to be limited to a counting tube having therein ten compartments or sections. Furthermore, despite the references to clockwise counting, the counting tube and circuit described herein can be easily arranged so that counting is counter clockwise.

The capacitors 31 permit negative input pulses to pass on to the G grids 28. Thus, the potential difference between the cathode 22 and the G grids 28 is not changed by application of negative input pulses to the cathode 22. Further, the capacitors 31 serve to hold the G grid D.C. levels at previous values for a time. This is desirable since, for example, the G grid 28-2 of compartment 2 is kept positive before the application of an input pulse by the action of electrons bombarding the target electrode 27 of compartment 1. When the input pulse is applied, the current in compartment 1 may shut off rapidly and the voltage at the G grid of compartment 2 may drop too low to permit electrons to pass to the target electrode 27 of that compartment. The presence of the capacitors 31 holds the G grid D.C. levels for the time constant of the resistor 30, capacitor 31 circuits, and thereby gives the counting tube 20 time to count, or step.

The D.C. source 34, which may be an adjustable or variable supply, adjusts the level of current flow in the counting tube, and may also be used to cut off the tube. The capacitor 35, in parallel with the D.C. source 34, insures a low A.C. impedance path from the input terminal 40 to the control grid 23. Similarly the capacitor 18 by-passes the D.C. source 32. The capacitors 41, 42 provide negative input pulses with a low A.C. impedance path to the A 25 and B 26 grids. Thus, the A 25 and B 26 grids are pulsed negative with the cathode 22, control grid 23, and G grids 28. It is to be noted that only the target and the collector electrodes are not so pulsed by negative inputs.

Since the output appears in a target electrode circuit, separation of input and output pulses is obtained when counting negative pulses with the novel tube and circuit of this invention. It is possible, however, to cause the tube to count by application of a positive input pulse to all the target electrodes and to the flip-flop 80. For counting positive pulses, the circuit of Fig. 1 must be modified so that a lead extends from the junction of the input terminal 40 and the input resistor 33 to each

target electrode 27 through a capacitor, not shown, and so that the lead 91 is grounded and not joined to the aforementioned junction. Further, the flip-flop capacitors 41, 42 and the capacitor 35 are omitted. However, the input terminal 40 and the input resistor 33 remain connected to the input of the flip-flop.

The operation of this device when triggered by positive pulses to the flip-flop and the target electrodes is illustrated by Fig. 4. Since the potentials V_k , V_c , and V_0 , which represent respectively the cathode potential, the collector potential, and the potential at which secondary emission of the target electrode material is unity, remain unchanged, the operation is along the single curve 94. The load line 60 intersects the operating characteristic at the two stable values of target potential V_k and V_2 . In order to effect reliable high speed counting action, the following conditions must be satisfied. First, the rise time of the applied pulse V'' must be sufficiently short so that the target potential may rise above $V_0 + \Delta V$ against the negative charging action below $V_0 + \Delta V$. Second, the pulse length should at least be such that before the removal of the pulse, the target electrode has charged to a point on the curve of Fig. 4 so that at the removal of the pulse, the target will not be carried back along the curve past $V_0 + \Delta V$. Third, while the amplitude of each positive input pulse V'' must be greater than $V_0 + \Delta V$, the pulse amplitude should not be so great as to carry the target electrode potential back past $V_0 + \Delta V$ upon removal of the pulse. Fourth, the potential difference between V_2 and $V_0 + \Delta V$ must be greater than $V_0 + \Delta V$ minus V_k in order to prevent the removal of the pulse V'' from carrying the potential of the target electrode back past $V_0 + \Delta V$ and back to stability at V_k . Conditions 3 and 4 may be easily met by adjusting the common collector potential V_c accordingly.

The application of such a positive input pulse of amplitude V'' will cause an energized compartment, for example 1, to cut off due to the flip-flop 80 switching the A and B grid voltages. Electrons cannot pass the negative A grids 25, and thus only the even numbered compartments are capable of being triggered. In all the even numbered compartments the B grids 26 will be positive and the target electrodes will have been pulsed to a potential greater than $V_0 + \Delta V$. However, only in compartment 2, adjacent in a clockwise direction to the previously energized compartment 1, will the G grid voltage be of such a positive value so as to permit conduction. All the other G grids except that of compartment 1 will be at zero or a slightly negative bias due to voltage dividing by the resistors 29, 30, 36 and 37, voltage holding by the capacitors 31, and the action of the battery 32. Therefore, conduction will take place only in compartment 2, and its target electrode will charge toward the stable potential V_2 . If the pulse V'' is of a nature as set forth above, its removal will not affect the charging action of the target electrode, and the target will stabilize at V_2 . Thus, the application of a positive pulse to the target electrodes 27 and to the flip-flop 80 will cause the tube 20 to count, or step, one position clockwise.

