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ELECTRONIC SWITCHING DEVICE

Filed Dec. 31, 1943 2 Sheets-Sheet 1

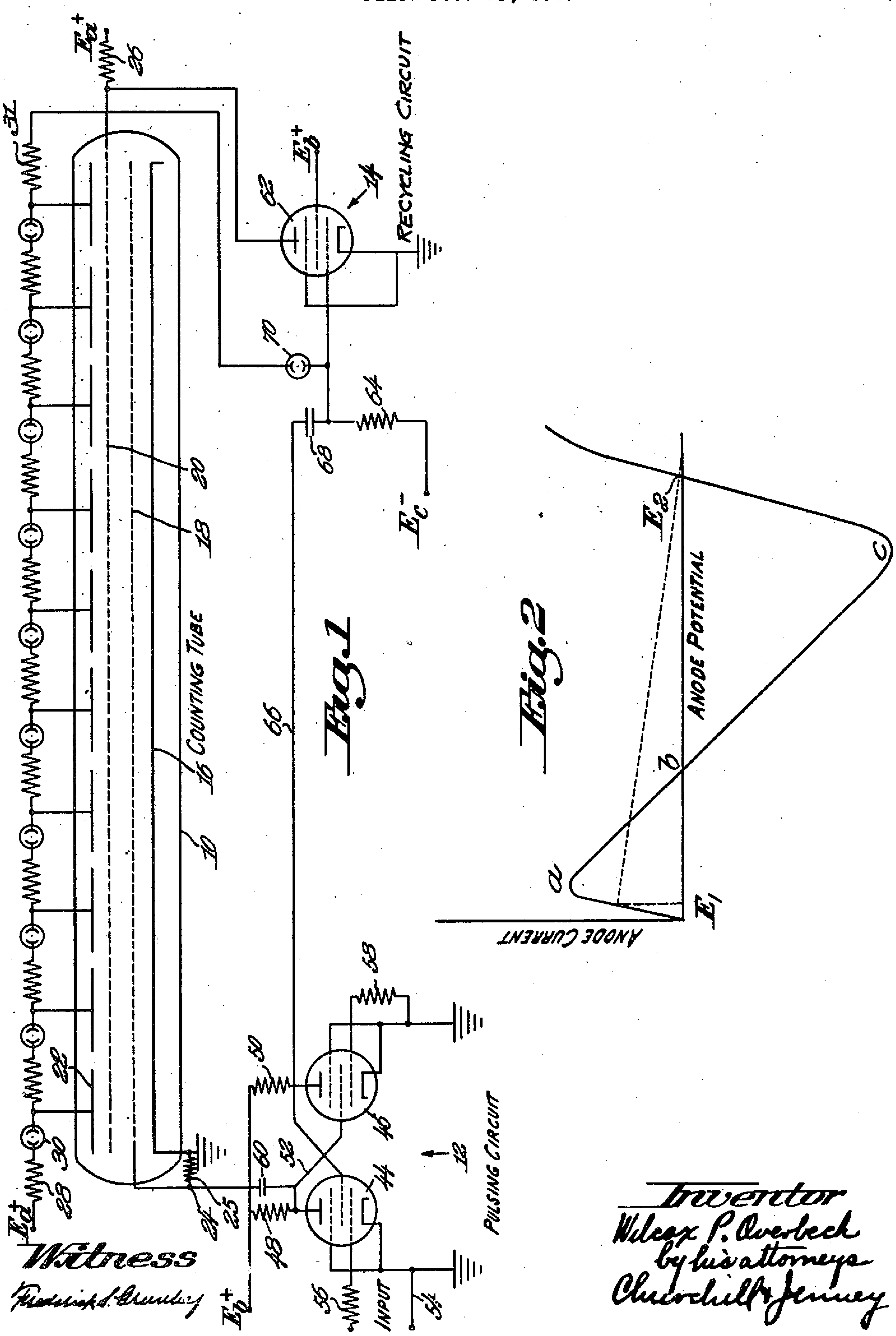

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Fig. 3

