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IMPULSE COUNTING TUBE

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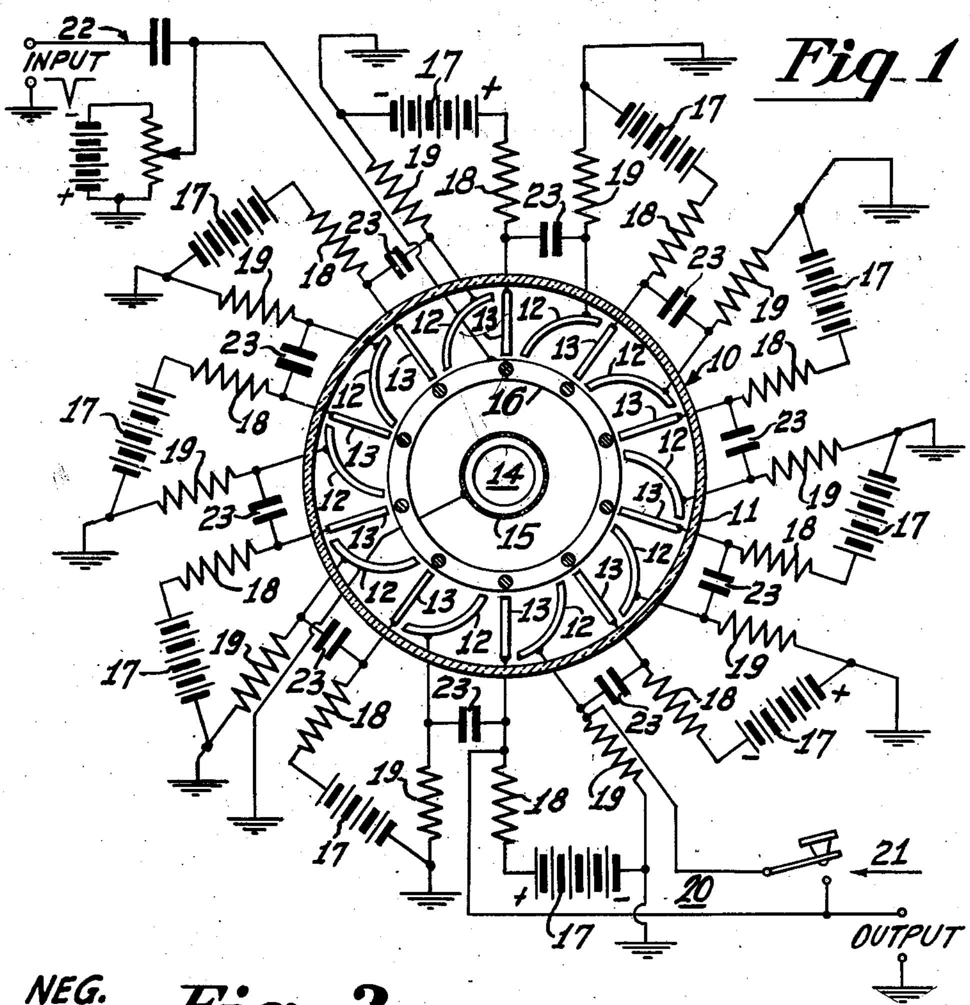

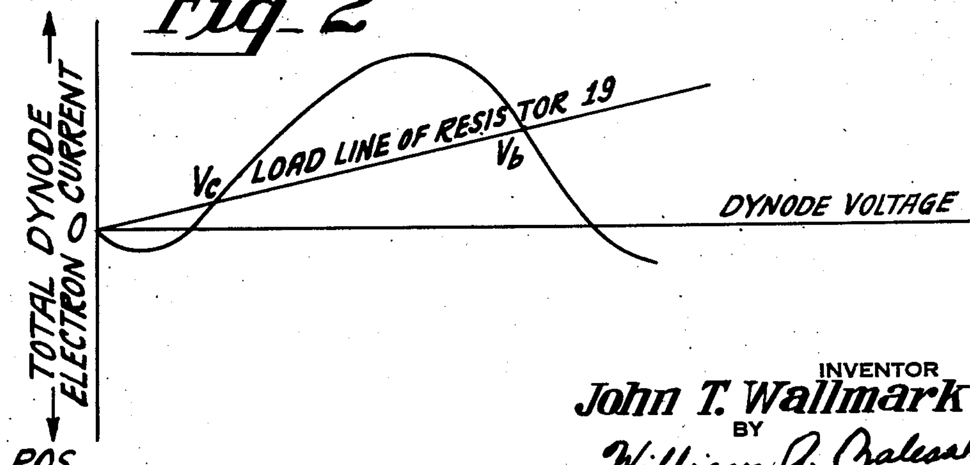

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IMPULSE COUNTING TUBE

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This invention relates to electron discharge devices and more particularly to discharge devices which employ secondary emission electrodes and are suitable for counting electrical impulses.

