Dec. 11, 1951 A. H. REEVES ET AL 2,577,809

# COLD CATHODE ELECTRIC DISCHARGE TUBE

Filed Jan. 21, 1949 4 Sheets-Sheet 1

FIG. 1.

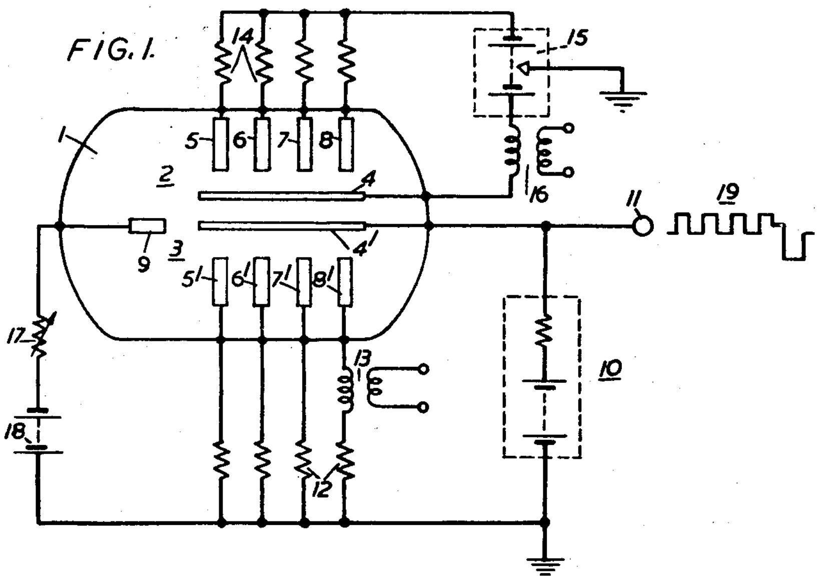



FIG. 2.

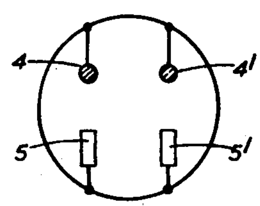



FIG. 3.

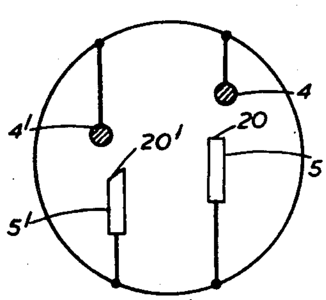
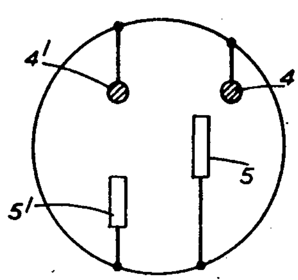



FIG. 4.

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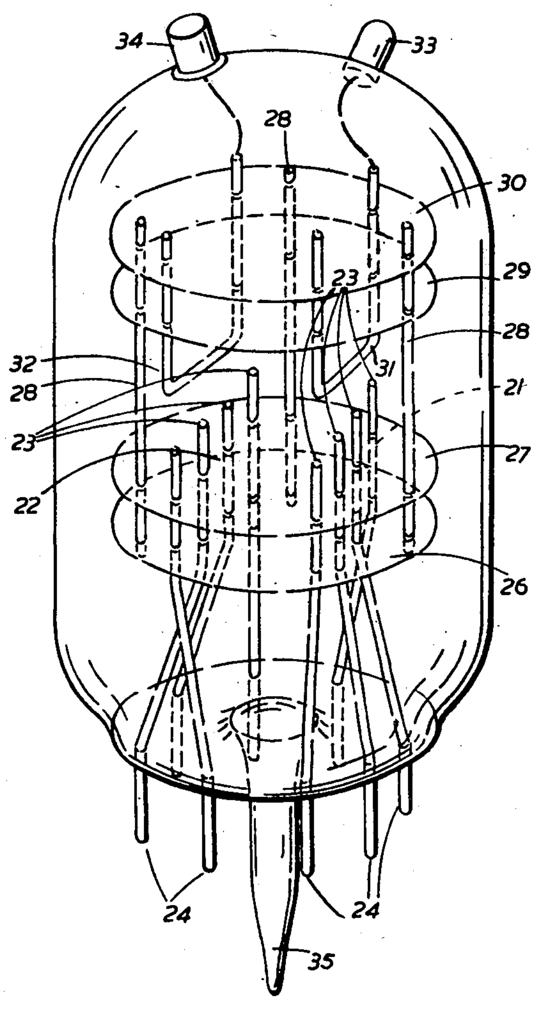
Filed Jan. 21, 1949 4 Sheets-Sheet 2

FIG.5.