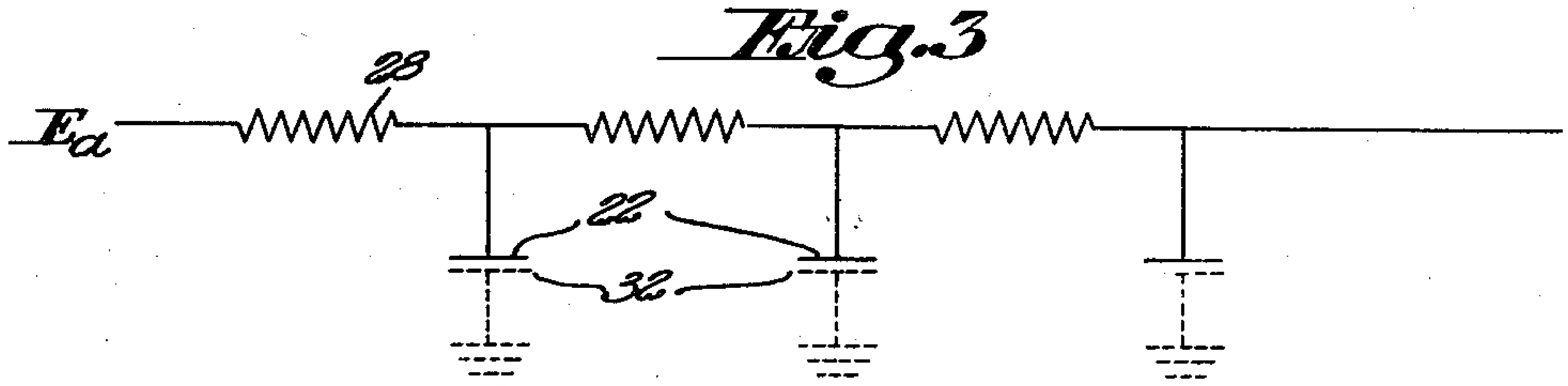


Fig. 4

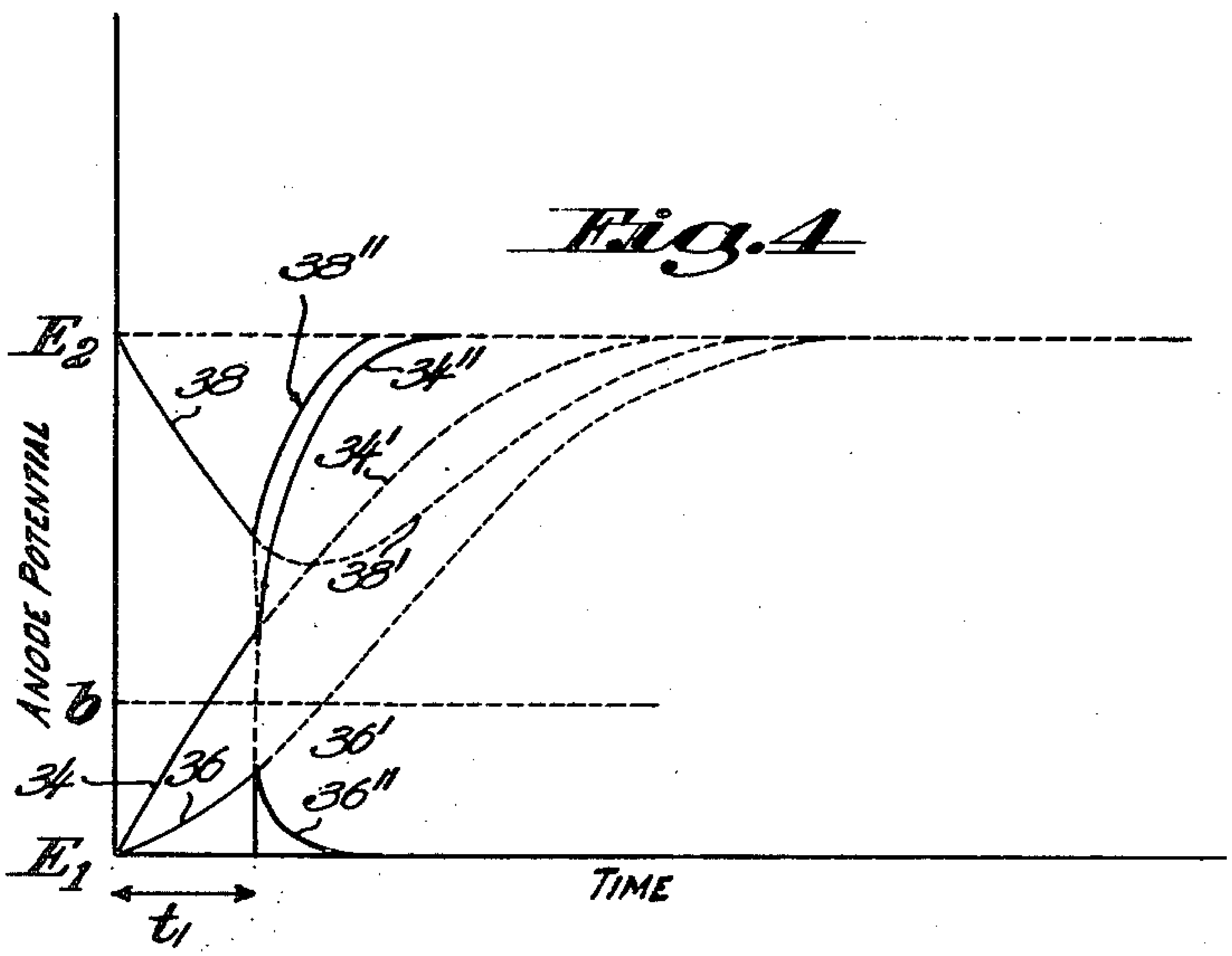
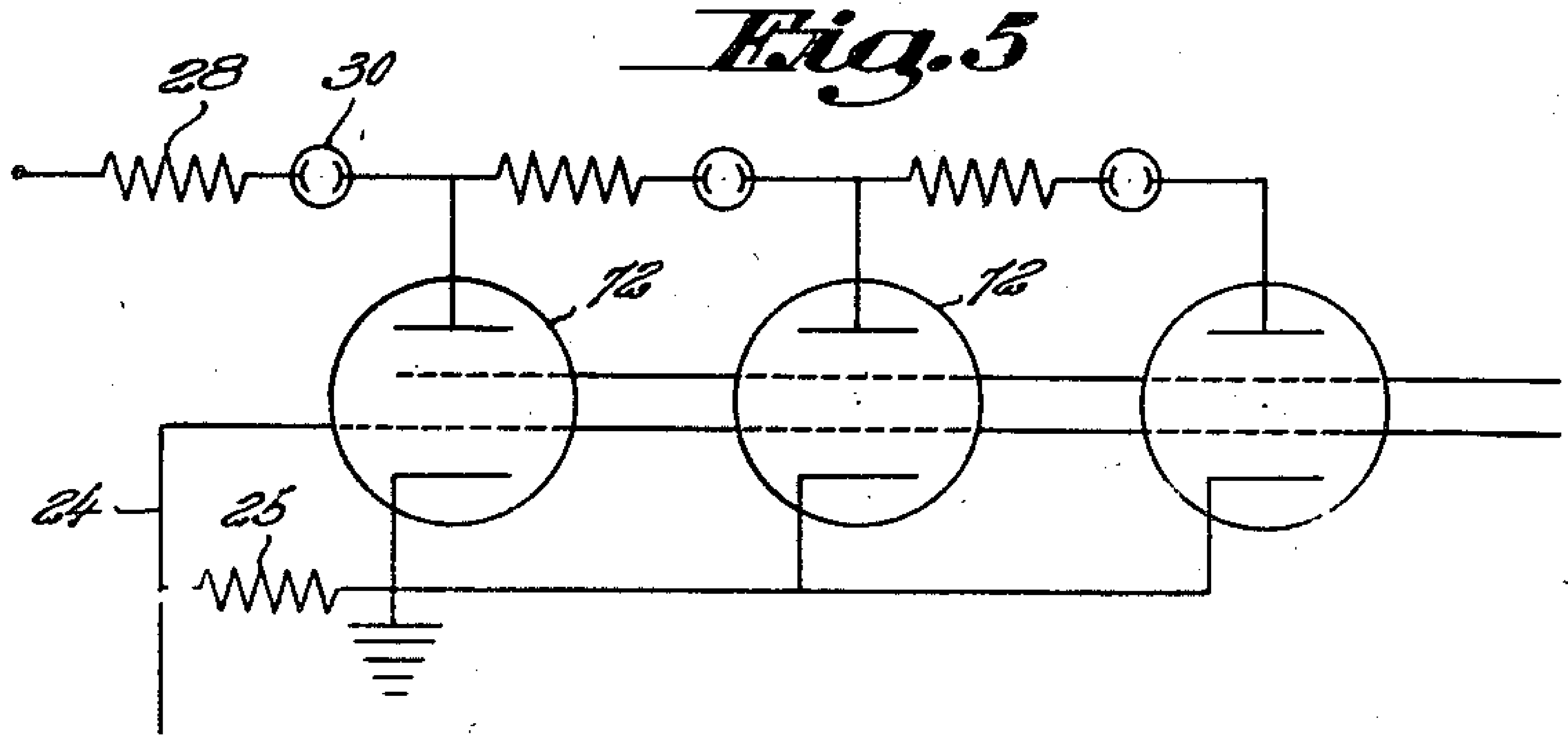


Fig. 5



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ELECTRONIC SWITCHING DEVICE

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11 Claims. (Cl. 250—27)

1

The present invention relates to electronic switching devices such as are used in counting systems.