In the art of electronic digital computers it is customary to employ circuits which are adapted to count electrical impulses. These circuits usually include a plurality of component parts, such as successive counting stages, each of which has two stable conditions between which it may be switched by electrical impulses. The operation of one large variety of such component parts is based on the use of gas discharge tubes which themselves have two stable conditions, i. e., they are either ionized or de-ionized. Component parts of this type have the disadvantage that their speed of change-over from one of the stable conditions to the other is limited by the deionization time of the gas tube. The operation of another large variety of such component parts is based upon the regenerative interconnection of pairs of cooperating amplifying tubes. Circuits using component parts of this type have the disadvantage that they require many vacuum tubes and therefore large amounts of heater power and considerable circuitry for interconnecting the tubes. Moreover, they have the added disadvantage that their large amounts of circuitry entail increased stray capacitances thus lengthening certain RC time constants and lowering the top rate of impulse counting.

It is an object of my invention to provide an electron discharge device of improved design particularly suitable for use in electronic counting circuits.

It is another object of the present invention to devise a hard-vacuum type of electron discharge device which can be so used in an electronic counting circuit that the one device will provide a plurality of stable conditions among which it can be rapidly switched by the application of electrical impulses.

It is a further object of the present invention to devise a discharge device as set forth above which is so arranged that said circuit may be relatively simple and compact to the end that its stray capacitance will be small and its top counting rate high.

It is a further object of the present invention to devise a counting circuit of simplified construction and increased top counting speed.

Other objects, features and advantages of this invention will be apparent to those skilled in the art from the following detailed description of an illustrative embodiment of this invention and from the drawing in which:

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Fig. 1 represents a cross-sectional view of a discharge device according to the present invention and indicates how its elements may be interconnected to form a novel impulse counting circuit; and

Fig. 2 is a plot of the current-versus-voltage characteristic of each of the secondary emitters employed in the discharge device illustrated in Fig. 1.

The counting tube 10 shown herein in Fig. 1 may be considered as comprising within a single envelope 11 ten dual-stability discharge devices which can be suitably interconnected to provide a complete decade of ten counting stages. As so considered each dual-stability discharge device includes a secondary-emitter electrode 12 (which will also be referred to as a dynode) and a collector electrode 13 cooperating therewith. Thus the tube 10 includes ten pairs of the electrodes 12, 13. These pairs of electrodes are arranged annularly around a centrally positioned cylindrical cathode 14 which may be of the indirectly heated type, the heater not being shown in the drawing. Cathode 14 carries on its outer cylindrical surface a coating of emissive material 15 which may be of any conventional type. Between the cathode and the annular row of pairs of electrodes 12, 13 there is a squirrel-cage control grid 16.

Each of the collector electrodes 13 is positioned to extend radially outward from one of the wires of the grid 16 in such a position as to be within its electron "shadow." On the other hand, each of the secondary emitter electrodes 12 is positioned somewhat crosswise to a radial direction in such a position as to be between the electron shadows of the two adjacent grid wires and in the path of rectilinear electron flow from the cathode, i. e., as to intercept on one of its surfaces primary electrons emitted by the cathode. In this arrangement the grid, besides having its usual current-controlling function, has the additional function of forming the primary electrons from the cathode 14 into a number of beams each of which is directed away from the collector electrodes 13, i. e., between two of them, and toward one of the secondary emitter electrodes 12. This additional function of the grid may be considered as involving both shielding action (that of shielding the collector electrodes from primary electrons by the physical presence of a grid wire between the inner edge of each collector electrode and the emissive surface of the cathode) and focusing action (that of focusing the primary electrons into ten radial beams each of which is directed toward one secondary emitter and not in the direction of any collector). The secondary emitter electrodes 12 may be made of any appropriate known material such as a silver magnesium alloy. Each of the collector electrodes 13 and each of the secondary emitter electrodes 12 is insulatingly supported within the envelope 11, i. e., none of these elements is directly connected electrically with any of the others or with any of the other tube elements. On the other hand, all parts of the squirrel-cage grid should preferably be directly connected together electrically so that at any instant they will be at the same potential. Accordingly, the grid may be a single unitary metallic structure which, as a whole, is insulatingly supported with respect to all of the other tube elements, viz., with respect to the electrodes 12, 13 and to the cathode 14. In actual embodiments of tubes according to this invention an individual lead extends through the envelope 11 from each electrode 12, each electrode 13, the control grid 16, and the cathode 14, to an appropriate external terminal, not shown, such as a terminal pin, to permit each of these tube electrodes to be individually connected to a different part of an appropriate external circuit.

