

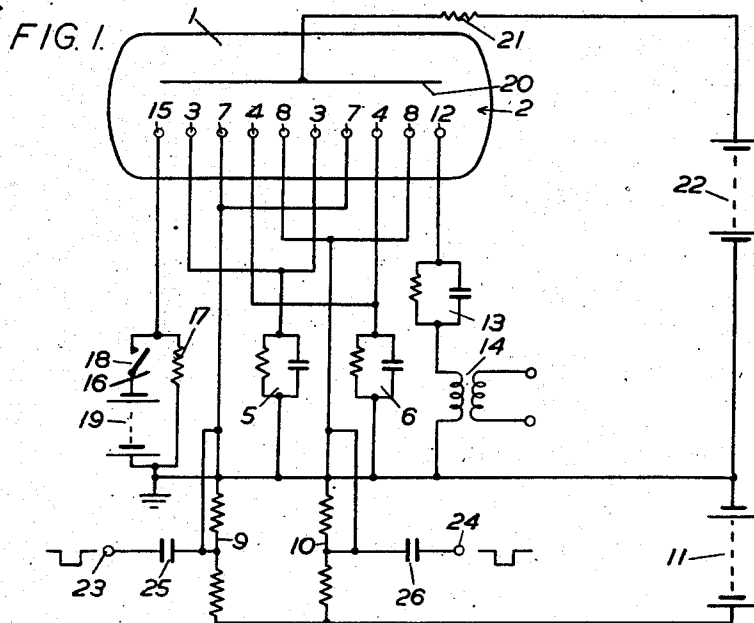
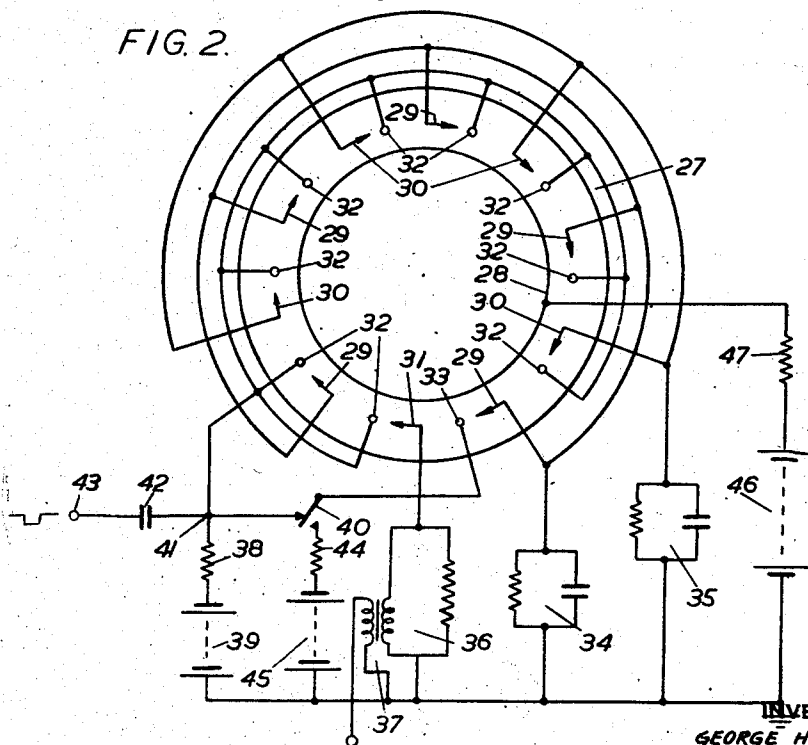
May 22, 1951

G. H. HOUGH
ELECTRIC DISCHARGE TUBE

2,553,585

Filed Sept. 27, 1949

5 Sheets-Sheet 1



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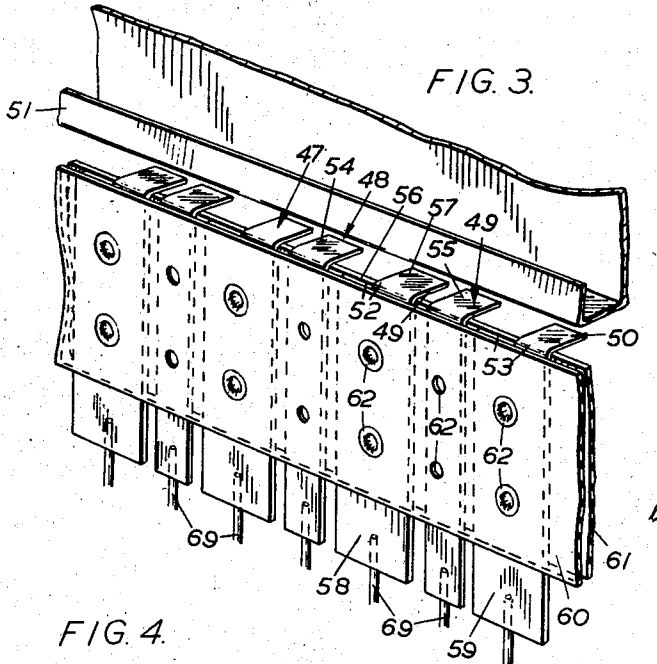
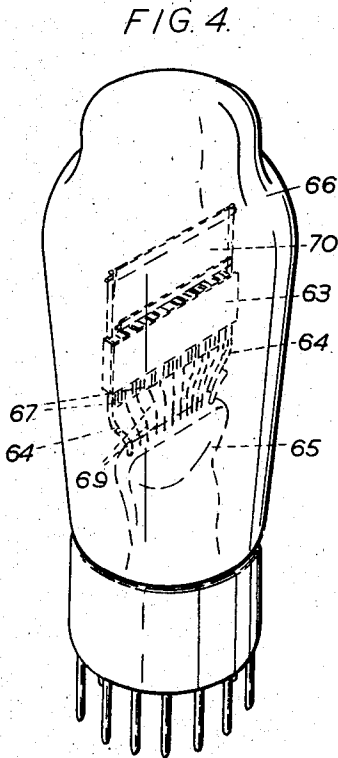
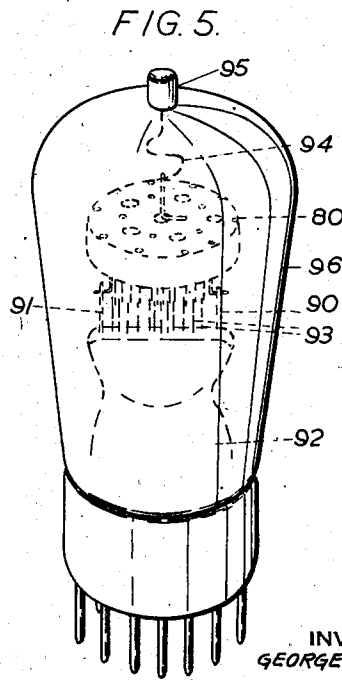
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5 Sheets-Sheet 2