The principal object of the present invention is to provide an electronic switching or counting system capable of operation with simplified circuits and capable of reliable high speed operation.

With this object in view, the present invention makes use of transient phenomena in negative-resistance circuits having two conditions of stability. A number of anodes are arranged for locking in either of two stable conditions. Upon release of the anodes by momentarily cutting off anode current, the anodes follow a prescribed transient behavior by which each anode tends to swing over from its original condition to the opposite condition of stability. By proper limitation of the operating pulse, the original condition may be interrupted at an instant when the behavior of the system corresponds to the desired switching action; in particular, by the use of appropriate circuits only a single anode will be converted from one stable condition to the other under the action of a pulse applied to the system. The negative-resistance characteristic is preferably obtained by secondary emission phenomena.

One of the principal advantages of the present invention is that it gives a reliable counting system with utmost simplicity of external circuits. A single control electrode may be used for initiating the stepping action for all the anodes, thus avoiding the use of priming circuits, transfer circuits and the like.

In the accompanying drawings, Fig. 1 is a diagram of the preferred form of counting tube embodied in a decimal counting system; Fig. 2 is a diagram illustrating the conditions of stability of the secondary emission anodes; Fig. 3 is a diagram of the equivalent circuit of the anode; Fig. 4 is a diagram illustrating the transient behavior of the anode circuits; and Fig. 5 is a diagram of a modified form of system utilizing individual tubes.

The system shown in Fig. 1 comprises a counting tube **10**, a pulsing circuit indicated generally at **12**, and a recycling circuit indicated generally at **14**.

The tube **10** comprises a cathode **16**, indirectly heated in any suitable manner, as by a filament, a control grid **18**, a screen grid **20**, and a plurality of anodes **22**. For counting in the decimal system, ten anodes are used. The cathode is grounded. The control grid is connected to the pulsing

2

circuit by a connection **24**, which is connected through a resistor **25** to ground. The screen grid is connected through a resistor **26** with a source of positive potential E_a. The anodes are separately connected to the junctions of a series of resistors **28**. A glow lamp **30** may be included in series with each resistor **28** for purposes to be later described. The first resistor **28** is connected to the positive source E_a. There is one resistor **28** (and glow lamp **30**, if used) ahead of each anode. A resistor **31** connected to the last anode leads to the recycling circuit **14**, as will be described later.

The tube **10** makes use of secondary emission phenomena. With fixed potentials on the control grid and screen grid, the current-voltage characteristic of any anode is represented by Fig. 2. At zero anode potential, electrons flow from the cathode to the screen grid and none reach the anode, so that the anode current is zero. If a slight positive potential is applied to the anode, it robs the screen grid of some electrons, and there is a positive anode current. The velocity of electrons arriving at the anode is determined by the anode potential, and as the potential increases, the electron velocity likewise increases. At higher anode potentials, the electrons arriving at the anode have sufficient velocity to knock secondary electrons loose from the anode surface, and these secondary electrons are drawn to the screen grid. The resultant anode current is determined by the difference between the number of primary electrons arriving at the anode and the number of secondary electrons leaving it. The positive anode current reaches a maximum at a certain potential a, beyond which the characteristic has a negative slope. At a certain anode potential, indicated at b, the value of which depends on the character of the anode (about 50 volts with a stainless steel anode), there are as many electrons released from the anode as are received by it, so that the resultant anode current is zero.

As the anode potential increases beyond b, each primary electron can release more than one secondary electron, and the anode current becomes increasingly negative, reaching a minimum at c. The part of the curve between a and c is the negative-resistance portion of the characteristic. As the anode potential increases further and approaches the screen grid potential, fewer secondary electrons are drawn to the screen grid, and the anode current rises towards zero. When the anode potential exceeds the screen grid potential, the secondary electrons no longer are drawn to the screen and the anode current returns to a positive value, made up only of primary electrons. In Fig. 2, the screen grid potential is chosen to be about three times the zero-current potential *b*, which is satisfactory for the present invention.