Fig. 1 shows the counter tube 10 connected into a suitable counting circuit. A source of direct current potential 17, which, as in Fig. 1, may be one of ten separate sources provided respectively for the different counting stages, or which may be a single common source, is connected between each secondary emitter electrode 12 and its cooperating collector electrode 13. To this end, the required connection to each collector electrode 13 is from the positive side of the source 17 over an individual load resistor 18, and that to each secondary emitter electrode 12 is from the grounded negative side of the source 17 over another individual resistor herein to be referred to as a dynode polarizing resistor 19.

In the present example the cathode 14 is grounded and the control grid 16 is polarized at a very small negative potential, i. e., nearly at ground potential. However, this counting circuit can be adjusted to be operative with both of these elements grounded. A readying circuit 20 comprises a push-button switch 21 and a pair of conductors connecting one of the terminals of this switch to the secondary emitter electrode 12 of one of the counting stages, which may be arbitrarily selected to serve as the first counting stage, and the other terminal to the collector electrode 13 which cooperates with the selected electrode 12, so that these electrodes may be didirectly interconnected by closing the push-button switch 21. There are provided an input circuit 22, over which negative pulses which are to be counted may be applied to the control grid 16, and an output circuit comprising a pair of terminals which are respectively connected to ground and to the terminal of the switch 21 connected to the collector electrode 13.

Typical operation of the circuit shown in Fig. 1 would be as follows: after the circuit has been fully assembled ordinarily there will be no cathode-to-collector primary electron current (due to the abovementioned shielding and/or beaming); no cathode-to-secondary emitter primary electron current (due to the zero potential of the secondary emitter electrodes); and no secondary-emitter-to-collector secondary electron current (due to the lack of primary bombardment of the second emitter electrodes). A space charge of primary electrons will hover between the outer surface of the cathode 14 and the zero-volt equi-

potential surface set up in the region between the outside of grid 16 and the annular row of secondary emitters and collectors (as a resultant of the B+ potential of the collectors, the zero potential of the secondary emitters and the slightly negative potential of the grid wires). If it should happen that primary electron current is flowing to one or more of the secondary emitter electrodes, for example, as a result of some inadvertence in setting up the circuit, this can be readily stopped by momentarily grounding it (or them).

The circuit is readied for counting by pressing the push-button switch 21. This will complete a closed direct-current loop including the source 17 for the first counting stage, or the common source 17 as the case may be, in series with the load resistor 18 and the dynode polarizing resistor 19 of this stage. This will cause the direct potential of the source 17 to be divided between these resistors with both the secondary emitter and the collector electrodes of the first counting stage polarized at a potential equal to that of the source 17 less the drop across the load resistor 18 or, as otherwise expressed, at a potential equal to the IR drop across the dynode polarizing resistor. The circuit constants should be so chosen that this potential is higher than V_b (see Fig. 2). In this condition of the first counting stage a beam of electrons will be drawn from the abovementioned electron space charge so as to pass between two of the wires of grid 16 and impinge onto the surface of the secondary emitter 12 of the first stage. Their bombardment will cause this emitter to release a number of secondary electrons for each primary electron. Many of these secondary electrons will return to this emitter so long as the push-button switch remains closed. However, at the instant when its push-button is released the potential of the collector electrode 13 will rise somewhat while that of the secondary emitter 12 will drop to V_b (see Fig. 2) so that, due to the potential difference between them, secondary electron current will start to flow to the former from the latter. Thus it is seen that current will continue to circulate in the same loop with the difference that a fairly high resistance space discharge of secondary electrons between the cooperating electrodes will complete the closed circuit in place of the low resistance path initially provided between the switch contacts.