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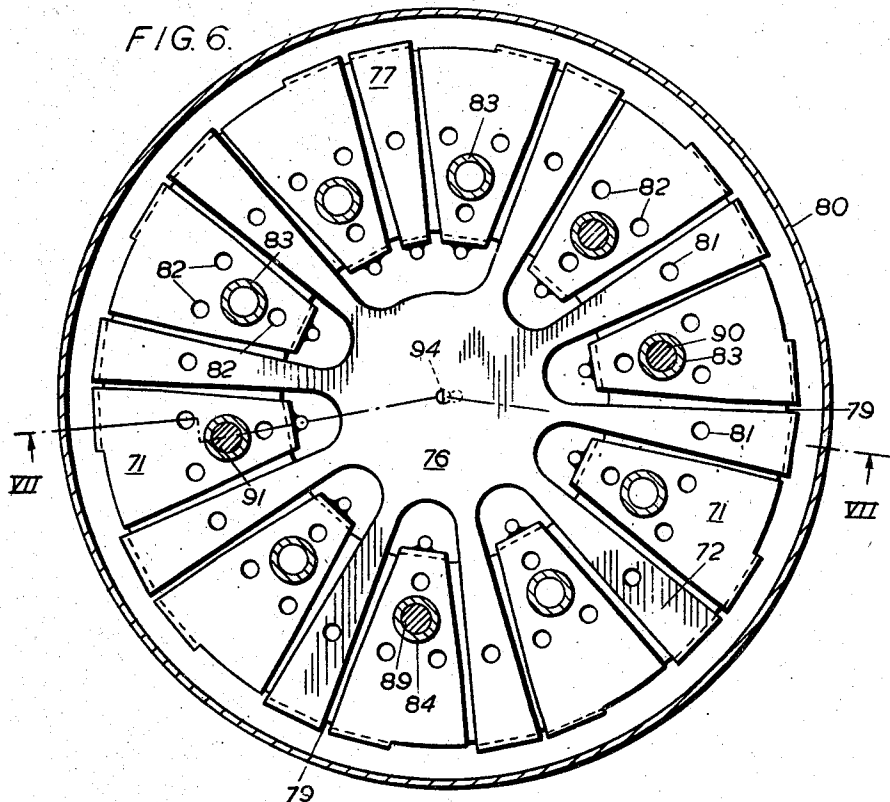
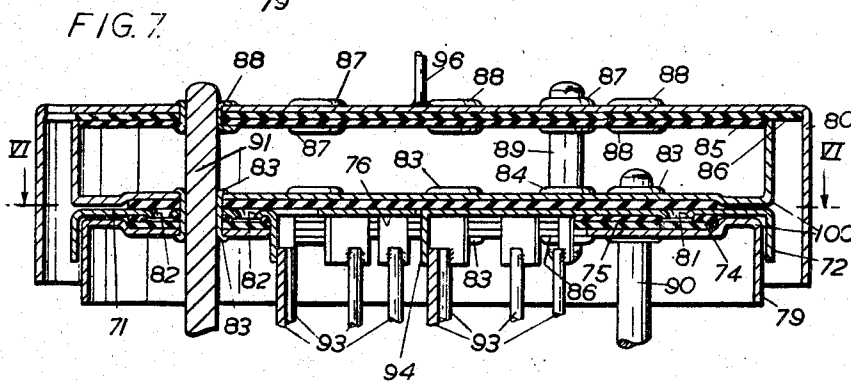
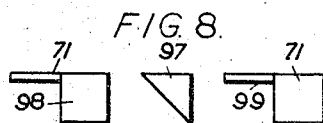
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2,553,585

Filed Sept. 27, 1949

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Filed Sept. 27, 1949

5 Sheets-Sheet 4

FIG. 9.

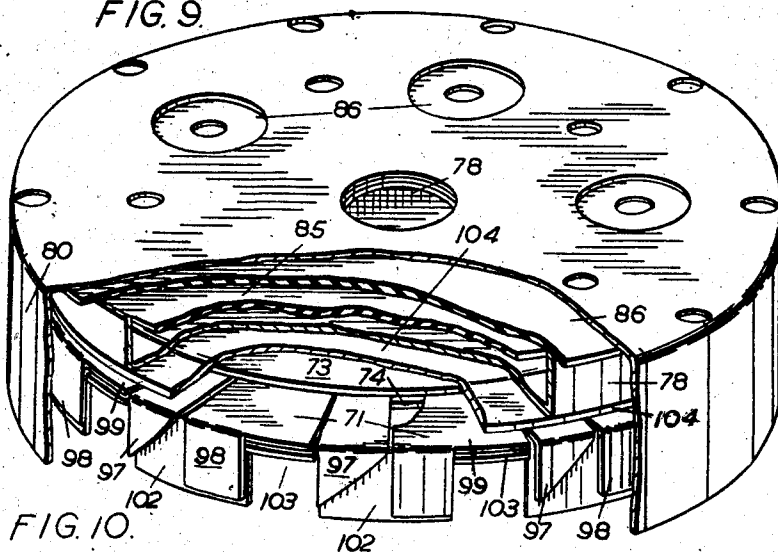


FIG. 10.

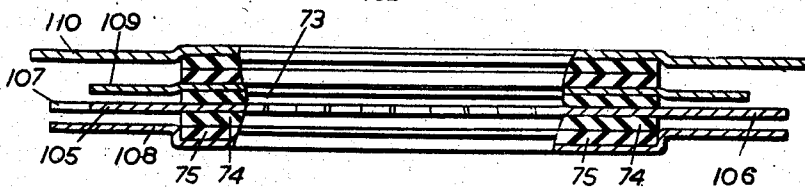
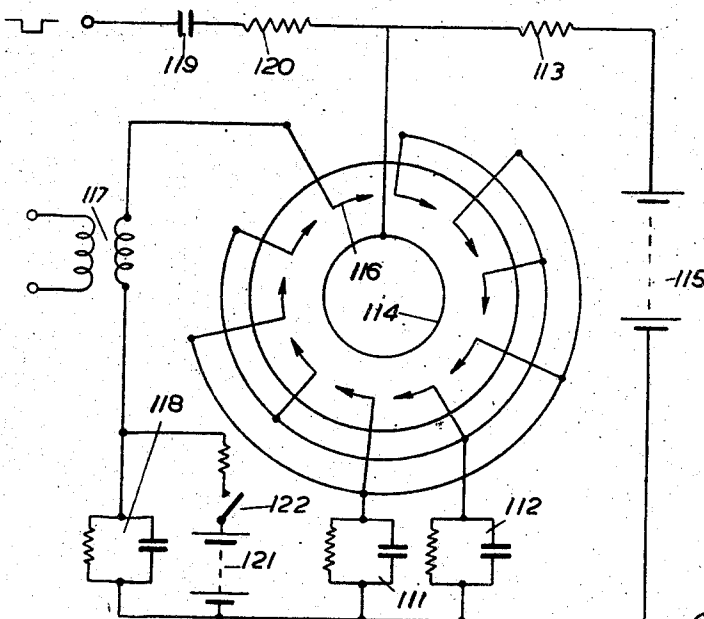


FIG. 11.