If there is a resistance in series with the anode, the operation is indicated by the diagonal straight line in Fig. 2, the slope of the line depending on the resistance. This dotted line intercepts the anode characteristic at two stable points, corresponding to anode potentials E_1 and E_2, lying respectively to the left and right of points *a* and *c*. A secondary-emission tube with series resistance must lock in at either one of these points. This constitutes an elemental trigger circuit.

In the arrangement of Fig. 1, each anode operates on a characteristic such as that shown in Fig. 2. It has been found that the secondary emission effect for each anode is substantially independent of the potentials on the other anodes. It is, therefore, possible to have adjacent anodes in opposite conditions of stability, which conditions will be maintained so long as the screen grid and control grid potentials are maintained at constant values.

The operation of the tube **10** as a counting device will first be described on the assumption that negative input pulses are applied to the connection **24**. The pulsing circuit **12**, by which the pulses are applied, will be described later in detail. For simplicity of initial explanation, let us consider a system in which the glow lamps **30** are not used. First let us assume that all anodes are locked at the low potential E_1, at which potential the current to each anode is positive as determined mainly by primary electron flow. It will be observed that the system comprises a ladder-type network in which the series elements are the resistors **28** and the parallel elements are the capacitances **32** of the anodes to ground, as illustrated diagrammatically in Fig. 3. If a negative pulse is applied to the control grid **18**, thus tending to cut off anode conduction, all of the anodes tend to rise in potential, but the first one rises most rapidly. This action is illustrated by graphs of the transient phenomena illustrated in Fig. 4, in which anode potential is plotted against time. The potential of the first anode starts to rise from E_1 along the curve **34**. If the negative potential were held on the control grid indefinitely, the anode potential would rise along the dotted portion **34'** of the curve until the anode potential ultimately reached E_2. The shape of the curve **34, 34'** may be determined approximately by the transient solution for the resistor **28** in series with the capacitance **32** between the first anode **22** and ground.

The conditions for the second anode are determined by the fact that its resistor **28** and its capacitance **32** are connected across the capacitance **32** between the first anode and ground, so that the rise of potential on the second anode is retarded by the necessity for charging the first capacitance. Hence its potential rises from E_1 along a curve **36**, which is below the curve **34**. If the negative control grid potential were held indefinitely, the anode voltage would follow the dotted curve **36'**, and eventually reach E_2. A similar transient characteristic might be drawn for each of the remaining anodes, and each such characteristic would lie below the curve **36, 36'**.

The invention contemplates that the negative potential applied to the control grid is not continued indefinitely, but is in the form of a pulse, terminating at a time t_1. The duration of this pulse is selected so that the curve **34** for the first anode will have risen above a certain critical potential which determines that the anode will swing over to the high potential condition, while the potential of the second anode will not have risen to such critical potential. In Fig. 4, the critical potential which determines whether a particular anode will swing to the high or the low stable potential is assumed to be the same as the zero-current potential *b*. At the termination of the pulse, therefore, the first anode will go immediately to the second stable condition represented by E_2, this rise of potential being indicated by the solid curve **34''**. The second anode will return to the initial stable condition E_1 along the solid curve **36''**. All subsequent anodes being at potentials below that of the second anode will also revert to the stable condition represented by E_1. The result of the application of the negative pulse, therefore, is that the first anode will be converted to the high potential condition and the remaining anodes will revert to the low potential condition.

On a subsequent negative pulse, the first anode, which now starts at the high potential condition, will tend toward the low potential condition along the curve **38**, which curve has a dotted extension **38'** representing ultimate return to E_2 if the control grid potential were maintained sufficiently long at negative potential. At the termination of the pulse, the anode potential rises rapidly along the curve **38''** to its initial high value E_2. The second anode follows a curve similar to that represented by curve **34, 34''** to the high potential E_2, while all subsequent anodes drop back to E_1 along curves similar to **36, 36''**.

In general, therefore, the tube will have none, one, two or more of the first anodes at the high-potential condition and all the remaining anodes at the low-potential condition. The application of a negative potential to the grid **18** tends to convert each low-potential anode to the high-potential condition; that is, if the grid potential were maintained for a sufficiently long time all anodes would arrive at the high-potential condition. By limiting the pulse duration, however, the transient swings of all but one of the initially low-potential anodes are stopped before the anode potential passes through the critical value *b*. For only one anode is the transient allowed to pass through the critical value. Therefore, the resultant action of a pulse of proper duration is to leave all of the original high-potential anodes in the high-potential condition, to convert the first low-potential anode to the high-potential condition, and to leave all remaining anodes in the low-potential condition. In other words, each pulse increases by one the number of high-potential anodes until all of the anodes arrive at the high-potential condition.