While the secondary emitter electrode will draw primary electron current, it will release a considerably larger secondary electron current. Therefore its total electron discharge current will be negative, see Fig. 2. This will produce an IR drop across the polarizing resistor 19 which is of appropriate polarity for maintaining the secondary emitter at a positive potential so that the first counting stage will remain stable in its new condition. Fig. 2 shows a plot of voltage versus total electron current for a representative secondary emitter. It illustrates a familiar characteristic of secondary emitters and shows how they each have two stable operating points V_b and O for a particular value of load resistor. This figure is suggestive of how the circuit can be designed with regard to the values of its component parts by following known principles.

Once thus readied, the counting circuit will remain in this stable condition, which is only one of a considerable number thereof into which it may be placed, until a negative pulse reaches the grid 16 to cut off the beam of primary electrons which is flowing to the first counting stage.

When a negative pulse of appropriate magnitude reaches the grid 16 it will cut off this beam of primary electrons. This will stop the secondary emission and hence the circulation of secondary electron current in the first counting stage, and this, in turn, will eliminate the IR voltage drops across the dynode polarizing resistor and the load resistor. Thus, the first counting stage will be restored to its original stable condition (which condition will be referred to herein as the passive stable condition), i. e., will be restored to its condition of neither drawing any primary electron current nor circulating any secondary electron current. During the transition back to this condition the potential of its collector electrode will rise sharply toward the full potential of the source 17. This will apply a positive impulse to the secondary emitter of the stage which is adjacent to the first counting stage in the clockwise direction around the tube, i. e., the second counting stage, over a coupling condenser 23. The positive impulse will switch the second stage to its stable condition in which primary electron current is drawn to the secondary emitter and secondary electron current flows in a closed loop as described above (which condition will be referred to herein as the active stable condition). From the foregoing it is apparent that while each stage has only two stable conditions, the circuit as a whole has twice as many stable conditions as the number of its stages.

As counting progresses, each input pulse will switch to the passive stable condition that one stage, whichever one it is, which at that time is in the active stable condition, with the result, as explained above, that the stage which is adjacent thereto in a clockwise direction will be switched to its active stable condition. If ten stages are employed, as in the example shown herein, then after ten pulses the entire circuit will be returned to its ready-for-counting stable condition, the condition in which it was initially placed by pressing the push-button switch 21. Thus the counting circuit as a whole completes one cycle of operation after receiving as many pulses, n, as the number of its stages. In one of these complete cycles: the first counting stage is switched from its active to its passive stable condition; each of the other stages is successively switched first to its active stable condition and then back to its passive stable condition; and, when the nth pulse is counted, the first counting stage is switched back to its active stable condition whereby the circuit is re-readied for counting a new group of n pulses.

Thus, as will be obvious to those familiar with the art of digital computers, a transient taken from some appropriate circuit point of first counting stage may be utilized to provide an output signal once for every n input signals (for every ten negative pulses in the example herein). Accordingly, a circuit may be built according to the present invention for dividing a large number of received impulses by any predetermined number, n, such as ten. As is known, indicating devices, such as glow discharge tubes, may be appropriately connected to the individual stages to show in which of their stable conditions each of them ends up after a period of counting so that the one circuit will itself indicate the entire count, if the total number of pulses is to be less than the number of stages, or so that, if the number of pulses is greater than the number of stages, the circuit will provide the unit count in a decimal system arrangement (or in a corre-

sponding arrangement for some other number system which is similar but uses a base other than ten) with one or more similar circuits being made respectively to provide the tens count, the hundreds count, etc. if the total number of pulses is to be more than the number of stages. In such an arrangement the circuit providing the tens count would receive as its input a negative pulse taken from the first counting stage of the circuit providing the units count; similarly, a circuit providing the hundreds count would receive as its input negative pulses taken from the first counting stage of the circuit providing the tens count; and so forth.

In most prior art electronic digital computers the pulses which are to be counted are processed through shaping circuits so that the input pulses to the computer counting circuits will have certain characteristics which are necessary to insure dependable operation thereof; for example, in some counting circuits using short time-constant multivibrators very short steep input pulses are required as it is not possible for such multivibrators reliably to count pulses, such as low frequency sine waves, which have gradually sloping leading edges.