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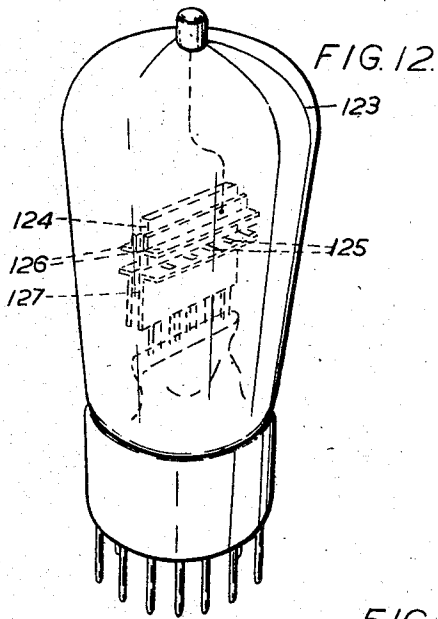
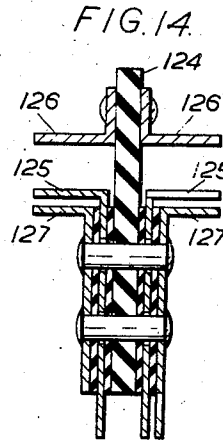
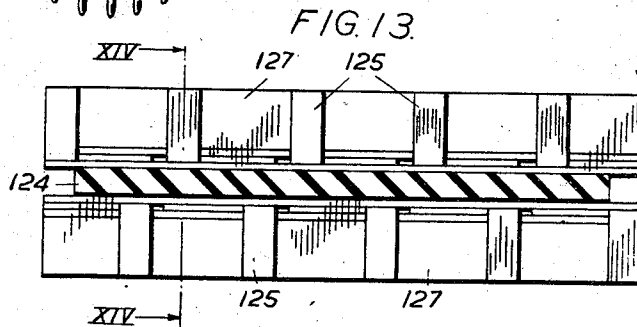
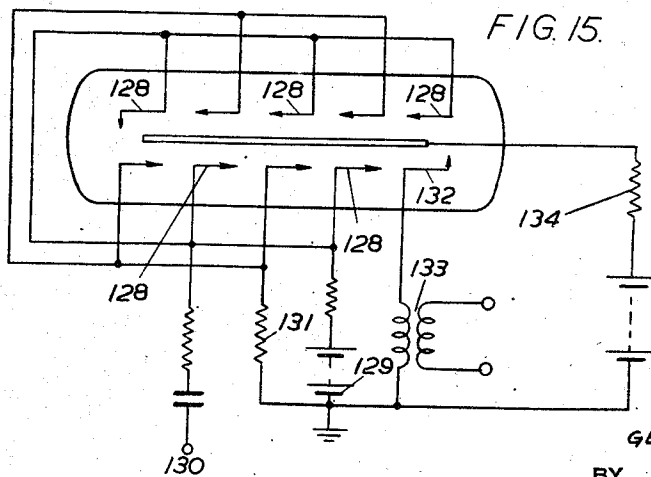
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2,553,585

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5 Sheets-Sheet 5



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UNITED STATES PATENT OFFICE

2,553,585

ELECTRIC DISCHARGE TUBE

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Application September 27, 1949, Serial No. 118,055
In Great Britain September 30, 1948

21 Claims. (Cl. 315—336)

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The present invention relates to cold cathode electric discharge tubes of the type known as sequence discharge tubes.

A sequence discharge tube is a cold cathode gas-filled tube comprising an ordered array of discharge gaps arranged to be fired in sequence, the discharge at one gap priming the next succeeding gap.

One arrangement of a sequence discharge tube is a multi-cathode tube having the cathodes in line or spaced around a circle and co-operating with a common anode. In normal operation, after the first cathode of the array is covered with glow from discharge thereat and the next gap is fired, glow also appears at the second cathode; the third gap then fires in its sequence so that now all three cathodes are glowing. The process is continued along the array until all gaps are discharging simultaneously. From the point of view of the circuit engineer it is sometimes a disadvantage to have all the earlier gaps in a sequence discharging, rather than that the discharge be transferred in sequence from gap to gap, only one gap at a time being maintained in a state of discharge. In the case of a tube having a common anode, if the discharge were to be transferred from gap to gap then the mean anode current for the tube would tend to remain constant, whereas in the first arrangement the mean anode current is continually increasing as first one and then more gaps are fired. Although it is possible to arrange that only gap of a sequence shall be discharging at any one time, there is then an ambiguity as to which gap shall be the next to fire. For example, suppose gap No. 3 gap to be discharging, the discharge having been transferred in some manner from gap No. 2 then at gap No. 2 there will be a residual ionisation from its own discharge and also ionisation from the discharge existing at gap No. 3, while at gap No. 4 there will be the ionising effect of the glow at gap No. 3. There is thus a very good chance of gap No. 2 firing next rather than the desired gap No. 4.

It is an object of the present invention to provide a cold cathode sequence discharge tube in which discharge may be transferred by ionisation and field coupling from one gap to the next in sequence, without ambiguity as to the direction in which the transfer shall proceed along the array. This is accomplished by arranging that the ionisation and field coupling to a later gap in the ordered array shall be greater than that to an earlier gap.

The term "ionisation coupling" is used in the

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present specification to denote the sum total of the effects of discharge at one gap on the striking potential of another due to migration of charged particles of either sign or of photons from one gap to the other. The term "field coupling" is defined as the influence of the electric field in a discharging gap upon the field of a neighbouring gap.

In one aspect, the invention provides a cold cathode gas-filled electric discharge tube characterised in this that the electrodes of an ordered array of discharge gaps are so constructed and arranged as to favour a transfer of discharge from gap to gap in succession along said array in one direction rather than the other. The invention will be described with reference to the accompanying drawings in which:

Fig. 1 shows, for purposes of explanation, a circuit arrangement according to a previous proposal;

Fig. 2 shows a circuit arrangement similar to Fig. 1 but using a tube according to the present invention;

Fig. 3 shows diagrammatically, the basic geometrical arrangement of discharge gap electrodes according to the present invention;

Fig. 4 shows a practical tube using the construction illustrated in Fig. 3.

Fig. 5 shows a further embodiment of the invention using a circular discharge array.

Fig. 6 shows a cross-section through the electrode assembly of Fig. 5 along the line B—B of Fig. 7.

Fig. 7 shows a cross-section of the electrode assembly along the line A—A of Fig. 6;

Fig. 8 is a diagrammatic plan view of a modified electrode construction for the tube of Fig. 5;

Fig. 9 is a fragmentary illustration of a further modification to the construction shown in Figs. 6 and 7;

Fig. 10 is a diagrammatic illustration, in part sectionalised, of a further embodiment of the invention;

Fig. 11 is a circuit diagram illustrating another embodiment of the invention;

Figs. 12, 13 and 14 show the constructional features of another embodiment, Fig. 13 being a plan view of the cathode array and Fig. 14 a section through the line A—A of Fig. 13;

Fig. 15 is a circuit diagram illustrating the use of the tube of Figs. 12 to 14.