The foregoing description of operation is based on the assumption that glow lamps **30** are omitted. The use of the lamps performs two functions; first, to give an indication of the number of pulses that have been applied to the tube, and second, to alter the transient characteristics of Fig. 4. As for the first function, it will be noted that only one of the glow lamps is included between a high-potential and a low-potential anode, and only that lamp will ignite. The single ignited lamp is an indicator of the number of applied pulses.

The function of the lamp in altering the characteristics of Fig. 4 may be understood by noting that a lamp will not ignite until the potential applied to it exceeds a certain definite value. Hence, all anodes beyond the last high-potential anode are at zero potential rather than at E_1. This means that the transient characteristic represented by 36 starts from a lower point and will not start to rise at zero time, in fact, if the pulse is sufficiently short, the potential of the anode may remain at zero. The characteristics represented by 34 and 38 tend to follow the indicated curves, at least approximately, since for these anodes the ignition potential of the glow lamps is rapidly exceeded. The glow lamps, therefore, provide a more reliable action in effectively discriminating between the anode that is to kick over to the high potential condition and those that are to remain in the low potential condition.

Since the operation of the tube 10 is most effectively carried out by sharply defined pulses of fairly critical duration, the special pulsing circuit 12 is provided. This circuit comprises two pentodes 44 and 46, the anodes of which are excited by a source of positive potential E_b through resistors 48 and 50. The suppressor grids of both tubes are grounded, and the screen grid of each tube is connected at 52 with the anode of its companion tube. An input circuit 54 including a resistor 56 is connected between ground and the control grid of the first tube 44. An alternating potential is applied to the circuit 54. The control grid of the second tube is connected to ground through a resistor 58. The anode of the first tube 44 is connected through a condenser 60 with the circuit 24 leading to the control grid of the counting tube 10.

The tubes 44 and 46 form a binary pair in which one tube is at high anode potential and the other tube is at low anode potential. The anode potential of the first tube 44 is normally at the high value (anode non-conducting) and that of the second tube 46 is at the low value (anode conducting). A positive potential applied through the input circuit 54 to the control grid of the tube 44 converts the anode of the first tube 44 to the conducting (low-potential) condition and that of the second tube to the non-conducting (high-potential) condition. Thus a negative pulse is transmitted through the condenser 60 to the grid 18 of the counting tube, and it is this pulse which is utilized to operate the counting tube, as above described. The duration of this pulse is determined by the time constant of the circuit composed of the condenser 60 and the resistor 25, and the pulse duration is so chosen as to give the results heretofore described in connection with Fig. 4.

A negative potential applied to the pulsing circuit through 54 results in restoring the tubes 44 and 46 to the original condition, and also in transmitting to the counting tube a positive pulse, which, however, has no effect on the conditions existing in the counting circuit. Thus, with an alternating potential input at 54, only the positive half-waves are counted.

In the system thus far described, successive impulses will ultimately bring all of the anodes 22 to the high potential (E_2) condition. For subsequent counting operations, it is necessary to restore the counting tube to its original condition, and this is preferably accomplished automatically by means of the recycling circuit shown at 14. This circuit comprises a pentode 62 having its cathode and suppressor grid grounded, its control grid negatively biased from a source E_c through a resistor 64, and its screen grid excited from the source E_b. The anode is connected to the screen grid 20 of the counting tube, whereby the positive potential E_a is applied to the anode through the resistor 26.

A connection 66 leads from the anode of the second pulsing tube 46 through a condenser 68 to the grid of the tube 62. Also, a connection runs from the last anode of the tube 10 through the resistor 31 and a glow lamp 70 to the control grid of the tube 62.