In practicing the present invention it also is desirable to use pulse shaping circuits to assure the most reliable operation of the counting circuit. Some pertinent factors are considered below. Firstly, each input pulse must be of sufficient negative amplitude either to cut off all of the primary electron current to any active stage or to so greatly reduce it that the secondary electron current which is circulating in that stage will drop below a value at which the potential developed across the polarizing resistor 19 of the active stage (see V_c of Fig. 2) is inadequate to maintain or increase the instantaneous flow of primary electrons. Secondly, each input pulse should have a trailing edge which is relatively sharp and occurs at a particular time in order to permit the last-active stage successfully to switch the adjacent stage over to its active stable condition. The RC time constant of each of the portions of the counting circuit which comprises the polarizing resistor 19 of a given stage, a by-pass capacitor (not shown but which in practice will be connected across the common battery 17 or the battery 17 for that stage as the case may be), the load resistor 18 of the next counting stage, and the coupling capacitor 23 which interconnects these resistors, ordinarily will be kept small for the sake of permitting very high counting speeds. In general this RC constant should be shorter than n times the period between the highest frequency pulses which are intended to be counted. Because of this short time constant the coupling capacitor will quickly charge up each time that a positive impulse is applied over it from one stage to the next and this will tend to differentiate the positive-going voltage change produced at the collector electrode of the former stage. Therefore it is possible, if an input negative pulse has either a gradually sloping trailing edge or a steep trailing edge which occurs considerably later than the instant when the pulse first became effective to cut off the tube, that it will continue to cut off the primary electron current beyond the time when the differentiated positive starting impulse ceases to be applied from the last-active stage to the next one. Accordingly, it is desirable that once the voltage of an input pulse has reached a sufficient level to cut off the primary current of the tube it should thereafter very quickly return to a value at or near to zero.

On the basis of these considerations it would be theoretically feasible to use input pulses having the form of negative saw teeth which precisely attain a certain peak value which is related to the cut-off potential of the tube. However, it is obviously undesirable to have to depend upon the accuracy with which the peak amplitude of the input pulses can be controlled or to have to depend upon the fact that the tube will always cut off when its grid attains a certain precise potential, especially since this potential will be in part a function of the D. C. bias applied to the grid and since it may be necessary to vary the bias in adjusting the circuit. Moreover, due to the charging of the input circuit, pulses of the same peak amplitude but whose leading edges have different angles of slope, will not act in the same way upon the counting circuit. And finally it is unlikely that the pulses which are to be counted will ordinarily happen to be such exact saw teeth and it is not particularly convenient to reshape heterogeneous pulses into such saw teeth. Accordingly, it is a proper generalization that it is preferable always to apply short negative pulses to this circuit, i. e., pulses having sharp leading edges, as well as sharp trailing edges, and which are of short durations. When such pulses are used their amplitude is not critical though it should be adequate to cause a switch-over. Accordingly, in the use of a circuit of this kind it may be well to follow the common practice of using pulse shaping circuits including a high-gain amplifier to steepen the leading edge followed by a differentiator for limiting the duration of the amplified pulse and incidentally producing a steep trailing edge.

It will be apparent to those skilled in the art that apart from the simplicity and compactness of the electron discharge device described herein it affords certain very desirable operational advantages. For example, because of the very high transconductance of each of the counting stages, very positive and reliable counting can be accomplished by the use of pulses of very small power. The input impedance of the grid **16** can be designed to compare favorably with that of the paralleled control grid impedances of the plurality of individual vacuum tubes commonly employed in other forms of counting circuits. Thus, the negative input pulses may be provided from a source having a high output impedance, i. e., the pulses may contain very little energy. Yet such a grid, if properly designed according to known principles, for example, if it is built to have a fine mesh and to be very close to the cathode, will be able to control considerable primary electron current with such pulses. If desired the grid may be designed not to have any shielding and/or beam-forming action but to function only as a primary-current control electrode, for example, it may be designed with a fine mesh as mentioned above. However, when this is done separate shielding and/or beam-forming elements should be added to the tube to perform the function of keeping primary electrons from going to the collectors.