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Filed Jan. 21, 1949 4 Sheets-Sheet 3

FIG. 6.

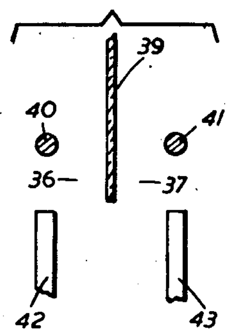



FIG. 7.

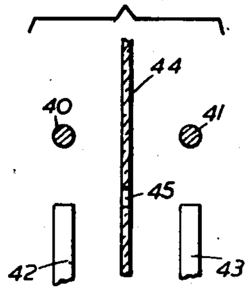



FIG. 8.

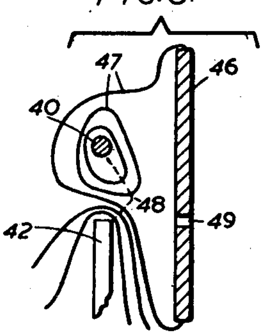



FIG. 9.

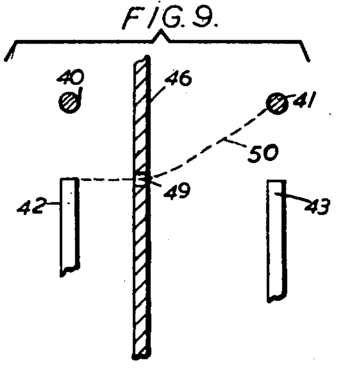
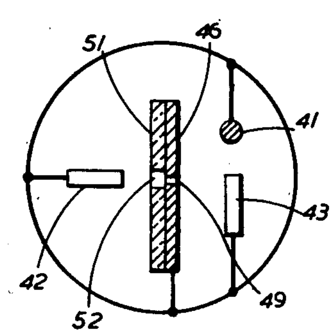



FIG. 10.

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Filed Jan. 21, 1949 4 Sheets-Sheet 4

FIG. 11.

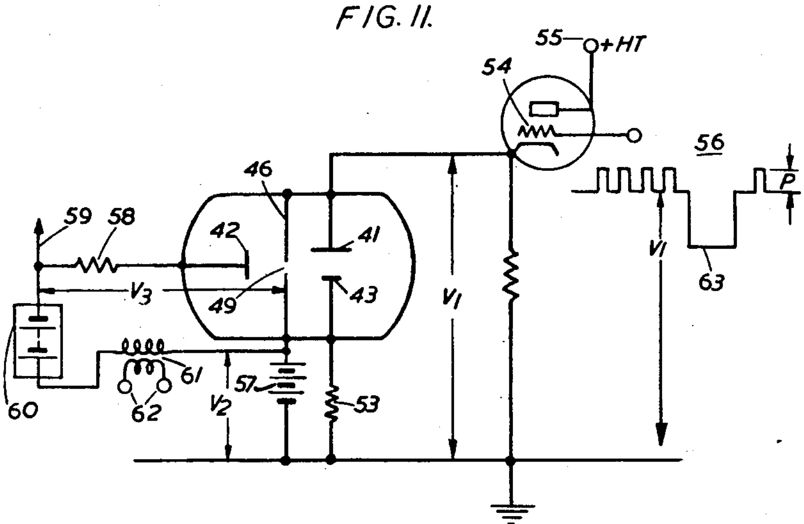
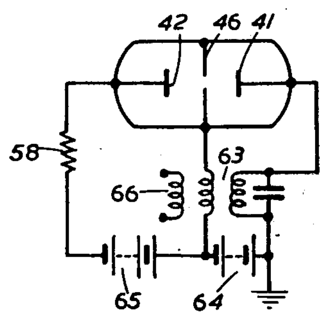



FIG. 12.