Normally the anode of the tube 62 is non-conducting, because of the negative bias on the control grid. At the conclusion of each pulsing operation of the pulsing circuit 12, a positive pulse is applied to the control grid of the tube 62 through the connection 66 and condenser 68. It will be recalled that under the action of a positive pulse applied to the input circuit 54 of the pulsing circuit 12, the second tube 46 is converted from low to high anode potential. This conversion sends a positive pulse over the connection 66 and through the condenser 68 to the grid of the tube 62, at the same time that a negative pulse is being transmitted to the counting tube through the condenser 60. Ordinarily this positive pulse is insufficient to overcome the negative bias E_c applied to the grid, and the tube 62 therefore remains in non-conducting condition. However, if the last anode 22 of the counting tube 10 has been brought to its high potential condition by the action of the negative pulse applied to the counting tube, conduction will have been established through the resistor 31 and the glow lamp 70, thus priming the grid of tube 62 so that the last part of the pulse applied through 68 will momentarily swing the grid to a positive potential. The anode circuit of the tube 62 then becomes conducting, and draws sufficient current through the resistor 26 to lower the potential on the screen grid 20 of the counting tube. This cuts off conduction to all anodes in the counting tube, and restores all anodes 22 to the potential E_1. As soon as that happens, the priming potential on the grid of the tube 62 is removed and the non-conducting condition of that tube is restored, so that the screen grid 20 is brought back to its normally constant potential.

The foregoing operation of the recycling circuit may be availed of to initiate operation of any suitable carry-over device for counting in a subsequent stage.

For the separate single tube 10, a number of individual tubes 72 may be substituted as shown in Fig. 5. These tubes have their cathodes, control grids and screen grids connected together and their anodes separately connected to an input network composed of the resistors 28 and glow lamps 30. The tubes 72 may be otherwise connected with the pulsing and recycling circuits, exactly as is the single tube 10 of Fig. 1.

From the foregoing description it will be observed that the counting device 10 (or the individual tubes 72) forms a counting system in which one of the principal advantages lies in the simplicity of the connections. A single external connection to each of the grids 18 and 20 is sufficient, and the use of complicated transfer and priming circuits is avoided. The external circuits for the anodes comprising only the resistors 28 (with or without the glow lamps 30) are exceptionally simple in their connections. The tube is preferably under very high vacuum and the results of the present invention are attained without reliance on ionization phenomena.

The switching action in the present invention may be regarded as resulting from the distinctive transient behavior of circuits under different potential conditions. Thus the circuit is converted from one condition to another by first cutting off anode current, thereby releasing the anodes from their original condition of stability and allowing the several anode circuits to follow their natural transient behavior for a specified time, as indicated in Fig. 4, and then restoring the anode current when the instantaneous conditions correspond to the conversion of a single anode from a previous low-potential condition to the high-potential condition. This is, in fact, a specific example of more general operation. Since the transient characteristics of the several anodes are quite different from one another, it is possible, by controlling the pulse duration, to cause other combinations of effects; for example, by reference to Fig. 4 it will be seen that by somewhat increasing the pulse time, it is possible to convert two anodes from the low-potential to the high-potential condition. It will be clear to those skilled in the art that a variety of selective actions may be obtained.

Having thus described the invention I claim:

1. An electronic switching system comprising a plurality of anodes, common and substantially equipotential grid means for the anodes, means for establishing independent negative-resistance characteristics for the anodes to cause each anode to assume either a high-potential or a low-potential condition of stability, a network including circuit elements connected between adjacent anodes and independent capacitances between the anodes and ground, whereby a change of potential on any anode results in retarded potential changes on succeeeding anodes, means for applying to the common grid means a pulse to release all of said anodes from their stable conditions, the duration of the pulse being limited to cause conversion of selected anodes from one stable condition to the other.

2. An electronic switching system comprising a plurality of anodes, common and substantially equipotential grid means for the anodes, means for establishing independent negative-resistance characteristics for the anodes to cause each anode to assume either a high-potential or a low-potential condition of stability, a network including circuit elements connected between adjacent anodes and independent capacitances between the anodes and ground, whereby a change of potential on any anode results in retarded potential changes on succeeding anodes, means for applying to the common grid means a pulse to release all of said anodes from their stable conditions, the duration of the pulse being limited to cause conversion of only a single anode from one stable condition to the other.

3. An electronic switching system comprising a plurality of anodes, each capable of stable operation at either high or low anode potential, common and substantially equipotential grid means for releasing all of said anodes from their stable conditions, resistances connected between adjacent anodes and forming a network with the capacitances of the anodes to ground, means for applying to the common grid means a pulse to release all of said anodes from their stable conditions whereby each anode tends toward the opposite stable condition, the duration of the pulse being limited to cause reversion to the original stable condition of anodes which do not pass through a critical potential.

4. An electronic switching system comprising a plurality of secondary emission anodes each capable of stable operation at either high or low anode potential, common and substantially equipotential grid means for the anodes, a resistor in series with the first anode and resistors connecting adjacent anodes, means for applying a negative pulse of limited duration to the common grid means, tending to cut off conduction from all anodes and thereby to cause each anode to swing toward the opposite condition of stability according to a transient, the character of which differs for the successive anodes, the termination of the pulse being such as to determine reversion of selected anodes to their original conditions of stability.