Thus it appears that very weak input pulses can switch on and off substantial electron bombardment of one or more secondary emitter electrodes. Moreover, these pulses will control even greater secondary electron currents due to the fact that each primary electron will cause the emission of a plurality of secondary electrons. The advantages gained by being able to switch on and off large secondary electron currents by the use of weak pulses are that the counting action is very positive and reliable and that devices, such as glow discharge indicators, may be directly operated from potentials which the switching causes the counting circuit to produce in its various stages.

If desired, a number of readying circuits **20** may be employed instead of just one so that the stable condition prior to the count of one, i. e., the stable condition for the circuit as a whole, is different from that which has been described above in which only the first stage is in its active condition. For example, it might be desired to ready the counting circuit by placing all of the stages, except the first one, in their active stable conditions. If this were done, then, during counting, the condition of inactive stability would be progressively transferred from the first stage to the second, thence to the third, and so on around the tube in a clockwise fashion. Thus far, two extreme examples have been suggested. Obviously besides these any number of intermediate stable conditions could be employed for readying the counting circuit as a whole. For example, it would be equally feasible for any number of stages from two to $n-2$ to be placed in their active stable conditions as a preferred way of readying the circuit for counting. However this may be done, the pattern of distribution of conditions of active and passive stability which will be established around the annular ring of stages in readying it will simply move step by step in a clockwise direction during the counting of successive input pulses.

Despite the frequent references to clockwise counting, it is not intended that the arrangement shown herein cannot be reversed in an obvious manner so that counting is counterclockwise.

While I have indicated the preferred embodiments of my invention of which I am now aware and have also described only certain specific applications for which my invention may be employed, it will be apparent that my invention is by no means limited to the exact forms illustrated or the uses indicated, but that many variations may be made in the particular structure used and the purposes for which it is employed without departing from the scope of my invention as set forth in the appended claims.

What I claim is:

1. A counting tube comprising an evacuated envelope enclosing a source of primary electrons, a plurality of counting stages each including a secondary emitter electrode and a collector electrode, each of said secondary emitter electrodes being positioned to receive primary electrons from said source thereof, means positioned in the path of primary electrons from said source toward each of said collector electrodes for preventing primary electron current from being drawn from said source by said collector electrodes, a control grid between said source of electrons and said counting stages for responding to a negative voltage to cut off the flow of primary electrons to said secondary emitter electrodes, each of said secondary emitter electrodes and each of said collector electrodes being insulatingly supported with respect to all of the other electrodes, and means extending individually from these electrodes to the outside of said envelope for connecting them individually to external circuit elements.

2. A counting tube comprising an evacuated

envelope enclosing a cylindrical cathode, a squirrel-cage grid surrounding said cathode, a plurality of counting stages positioned in an annular row around the outside of said control grid, each of said counting stages comprising a secondary emitter electrode and a collector electrode positioned to receive secondary electrons therefrom, each of the secondary emitter electrodes being positioned to receive primary electrons emitted by said cathode, means for preventing primary electron current from being drawn from said cathode by said collector electrodes, each of said secondary emitter electrodes and each of said collector electrodes being insulatingly supported with respect to all of the others, and means extending individually from these electrodes to the outside of said envelope for connecting them individually to external circuit elements.

3. A counting tube as in claim 2 in which said means for preventing primary electron current from being drawn from said cathode by the collector electrodes comprises wires of said squirrel-cage grid which are positioned between the cathode and respective ones of said collectors to produce a primary electron shadow within said envelope in the region where said collector electrode is positioned.

4. A counting tube comprising an evacuated envelope enclosing a cylindrical cathode, a control grid surrounding said cathode, means for forming primary electrons which are radially accelerated away from said cathode into a plurality of beams each directed along a different radius from said cathode, a plurality of counting stages arranged in an annular row around the axis of said cathode, each of said stages including a secondary emitter electrode positioned to receive one of said beams of electrons and a collector electrode positioned between two of said beams of electrodes, the secondary emitter electrode of each stage being tilted toward its associated collector electrode so that secondary electrons which it will emit in response to bombardment by a primary electron beam will be directed toward said collector electrode, each of said secondary emitter electrodes and each of said collector electrodes being insulatingly supported with respect to all of the others, and means extending individually from these electrodes to the outside of said envelope for connecting them individually to external circuit elements.