In order that the nature of the invention may be more fully understood, reference will first be made to the circuit shown in Fig. 1 in which a sequence discharge tube 1 is so connected that

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the transfer of discharge may proceed along array 2 in either direction at will. For this purpose the cathodes are divided into two main groups, alternate cathodes being treated as storage cathodes on which discharge may be maintained for registering and counting purposes, the remainder being connected to act as transfer electrodes whose function it is to transfer the discharge from the storage cathode on one side of it to that on the other side. In Fig. 1 the two sets of cathodes, which we shall refer to respectively as "storage cathodes" and "transfer electrodes," are further subdivided each into two groups. The two groups of storage cathodes are each connected to ground through the parallel combination of a resistance and a condenser to provide a charge storing circuit.

Thus in Fig. 1, cathodes 3 form one group and cathodes 4 another, cathodes 3 being connected to ground through the resistance-capacity circuit 5, cathodes 4 through a similar circuit 6. Of the remaining cathodes, cathodes 7 form one group of transfer electrodes and cathodes 8 the other. The transfer electrode groups are connected to tapping points on respective potential dividers 9 and 10 which shunt a biasing battery 11 the negative terminal of which is grounded.

At one end of the array an independent storage cathode 12 is shown connected through its own time-constant circuit 13 and also through the primary 14 of a pulse transformer 14A which passes on to a further circuit information that a discharge is occurring or has occurred at cathode 12. At the other end of the array an independent cathode 15 is shown connected to ground through a separate biasing circuit 16 comprising a resistance 17 in shunt with the series combination of a switch 18 and biasing battery 19.

The common anode 20 of the discharge gap array is connected through a resistance 21 to the positive terminal of battery 22, the negative terminal of which is grounded. The anode and cathode resistances, together with the potential of battery 22 is so proportioned, that a discharge may be maintained at any one storage gap once that gap has fired, but it is arranged that the potential fall across the common anode load shall be sufficient to extinguish discharge at the storage gap when a transfer gap is fired. The bias applied to the transfer electrodes is such as to insure that the common anode battery shall not maintain a discharge at any of them. Terminals 23 and 24 enable pulses to be applied through the respective blocking condensers 24 and 25 to tapping points on potential dividers 9 or 10.

Assume now that a discharge is existing at one of the storage gaps. If a negative pulse of sufficient magnitude is applied to one or other of terminals 23 or 24, then discharge will occur at the transfer electrode adjacent the discharging storage cathode on one side or the other according to which terminal 23 or 24 has been activated. This transfer electrode has been primed by the discharge at the storage gap and the pulse voltage must not be sufficiently large to cause discharge to occur at any other of the transfer electrodes. When the transfer electrode fires the anode voltage tends to drop to the algebraic sum of the negative pulse voltage and the maintaining voltage of the transfer gap; the anode-cathode voltage of the storage gap is thus reduced below its maintaining voltage and it is

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extinguished, the pulses supplying sufficient voltage to maintain the discharge at the transfer electrode. The cathode potential of the gap which has just been extinguished is maintained positive with respect to earth due to the charge storing circuit to which that cathode is connected. On the other hand, the cathode potential of the gap on the other side of the transfer electrode now discharging is at or near earth potential as its resistance-condenser circuit is, as yet, uncharged. When the pulse has passed, current ceases to flow in the anode circuit so that the full battery potential appears across this next storage gap, which, under the influence of the ionisation and filed coupling from the transfer gap which has just gone out, now starts to discharge. The cathode charges up exponentially, so that for a time the anode current is greater than normal and this prevents any other storage gap firing; at the same time the cathode potential of the previously discharging storage gap continues to decay exponentially. If a further pulse is then applied to the same transfer electrode terminal, transfer will take place back to the original storage gap. On the other hand, if the pulse be applied to the other transfer electrode terminal, the discharge may be transferred to the next succeeding storage gap rather than to the preceding one. Thus, to set up a discharge sequence in one direction along the tube, alternate pulses may be applied to alternate transfer electrode terminals. According to the order in which the terminals are used the sequence may be made to proceed in either direction along the discharge array. The cathode 15 and its associated circuit 16 provides a "homing" facility for the circuit. If, when any storage gap is discharging, the switch 18 be closed, it may be arranged that discharge will occur at cathode 15 by reason of the negative bias from battery 19 and extinguish the discharge at the storage gap. When switch 18 is reopened, discharge at cathode 15 will be maintained to prime the adjacent storage electrode 3.

It will be appreciated that, for the above described circuit if, as is often—and, in fact, usually—the case, it is desired to count in one direction only, more or less complicated circuit arrangement must be made to apply successive pulses to the alternate transfer electrode terminals. It will also be appreciated that the necessity for the use of alternate terminals arises due to the uniform coupling of a discharging gap to either side. If we use a tube according to the present invention, in which the coupling is greater in one direction of the array than in the other, then, although we have lost the facility of being able to reverse the direction of sequence discharge, only one pulse input terminal will be required.

A somewhat similar circuit arrangement to that of Fig. 1, but using a tube according to the present invention, is shown in Fig. 2, in which the tube envelope, represented by the circle 27, contains a circularly arranged discharge array comprising an anode 28, a plurality of storage cathodes, which are given reference numerals 29, 30 or 31 according to their connections, and transfer electrodes similarly identified by reference numerals 32 and 33 respectively. The storage cathodes are represented by arrows and the transfer electrodes by circles, the direction of the arrows indicating the direction of greater coupling. The electrode constructions to effect this differentiation will be described later. Cathodes

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29 are connected to ground through the resistance-capacity circuit 34, cathodes 30 being taken to a similar circuit 35 and cathode 31 being connected to a separate resistance-capacity circuit 36 including the primary 37 of an output pulse transformer 37A. The transfer electrodes 32 are all connected via resistance 38 to a bias battery 39, the positive terminal of which is shown connected to ground. Transfer electrode 33 is normally connected via key 40 to the junction 41 of cathodes 32 and resistance 38 to which junction negative going pulses may be applied via the blocking condenser 42 from terminal 43. Transfer electrode 33 is alternatively connected by the key 40 to resistance 44 in series with a bias battery 45. The circuit is completed by the connection of anode 28 to battery 46 through resistance 47, the negative pole of battery 46 being grounded.

Although the mechanism of the unidirectional transfer of discharge is very different from that in the tube used in Fig. 1, the manner of operation of the circuit is similar, but only one transfer pulse input is needed. As in Fig. 1, the time-constant circuits 34, 35 and 36 prevent a storage gap just extinguished by discharge at a transfer electrode from re-firing due to residual ionisation in the gap, while the directional nature of the coupling between storage and transfer gaps ensures that the discharge sequence operates in the direction indicated by the arrows. When the key 40 is operated discharge of transfer cathode 33 extinguishes discharge at any of the storage cathodes so that when the key is released either the adjacent cathode 29 or cathode 31 is fired, depending upon the state of charge of the condensers in the respective circuits 34 and 36. If necessary, a second operation of the key suffices to transfer the discharge to that one of cathodes 29 or 31 it is desired to regard as the first storage cathode in the sequence.