5. An electronic switching system comprising a plurality of anodes, means for establishing primary conduction to the anodes, means for causing secondary emission from the anodes, whereby each anode is normally locked in at either a stable high potential or a stable low potential, electrical network means associated with the anodes to determine progressively different transient behavior of the anodes, common and substantially equipotential control grid means, means for applying a pulse to the grid means for initiating transient operation of the anodes, and means for limiting the pulse duration to effect selective conversion of anodes from one stable condition to the other.

6. An electric switching system comprising a plurality of anodes, common and substantially equipotential grid means for the anodes, means for establishing independent negative-resistance characteristics for the anodes to cause each anode to assume either a high-potential or a low-potential condition of stability, a network including circuit elements connected between adjacent anodes and independent capacitances between the anodes and ground, whereby a change of potential on any anode results in retarded potential changes on succeeding anodes, and a pulsing circuit for applying to the grid means a pulse tending to cut off conduction, said pulsing circuit having means for limiting the duration of the pulse to cause conversion of selected anodes from one stable condition to the other.

7. An electronic switching system comprising a plurality of anodes, common and substantially equipotential grid means for the anodes, means for establishing independent negative-resistance characteristics for the anodes to cause each anode to assume either a high-potential or a low-potential condition of stability, a network including circuit elements connected between adjacent anodes and independent capacitances between the anodes and ground, whereby a change of potential on any anode results in retarded potential changes on succeeding anodes, means for applying to the common grid means a pulse to release all of said anodes from their stable conditions, the duration of the pulse being limited to cause conversion of selected anodes from one stable condition to the other, said network including devices which become conducting only under potentials in excess of an ignition potential, whereby the transient changes on selected anodes at initially low potentials are retarded.

8. An electronic switching system comprising a plurality of secondary emission anodes each capable of stable operation at either high or low anode potential, common and substantially equi-

potential grid means for the anodes, a resistor in series with the first anode and resistors connecting adjacent anodes, means for applying a negative pulse of limited duration to the common grid means, tending to cut off conduction from all anodes and thereby to cause each anode to swing toward the opposite condition of stability according to a transient, the character of which differs for the successive anodes, the termination of the pulse being such as to determine reversion of selected anodes to their original conditions of stability, said network including devices which become conducting only under potentials in excess of an ignition potential, whereby the transient changes on selected anodes at initially low potentials are retarded.

9. An electronic switching system comprising a plurality of anodes, common and substantially equipotential grid means for the anodes, means for establishing independent negative-resistance characteristics for the anodes to cause each anode to assume either a high-potential or a low-potential condition of stability, a network including circuit elements connected between adjacent anodes and independent capacitances between the anodes and ground, whereby a change of potential on any anode results in retarded potential changes on succeeding anodes, means for applying to the common grid means a pulse to release all of said anodes from their stable conditions, the duration of the pulse being limited to cause conversion of only a single anode from one stable condition to the other, and recycling means operable when all anodes are at high potential to restore them to the low-potential condition.

10. An electronic switching system comprising a plurality of anodes, means for establishing primary conduction to the anodes, means for causing secondary emission from the anodes, whereby each anode is normally locked in at either a stable high potential or a stable low potential, electrical network means associated with the anodes to determine progressively different transient behavior of the anodes, common and substantially equipotential control grid means, means for applying a pulse to the grid means for initiating transient operation of the anodes, and means for limiting the pulse duration to effect selective conversion of anodes from one stable condition to the other, and recycling means operable when all anodes are at high potential to restore them to the low-potential condition.

11. An electronic switching system comprising a plurality of anodes capable of stable operation at either high or low anode potential, common screen grid means determining secondary emission characteristics for the anodes, common and substantially equipotential control grid means, pulsing means for applying to the control grid means a negative pulse tending to cut off anode conduction and to cause each anode to swing from its initial toward the opposite condition of stability, said pulsing circuit having provision for terminating the pulse at a time to cause reversion of selected anodes to their initial conditions, a recycling circuit including a tube having an anode and a control grid, connections from the pulsing circuit and the last anode of the switching tube to the grid of the recycling tube to cause anode conduction in the recycling tube when the last anode of the switching tube is at high potential, and connections between the anode and the recycling tube and said screen grid means for momentarily reducing the screen grid potential and thus to convert all anodes of the switching tube to the low-potential condition of stability.

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