5. An electron discharge device suitable for use as a counter tube including a cathode, a plurality of secondary emitter electrodes positioned radially of and around said cathode, a separate collector electrode positioned adjacent each of said secondary emitter electrodes, and control electrode means positioned between said cathode and said electrodes and having means for shielding said collector electrodes from primary electrons from said cathode.

6. An electron discharge device suitable for use as a counter tube and including an elongated cathode, a plurality of secondary emitter electrodes spaced around said cathode, a collector electrode adjacent each of said secondary emitter electrodes and comprising a planar member lying in a plane extending radially from said cathode, a control electrode positioned between said cathode and said electrodes and including members lying parallel to said cathode and shielding said collector electrodes from primary electrons from said cathode.

7. A counting circuit comprising a counting tube including an evacuated envelope enclosing a source of primary electrons, a plurality of counting stages each including a secondary emitter electrode and a collector electrode, each of said secondary emitter electrodes being positioned to receive primary electrons from said source thereof, means for preventing primary electron current from being drawn from said source by said collector electrodes, a control grid between said source of electrons and each of said counting stages for responding to a negative voltage to cut off the flow of primary electrons to said secondary emitter electrodes, each of said secondary emitter electrodes and each of said collector electrodes being insulatingly supported with respect to all of the others, and means extending individually from these electrodes to the outside of said envelope for connecting them individually to external circuit elements, a secondary electron current loop for each of said counting stages including a load resistor, a polarizing resistor and a source of direct current potential, said source of potential having its positive terminal connected to the collector electrode of said stage over said load resistor and its negative terminal connected to the secondary emitter electrode of said stage over said polarizing resistor, means for maintaining said source of electrons and the negative terminal of said source of potential at the same potential, an input circuit for applying negative pulses to the control grid of said tube, and means for readying the circuit by placing at least one of said stages in an active stable condition in which primary electron current flows to its secondary emitter electrode from said source of primary electrons, and secondary electron current circulates in said current loop.

8. A counting circuit as in claim 7 which also comprises means for biasing said control grid at a potential which is slightly negative with respect to said source of electrons.

9. A counting circuit as in claim 7 in which said means for readying the counting circuit comprises means for momentarily directly interconnecting the secondary emitter and collector electrodes of at least one of said counting stages.

10. A counting circuit as in claim 7 and includan output circuit for providing an output pulse each time that the counting circuit has counted the same number of input impulses as the number of its counting stages.

11. A system for counting pulses including an electron discharge device having a cathode, a plurality of secondary emitter electrodes positioned radially of and around said cathode, a separate collector electrode positioned adjacent each of said secondary emitter electrodes, and control means positioned between said cathode and said electrodes and having means for shielding said collector electrodes from said cathode, an energizing circuit connected between each secondary emitter electrode and each collector electrode and normally biased to inoperative conditions, means controlling one of said energizing circuits for initiating a discharge from said cathode to the respective secondary emitter electrode for said energizing circuit, said energizing circuit being adapted to maintain said discharge, a circuit connected to said control means to cut off the discharge to said secondary emitter electrode, and means coupling each of said energizing circuits to the next adjacent circuit for causing sequential initiations of discharges respectively from said cathode to successively positioned secondary emitter electrodes.

12. A counting tube comprising an evacuated

envelope enclosing a source of primary electrons, a plurality of counting stages each including a secondary emitter electrode and a collector electrode, each of said secondary emitter electrodes being positioned to receive primary electrons from said source thereof, means positioned in the path of primary electrons from said source toward each of said collector electrodes for preventing primary electron current from being drawn from said source by said collector electrodes, control means for cutting off the flow of primary electrons to said secondary emitter electrodes, each of said secondary emitter electrodes and each of said collector electrodes being insulatingly supported with respect to all of the other electrodes, and means extending individually from these electrodes to the outside of said envelope for connecting them individually to external circuit elements.

13. An electron discharge device suitable for use as a counter tube including a cathode, a plurality of secondary emitter electrodes positioned

in the path of rectilinear electron flow from said cathode, a separate collector electrode positioned adjacent each of said secondary emitter electrodes, and control electrode means positioned between said cathode and said electrodes and having means for shielding said collector electrodes from primary electrons from said cathode.

14. A counting tube as in claim 12, wherein each of said secondary emissive electrodes is positioned in the path of rectilinear electron flow from said cathode.

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