The manner in which unidirectional coupling is obtained in the present invention can now be explained. In Fig. 3 there is shown diagrammatically an array of four discharge gaps 47—50 formed between a common anode 51, two storage cathodes 52 and 53 and two transfer cathodes 54 and 55. Consider the three adjacent gaps 47, 48 and 49. By virtue of the geometry of cathode 52, gap 48 is formed of two portions namely that corresponding to the cathode "tail" 56 and that corresponding to the cathode plate 57. The tail has a smaller available discharge surface area than the plate but a considerably larger ratio of periphery to the surface area; furthermore it is further away from the anode than the plate 57. In consequence, the tail portion passes into abnormal glow at a lower current than the plate portion, but requires a higher maintaining voltage. This higher maintaining voltage, though in part due to the increased gap length between the anode and the cathode tail, is predominantly due to the greater diffusion of current from a strip-like cathode than from one with a smaller ratio of periphery to discharge surface area. Since the tail 56 is nearer the gap 47 than is the plate 57, when the gap 48 is primed by discharge at gap 47, cathode glow starts on the end of the tail adjacent to gap 47, and spreads over the whole tail surface. From the point of view of spread of the cathode glow, the tail and plate can be considered as constituting cathodes of two discharge gaps, the vertical step between the tail and plate discharge surfaces being equivalent to a small separation between the gaps. Due to the coupling

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between these discharge gap portions, when the cathode glow reaches the step, the striking voltage of the plate-anode gap portion is reduced to its maintaining potential so that this gap portion is now fired by the anode battery potential. Since the maintaining potential of the plate portion is lower than that of the tail, and it is possible to limit the total discharge current through gap 48 to a value at which the gap voltage is lower than the maintaining voltage of the tail portion; the discharge on the "tail", is therefore, extinguished and conduction maintained only on the plate portion. Hence, during storage, coupling from the discharge on plate 57 is much greater to the adjacent transfer gap 49 than to the preceding gap 47.

As is indicated in Fig. 3, the desired gap geometry may be constructed by forming the storage cathodes from metallic strip mounted edge on to the anode, a portion of the width of the strip adjacent the anode being cut away and the remaining portion being bent over to be broad-side to the anode.

In order to limit the discharge surface to the edge of the cathode tail, a convenient practical arrangement is to clamp the metallic strips shown at 58 and 59 between two sheets, 60 and 61, of mica or other suitable insulating material, so that the top edges of the micas are flush with the cutaway edge of the strip, the said remaining portion being a continuation of the strip bent over at right angles to the said edge to form the plate 57 projecting at right angles beyond the edges of the mica sheets. The transfer cathodes 54 and 55 are also formed from strips of the same thickness, and of width equal to the width of plate 57, similarly bent over the edge of mica sheet 61. The cathode assembly may then be held in position between sheets 60 and 61 by means of rivets indicated at 62. The bent-over portions of the transfer electrodes and of the storage cathodes are made approximately the same size so that the transfer gap and the adjacent portion of the preceding storage gap have similar electrical characteristics. The cathode tail 56 should be flush with the top edge of mica sheets 60 and 61, the under surfaces of the bent-over portions 57 and 55 should be slightly clear of the top edge of 61. It is preferred that the spacing between adjacent gaps be small, the separation between a transfer cathode and the storage cathode to either side of it being of the order of the length of the cathode fall for normal glow discharge, in which case the striking voltage for the gap adjacent a discharging gap is reduced by field and ionisation coupling to approximately the maintaining voltage of the primed gap.

A simple practical construction on the above lines is illustrated in Fig. 4, in which the cathode assembly 63 is shown mounted on support rods 64 from the press 65 of a conventional valve envelope 66. The lower ends 67, of the metal cathode strips are allowed to project below the insulators between which they are clamped so as to enable lead wires 69 to be welded to them. An anode 70, in the form of a metal sheet placed edge-on to the row of cathodes, the adjacent edge being turned over to provide a discharge surface parallel to the plane of the cathodes, is mounted on rods 64.

In an experimental tube made up on the above-mentioned principles, the storage cathodes were formed from 3.5 mm. wide nickel strip, a portion being cut away at one end to leave a

cathode plate 1.5 mm. square. The transfer electrodes were made from 1.5 mm. wide nickel strip, so that, when bent over, a tab similar to the tab on the storage cathodes was formed. The natural bend of the strips provided a sufficient difference in gap length between the edge-on and bent-over portions of the storage cathodes. Successive strips were mounted edge to edge with a separation of about 0.38 mm. between adjacent strips. The anode was also constructed from nickel strip. After assembly of the electrode structure and completion of the envelope, the tube was filled with a neon, hydrogen, argon mixture consisting 92% Ne, 7% H₂ and 1% A at a pressure of 100 mm. of mercury.

With the above construction and gas filling the tube had a static striking voltage of about 240 volts for all gaps, the maintaining voltage between the bent-over tabs and the anode being about 164 volts, the edge-on portions of the storage gaps having maintaining voltages about 10 volts higher, about 1 volt being due to the difference in gap length and the remainder due to the difference in shape of the discharge surfaces. The reduction of striking voltage (or coupling voltage) for different transfer electrode currents in the adjacent storage gaps to either side of a transfer gap is shown below.

	G ₁	G ₂
	Volts	Volts
1 ma.....	19	66
2 ma.....	29	79
4.5 ma.....	46	86

where G₁ denotes the adjacent gap earlier in the desired direction of sequence discharge and G₂ the adjacent later gap. It is seen that some 40-50 volts difference between couplings in the two directions was obtained.

Although a simple linear array such as just described may be of value in certain circuit applications, for use in a circuit such as described with reference to Fig. 2, a circular array construction is to be preferred. A further embodiment of the invention is illustrated in Figs. 5, 6 and 7. In this arrangement the storage cathodes 71 (Fig. 6), and transfer electrodes 72 are constructed from metallic strip, and are arranged radially, being sandwiched between an annular insulating plate 73 and a further pair of circular insulating plates 74 and 75 (Fig. 7) the edges of the plates being aligned and the previously mentioned edge-on portions of the storage cathodes projecting beyond the peripheral edges of the insulating plates. All but one of the transfer electrodes are formed as a plurality of fingers radiating from a central metallic member to form a spider 76 (Fig. 6), the edges of the fingers being bent over to form the extended cathode surfaces previously mentioned. The remaining transfer electrode 77 is similar to one of the above-mentioned fingers but is insulated from them. Separate storage cathodes are placed between adjacent transfer electrodes and the cathode assembly is in its turn sandwiched between a pair of annular metallic discs 78 and 79 having upturned rims directed away from one another, the bent-over portions of the storage cathodes and transfer electrodes extending over one of the rims, the clearance between the cathode surfaces and the discs being such that the discs may function as field control plates confining cathode glow to the desired surfaces of the cathodes. With this construction the anode

takes the form of an inverted cup-shaped electrode 80 secured to the cathode and control plate assembly, the wall of the cup surrounding the assembly so as to form with the storage cathodes and transfer electrodes a circular array of radial discharge gaps. It will be appreciated that a similar type of construction could be adopted in which the anode was internal rather than external to the cathode array.