Although specific embodiments of this invention have been shown and described, it will be understood that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of this invention.

What is claimed is:

1. An electron discharge device comprising a cathode, an array of secondary emitting targets opposite said cathode, a first and second electrode between each target and said cathode, means for applying a blocking potential to alternate of said first electrodes to prevent passage of electrons therethrough from said cathode to the associated targets, means normally applying a first potential bias to each of said second electrodes, and impedance means for applying a second potential bias to a second

electrode on occurrence of a discharge at the prior target in said array.

2. A high speed electronic counting tube comprising an evacuated envelope containing means for producing an electron beam, a control grid, a plurality of secondarily emissive target electrodes, a plurality of grids associated with each target electrode, and collector electrodes compartmentalizing each target electrode and its associated grids.

3. An electron discharge device comprising a cathode, an array of secondary electron emitting targets, electrode means between adjacent targets and defining distinct compartments for said targets, a first and second control electrode in each of said compartments between said cathode and the target in the compartment, means connecting a first group of alternate first electrodes together and a second group of alternate first electrodes together, and impedance means connecting each second electrode to its associated target and to the target of the prior compartment in the array.

4. A high speed electronic counting circuit comprising an evacuated envelope, means for producing an electron beam, a control grid, a plurality of annularly arranged secondarily emissive target electrodes, a plurality of grids associated with each target electrode, collector electrodes compartmentalizing each target electrode and its associated grids, an input terminal, D.C. potential means, an electronic switching device, a parallel resistor-capacitor network connected between the negative terminal of said potential means and the grid closest to each target electrode, the positive terminal of the potential means connected to said input terminal and to the beam producing means, and through a parallel capacitor-biasing means network to the control grid, said input terminal connected to a plurality of grids within the envelope through the electronic switching device, and a resistor network interconnecting each target electrode and its closest grid with the target electrodes of adjacent compartments.

5. An electron discharge device comprising a cathode, a plurality of secondarily emissive target electrodes positioned in an array, a plurality of control grids associated with each target electrode, electrode means compartmentalizing each target electrode and its associated grids, means including a resistor-capacitor network connected to each grid closest its target electrode for maintaining a first potential bias on said grid, and means connecting said grid to the next prior target in the array for maintaining a second potential bias on said grid on occurrence of a discharge at said prior target.

6. An electron discharge device comprising a cathode, a plurality of secondary emissive target electrodes positioned opposite said cathode, a plurality of control electrodes individual to each target electrode and interposed between said target electrodes and said cathode, first means connecting together a first group of control electrodes of alternate targets, second means connecting together a second group of control electrodes of the remaining alternate targets, and a bi-stable circuit having one output connected to said first means and the other output connected to said second means for alternately applying a bias potential to said control electrodes to inhibit passage of electrons from said cathode to the associated targets.

7. An electron discharge device in accordance with claim 6 further comprising a source of input pulses, means connecting said source to said cathode and to said bi-stable circuit, and means shunting said bi-stable circuit for applying pulses from said source directly to said control electrodes.

8. An electron discharge device comprising a cathode, an array of secondary emitting targets opposite said cathode, a first and a second control grid individual to each of said targets and interposed between said cathode and each of said targets, a source of signal pulses, means for

applying pulses from said source simultaneously to said cathode and said first and second control grids, means for normally applying a first bias potential to all of said second control grids, said last-named means including a potential source and a resistor-capacitor network between said source and each of said second control grids, and impedance means for applying a second bias potential to a second control grid on occurrence of a discharge at the next prior target electrode in the array.

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References Cited in the file of this patent

UNITED STATES PATENTS

2,638,541	Wallmark	May 12, 1953
2,742,590	Charton et al.	Apr. 17, 1956
2,766,376	Maynard et al.	Oct. 9, 1956