For a circular array with external anode, in one embodiment of the invention the transfer electrode spider comprises nine fingers stamped out of sheet metal with the edges of the fingers turned over at right angles as shown in Figs. 6 and 7, the resulting spider being approximately 14 mm. in radius. The spider is located on the annular mica sheet 74 by means of rivets 81 on the fingers. The separate storage cathodes and the remaining transfer electrodes are then similarly located on the mica by means of rivets 82 stamped out from the metal of the electrodes. The bent over tag portions of storage cathodes and transfer electrodes are each 2.5 mm. long, the edge-on portion of the storage cathodes being approximately 3.19 mm. long, while the gaps between adjacent electrodes are approximately 0.31 mm. The mica sheet 73 is placed over the cathode electrodes, and the third annular mica sheet 75 under sheet 74, the assembly being clamped between the annular field-control plates 78 and 79 so that while the rim of 78 is flush with the cathode tags that of plate 79 lies underneath them and is spaced therefrom approximately 0.125 mm.—the length of the cathode fall of potential for normal glow discharge. The field-control plates and the three mica sheets are riveted together by eyelets 83, which, together with other eyelets 84 passing through clearance holes in the cathode-clamp the control plates together and form a rigid cathode, transfer electrode and control plate sub-assembly. A pair of circular mica sheets 85 and 86 is used to locate the anode 80. The mica sheet 85 fits inside the rim of the upper field-control plate 78 and is riveted by eyelets 87 and 88 to the mica sheet 86 which projects beyond the rim of the plate and fits inside the anode 80 so as to ensure the exact location of the latter. The eyelets 87 also secure the anode 80, but the anode has clearance holes around eyelets 88. The anode assembly is secured by two rods 89 welded to eyelets 87 in the anode assembly and 84 in the cathode assembly. A pair of rods 90 and 91, welded respectively to an eyelet 83 on the cathode assembly and to an eyelet 88 (on the anode assembly), are used as support rods for the complete electrode assembly and are sealed in the press (Fig. 5) of a conventional valve base. Rod 90 serves as a lead to the field control plates 78 and 79. Leads 93 to the storage cathodes and transfer electrodes are welded to these members and pass through the central hole of the lower field-control plate to the press. The anode is taken by lead 94 to a top cap 95 on the envelope 96 of the tube (Fig. 5). Before sealing off, the tube envelope is evacuated, heat-treated and filled with the neon-hydrogen-argon mixture mentioned previously. With an anode-cathode spacing of 1 mm., the above tube has a static striking voltage of approximately 230 volts, the maintaining voltage to the storage cathodes and transfer electrodes being about 150 volts. The difference between forward and backward ionisation coupling is of the same order as for the linear array quoted above.

In operation in the circuit described above

with reference to Fig. 2, the transfer electrodes are biased 60 volts above earth and it is arranged that the cathodes, when they are conducting, shall be 50 volts above earth, the steady anode potential between pulses being 200 volts. Negative-going pulses of 25 microseconds wide and 80 volts amplitude are applied to the transfer electrodes.

As a result of experience gained in the use of the tubes described above with reference to Figs. 5, 6, and 7, it is now preferred to use a slightly modified construction with a view to increasing manufacturing and circuit tolerances. In the first place, it is preferred to shape the transfer electrodes so as to obtain some degree of directional coupling from these. To this end, the bent over portions of the transfer electrodes are cut to triangular shape as shown diagrammatically in plan in Fig. 8, where two storage cathodes 71 are depicted on either side of a modified transfer electrode 97. The bent over portion of the transfer electrode is shaped as a right angled triangle with its hypotenuse opposite the cathode plate 98, the right angle being adjacent the cathode tail 99. This construction decreases the coupling from glow on 97 to the plate 98, while leaving the coupling to the tail 99 unaltered; the construction also allows a reduction in the transfer electrode discharge current with a consequent increase in the input impedance of the tube.

Another important improvement concerns the restriction of cathode glow to the desired discharge surfaces, particularly in the case of the cathode tail. As shown on Fig. 7, metal field-control plates 78 and 79 are employed, surfaces of the control plates being spaced from the rear of the cathode plates and transfer electrodes and from the sides of the cathode tail by a distance less than that of the cathode fall of potential for normal glow. It will be seen, however, that the corners 100 of control plates 78 and 79 are somewhat rounded and this reduces their efficacy, particularly to either side of the cathode tail. It is therefore preferred to adopt the construction shown in the fragmentary drawing of Fig. 9 in which parts common to the construction of Figs. 6 and 7 have been given like reference numerals. In Fig. 9, the lower control plate 101, which replaces the member 79 of Fig. 7, is slotted, having bent over castellations 102 lying behind the transfer cathodes and the plate portions of the storage cathodes, the portions between the castellations being cut away so as to form projections between them, as indicated at 103, parallel to the cathode tails 99. The member 78, formerly the upper control plate, now serves merely as an anode locating cup, while a further member 104, sandwiched between it and the mica disc 73, functions as upper control plate. By this means the effect of the rounded corners 100 is eliminated and it can be ensured that cathode glow is confined to the desired surfaces.

No mention has so far been made of connections to the field control plates. In the interests of supply voltage tolerances it is preferred that they be given a positive bias of some 80 volts nominal, the actual value being chosen to achieve the widest operating voltage limits.

With the above mentioned modifications to the construction described with reference to Figs. 5, 6 and 7, typical D. C. characteristics are as follows:

D. C. breakdown voltage, storage cathode-anode -----volts 230

D. C. breakdown voltage, transfer cathode-anode -----volts 230
Maintaining potential (anode-cathode plate) -----volts 155

5 Maximum steady current -----ma. D. C. 5.5
Differential coupling -----volts 40
Saturation current of cathode tail -----ma. 0.5
Coupling between adjacent storage cathodes -----volts 30
10 Maximum plate current before glow spreads from cathode plate to cathode tail -----ma. 5.5

Typical operation conditions selected for a frequency range of 0-3 kc./s. over which the pulse output from the output cathode may approximate to square wave are as follows:

15 Anode supply voltage -----320 volts $\pm$ 30 volts.
Transfer cathode bias -----55 volts.
Control plate bias -----80 volts.
20 Anode load -----18 k Ω fixed
+50 k Ω variable

Storage cathode time constant circuit (networks

34, 35, Fig. 2) -----10 k Ω , 0.01 μ f.

25 Pulse amplitude -----80 volts.
Pulse width -----25 μ secs.

It should be noted that the tube will operate with a cathode time constant circuit as given above at frequencies higher than 3 kc./s., but the pulse output will no longer be square.

Another form of construction of a radial type of tube according to the invention is shown diagrammatically in Fig. 10. In this construction the bending over of electrodes is avoided, the electrodes being formed as plane or substantially plane discs with but shallow cup like depressions for locating purposes. The cathodes are formed, as in the manufacture of these members for the preceding embodiments, with a stepped edge to provide a cathode plate projecting beyond the cathode tail, but the plate is not bent over. In Fig. 10 a cathode tail is shown at 105 and a cathode plate at 106 and 107. The transfer electrodes are shaped similarly to the cathode plates and are not bent over. The field control plates 108 and 109 are circular, without serrations, the upper one, 109, projecting flush with the edges of the cathode tail and the lower one, 108, flush with the edges of the cathode plates. 45 The anode 110 is also substantially flat. Discharge at the cathode tail can occur only along its outer edge while discharge at the cathode plate is limited to its upper surface, which, of course, is still slightly closer to the anode than the edge portion forming the tail.

For some circuit arrangements it may be an advantage that the transfer electrodes as well as the storage cathodes shall be constructed to provide maximum unidirectional coupling. On the other hand, in a tube in which all the cathodes are constructed on the unidirectional principle, the use of separate transfer electrodes may be eliminated. As shown in the circuit diagrams of Fig. 11, the cathodes may be arranged in two groups, alternate cathodes being connected to respective resistance-capacity networks 111 and 112 through which the cathodes are grounded. A common anode resistance 113 connects anode 114 to battery 115. The cathode 116 (being the last cathode in the array) is shown connected independently through the primary 117 of a pulse transformer 117A and to a separate resistance-capacity network 118. The component values of the circuit may be arranged so that but one cathode at a time may remain conducting,

while negative extinguishing pulses are applied to the common anode via blocking condenser 119 and resistance 120. Each of these pulses carries the anode-cathode voltage below the maintaining potential of any gap in the array so that discharge is extinguished. After the pulse has passed, the same cathode is prevented from firing again due to its cathode potential being maintained positive by means of its resistance-capacity circuit, while the coupling to the next cathode in the array is sufficient to cause that cathode to fire. In this way, the circuit can be arranged to count negative pulses. It is evident that with such a design, and using a circular array, the circuit may be arranged to have a simple homing feature, so that the circuit may be set up with a predetermined gap discharging whereby the count may always commence at the same gap. In Fig. 11 this facility is provided by the battery 121 and key 122 shunted across the network 118.

The circuits so far described all require the use of time-constant circuits. Thus, if in the circuit of Fig. 11 the time-constant circuits 111, 112 and 118 were omitted, it is probable that after passage of an extinguishing pulse the cathode which has just been extinguished would fire again—due to the residual ionisation in that gap—before ionisation coupling had enabled a discharge to be established at the next gap. In the circuit at Fig. 11, this is prevented, of course, by the cathode that has just been fired, being maintained positive for a time by its resistance-capacity circuit. We have found, however, that it is possible to eliminate the time-constant circuits if we reintroduce the transfer electrodes, but shape these similarly to the storage cathodes, so that every cathode, not only the storage cathodes, but also the transfer electrodes provide unidirectional ionisation and field coupling.

An embodiment of the invention using fully directional transfer electrodes is illustrated in Figs. 12, 13, and 14 in which the electrode structure of the tube 123 comprises a central sheet 124 of mica or other suitable insulating material, having the cathode electrodes 125 eyeletted to it on either side so as to form in effect, two arrays, the direction of sequence on one side being the opposite to that on the other side. A pair of anodes 126, suitably connected together, is mounted on the insulating sheet over the respective lines of cathodes and it is arranged that the cathodes at one or at both ends protrude from beyond the edge of the mica sheet 124, as shown in Fig. 13, so that coupling may occur between the last gap on one side and the first gap on the other side of the sheet. In this way, the equivalent of a circular array is obtained, the discharge sequence going down one side of the sheet and up the other. Field control plates 127 to limit the spread of cathode glow to the desired cathode areas are also shown fixed to the main supporting sheet. The assembly is incorporated in a normal valve envelope as shown in Fig. 12. A circuit for use with this tube is shown in Fig. 15.

In Fig. 15 the transfer electrodes 128 are biased positively by battery 129 so that they will only maintain a discharge in the presence of a pulse applied to terminal 130. The remaining cathodes, the storage cathodes, are connected to ground—preferably through a resistance 131 so as to equalise the load for all cathodes, as one of the cathodes, indicated at 132, is connected to the primary 133 of a transformer 133A providing means for passing intelligence to a further cir-

cuit. The common anode lead 134 is arranged as in previous examples and negative-going pulses are applied to the transfer electrodes via terminal 130. These pulses must be sufficiently long for the residual ionisation to decay in the gap which is extinguished by firing of the transfer gap. Due to the unidirectional ionisation coupling feature, the coupling from the transfer gap is greater to the next succeeding storage gap than to the gap which has just been extinguished. Similarly, during the inter-pulse interval, when one of the storage cathodes is glowing, the coupling to the succeeding transfer gap is greater than to the preceding transfer gap.

A device manufactured on the lines of the embodiment of Figs. 12 and 15 and having substantially similar electrode dimensions to those quoted above has been found to count at a pulse repetition rate of 30 kc./s.

In some embodiments so far described, where the storage cathodes and transfer electrodes comprise bent-over portions of metallic strip, it would be possible and advantageous from the point of view of still further reducing backward coupling to arrange that these tabs were not all bent over in the same direction. For example, in the embodiment described with reference to Fig. 3, each storage cathode tab and its adjacent transfer electrode tab can be bent over in the same direction, the next pair of tabs being bent over in the opposite direction. With the other arrays the electrode assembly arrangements may require modifications, such as will be evident to those skilled in the art, in order conveniently to include this feature of increased spacing between cathode tabs.

While the principles of the invention have been described above in connection with specific embodiments, and particular modifications thereof, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of the invention. In particular it should be pointed out that, while for the circuits which have been illustrated, embodiments of the invention have required only a single common anode, sub-division of the anode, possibly with a separate circuit connection such as will occur to those skilled in the art, need not effect the unidirectional coupling features of tubes according to the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

I claim:

1. A cold cathode gas-filled electric discharge tube comprising electrode means defining an array of separate glow discharge gaps thereamong, given of said electrode means having two portions, the first portion presenting a larger surface area to the gap than the second portion, each said first portion having a larger discharge current and lower maintaining voltage characteristic than said second portion, the first portion of each of said given electrode means adjacent to the second portion of a different of said given electrode means, whereby ionization and field coupling between said given electrode means takes place, and the priming of a second portion of a given electrode means is transferred to the first portion thereof resulting in unidirectional successive gap discharges, means for causing the discharge of the gaps in said array and means for deriving an output from said tube for utilization.

2. A cold cathode gas filled electric discharge tube comprising a plurality of electrodes defining an intermediate discharge gap positioned between

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a first and a third gap, the three gaps being arranged so that a discharge at the first gap shall prime the intermediate gap and discharge at the intermediate gap shall prime the third gap, characterised in this, that the said intermediate gap has two portions, the first portion, adjacent the said first gap, being constructed to pass into a condition of abnormal glow discharge at a lower discharge current than the remaining portion, adjacent the said third gap, and to have a higher maintaining voltage than the said remaining portion, in order that when primed by discharge at said first gap, discharge at the said intermediate gap may start at the said first portion and transfer to the said remaining portion.

3. A discharge tube according to claim 2 comprising an ordered array of electrodes defining discharge gaps arranged so that the gaps may be fired in succession along the said array with a discharge at one gap priming the next gap, characterised in this, that all the gaps between the first and the last gap in said array are arranged as specified for the said intermediate gap.

4. A discharge tube according to claim 2, comprising an ordered array of electrodes defining discharge gaps arranged so that the gaps may be fired in succession along the said array with a discharge at one gap priming the next gap, characterised in this, that alternate gaps in the said array are arranged as specified for the said intermediate gap.

5. A discharge tube according to claim 2 wherein said electrodes comprise a plurality of cathodes and a common anode, and each cathode of the said intermediate gap is formed of two portions a cathode tail and a cathode plate, the ratio periphery to area of discharge surface being greater for the said tail than for the plate, whereby the rate of diffusion of current during discharge between said common anode and the tail is greater than the corresponding rate during discharge between the said anode and the cathode plate.

6. A discharge tube according to claim 5 in which the discharge surface of the cathode plate is closer to the said anode than that of the cathode tail.

7. A discharge tube according to claim 6 in which the said cathode is formed from metallic strip mounted edge-on to the said anode, the end of the strip adjacent the anode being made with a tag forming the said cathode plate, projecting beyond an edge portion forming the cathode tail.

8. A discharge tube according to claim 7 in which the said tag is bent over so as to be at an angle to the remaining portion.

9. A cold cathode gas-filled electric discharge tube comprising a plurality of electrodes defining an array of separate glow discharge gaps thereamong, a first of said electrodes common to each of said gaps, a plurality of second electrodes, each having two portions in gap relation to said first electrode, the first portion of each of said second electrodes presenting a larger surface area to said first electrode than the second portion of each of said second electrodes, each said first portion having a larger discharge current lower maintaining voltage characteristic than said second portion, a plurality of third electrodes in gap relation to said first electrode, one of said third electrodes disposed alternately between said second electrodes, each of said third electrodes being adjacent to the first portion of one of said second electrodes on one side thereof and

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adjacent to the second portion of a different of said second electrodes on the other side thereof, whereby ionization and field coupling between successive of said third electrodes and the second portion of an adjacent second electrode takes place, and the priming of said second portion is transferred to the first portion of said adjacent electrode thereby resulting in unidirectional successive gap discharges.

10. A cold cathode gas-filled electric discharge tube as claimed in claim 9 further comprising a fourth electrode disposed between a pair of said second electrodes in similar manner to said third electrodes, and in gap relation to said first electrode, said fourth electrode adapted to be connected to a utilization means.

11. A cold cathode gas-filled electric discharge tube as claimed in claim 9 wherein said second electrodes are formed of metallic strip mounted edge-on to said first electrode, the ends of the strips being bent over to be broadside to said first electrode.

12. A cold cathode gas-filled electric discharge tube as claimed in claim 10 further comprising a set of plates of insulating material and wherein said metallic strips are sandwiched between said insulating plates, aligned edges of said plates being substantially flush with the edge-on surfaces of the second portions of said second electrodes, whereby said plates limit cathode glow to the surface of second portions of said second electrodes adjacent said first electrode.

13. A discharge tube according to claim 12 in which the said plates are secured to support rods sealed in a glass press forming part of the envelope of said tube.

14. A discharge tube according to claim 13 in which a common anode is secured to the said support rods.

15. A discharge tube according to claim 14 in which the said anode is in the form of a metal sheet having a bent-over edge portion substantially parallel to the bent-over portions of the cathode assembly.

16. A cold cathode gas-filled electric discharge tube as claimed in claim 9 wherein said array is radially arranged and further comprising a pair of circular field control plates, each of said second electrodes sandwiched between but insulated from said control plates, a first of said control plates having a down-turned castellated rim, said third electrodes having portions constituting their respective discharge surfaces turned over said rim, the said second electrodes intermediate the said third electrodes each having its second portion substantially flush with the parallel portion of both said control plates and its first portion turned over the rim of said first control plate, the spacing between said second electrodes and said control plates being such that the gap between any discharge surface of a second electrode at which discharge is not desired and an adjacent control plate surface is less than the length of the cathode fall of potential for normal glow discharge at such cathode discharge surfaces, said first electrode surrounding all of said electrodes and said control plates and forming radial discharge gaps with respective of said electrodes.

17. A discharge tube according to claim 16 in which said second electrodes comprise cathodes and are secured to the said field control plates with insulating spacing and locating washers to form a unitary structure and said first electrode

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comprises a cup-shaped anode within which the said unitary structure is mounted.

18. A discharge tube according to claim 16 in which the unitary structure of the cathode array comprises a cup-shaped member having the rim of the cup upturned (i. e. oppositely directed to the rim of the lower control plate) the anode being mounted on insulating washers located by the rim of the cup.

19. A discharge tube according to claim 16 in which said third electrodes comprise transfer electrodes and whose bent-over portions are triangular in shape, the angles of the triangle being such that the centroid of the triangle is closer to the second portion of a second electrode of the next adjacent gap on one side of a third electrode than to the first portion of a second electrode of the adjacent gap on the other side in the ordered array.

20. A discharge tube according to claim 16 comprising a radially arranged unidirectional discharge gap array in which the cathodes are sandwiched between, but insulated from a pair of circular upper and lower field control plates having substantially planar edges, the lower plate having a larger diameter than the upper; alternate cathodes (transfer electrodes) having co-planar discharge surfaces the outer edges of which are substantially flush with the outer edge of the lower field control plate the remaining cathodes (storage cathodes) each having a circumferal edge portion (the cathode tail) substantially flush with the edge of the upper field control plate and a radially extending portion (the cathode plate) having its circumferal edge substantially flush with the lower field control plate and a radially extending portion (the cathode plate) having its circumferal edge substantially flush with the lower field control plate; the spacing between the cathodes and the control plates is such that the gap between any cathode surface at which discharge is desired and an adjacent control plate surface is less than the length of the cathode fall of potential for normal glow discharge at those cathode surfaces; and in which an anode is

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mounted above the said upper field control plate to form a discharge surface substantially parallel to the upper surfaces of the cathode projecting beyond the upper field control plate.

21. A cold cathode gas-filled electric discharge tube comprising a sheet of insulating material, a plurality of electrodes mounted in line on said sheet, a first of said electrodes common to each of said other electrodes and defining an array of separate discharge gaps therewith, said other discharge gaps having two portions in gap relation with said first electrode, the first portion of each of said other electrodes presenting a larger surface area to said first electrode than the second portion of each of said other electrodes, each said first portion having a larger discharge current and lower maintaining voltage characteristic than said second portion, said first portion being bent over, transverse to a plane of said insulating sheet, a similar discharge array mounted on the reverse side of said insulating sheet back-to-back with said first array, the said other electrodes in the two arrays being oppositely divided so that the discharge sequence on one side of said sheet is opposite to that on the other, the arrays being positioned on said sheet so that at one or both ends, the other electrodes at the end of each array projects beyond the edge of the said sheet to provide ionization and field coupling between each array, whereby a discharge sequence may be propagated along the array on one side of said sheet and may proceed back along the array on the other side, means for causing the discharge of the gaps in said arrays and means for deriving an output from said tube for utilization.

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