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Patented Dec. 11, 1951 2,577,809

# UNITED STATES PATENT OFFICE

2,577,809

## COLD CATHODE ELECTRIC DISCHARGE TUBE

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Application January 21, 1949, Serial No. 72,046
In Great Britain January 22, 1948

16 Claims. (Cl. 313—188)



The present invention relates to cold cathode gas-filled electric discharge tubes of the type in which the striking potential of one gap is reduced by the presence of a discharge at a neighbouring gap in the same envelope.

It is an object of the present invention to provide a cold cathode gas-filled electric discharge tube in which ionisation products may migrate from the first of a pair of glow-discharge gaps to a second discharge gap more readily than from said second gap to said first gap, whereby the striking potential of said second gap may be lowered by discharge at said first gap, but the striking potential at said first gap is substantially independent of the discharge at an anode potential of said second gap.

Although numerous possible applications of such a tube will occur to those skilled in the gas tube circuit art, the present invention has been conceived with the object of enabling two or more sequence discharge arrays to be used in a single tube envelope and to have substantially uni-directional coupling between them. Sequence discharge tubes are disclosed in co-pending application No. 763,655, filed July 25, 1947, by A. H. Reeves, and may be defined for present purposes as cold cathode tubes having an array of gaps so arranged that when one gap is fired, ionisation products migrate into the neighbouring gap and reduce its striking potential. In this way successive voltage pulses applied in common to the electrodes of the array may cause gaps to fire in sequence from a given "starting" gap. Such tubes may be used, inter alia, as electrical counters in calculating machines or as message registers in automatic telephone circuits. If desired, a steady polarising potential may be applied between the anodes and cathodes of the gaps of the sequence arrays, so that a gap, once fired, may remain in a discharging condition indefinitely. In order to extinguish the discharges, the polarising potential must be removed, or reduced below a critical value—the maintaining voltage—for a time sufficient for deionisation to take effect. Thus, if high rates of counting are envisaged it may be necessary to use a pair of tubes alternately, one counting while the other is being deionised. As disclosed in co-pending application No. 31,323, filed June 5, 1948, by A. H. Reeves, two or more sequence discharge arrays may be mounted in a single envelope and arranged so that ionisation coupling between the arrays may enable second counting array to "take over" from a first array while the discharges at the first array are extinguished.

It is a further object of the present invention to provide a sequence discharge tube having two cold cathode discharge arrays with unidirectional coupling between corresponding discharge gaps of the two arrays.



It is yet another object of the invention to provide such a tube in which the discharge arrays are so dimensioned that any given number of the successive gaps in the first array may be fired and maintained in a discharging condition for an indefinite time during which a sequence discharge may take place along the other array to provide information as to the number of gaps of the first array that have been fired.

In the prior applications referred to above, no distinction was made as to whether the coupling between gaps was ionic or electronic, all ionisation products being referred to generally as "ions." Certain embodiments of the present invention rely on discriminatory treatment of the migration of positive ions and electrons between gaps. Thus in one type of embodiment, by the application of suitable polarising potentials, ions from the first gap are caused to migrate to a second gap, while ions from the said second gap are inhibited from migrating to the first gap. In other types, unidirectional electronic coupling is used, there being negligible ionic coupling.

Embodiments of the invention will be described with reference to the accompanying drawing in which:

Fig. 1 illustrates diagrammatically one particular use of a discharge tube according to the present invention;

Fig. 2 shows diagrammatically two pairs of electrodes in a discharge tube of the type shown in Fig. 1;

Fig. 3 shows an arrangement of a pair of discharge gaps having unidirectional coupling between them;

Fig. 4 shows an alternative arrangement of the electrodes of a unidirectionally coupled pair of discharge gaps;

Fig. 5 shows a practical embodiment of a discharge tube according to the invention;

Figs. 6 and 7 show further electrode arrangements according to the invention;

Fig. 8 is a diagram for explaining further embodiments of the invention;

Figs. 9 and 10 illustrate still further electrode arrangements according to the invention, and

Figs. 11 and 12 are circuit diagrams to illustrate the use of certain embodiments of the invention.

In Fig. 1, the gas tube 1 comprises two discharge arrays 2 and 3, each being shown as having a common anode 4, 4' respectively and four individual cathodes, 5, 5', 6, 6', 7, 7' and 8, 8', the primed numerals referring to array 3, the others to array 2. In addition, a separate cathode 9 is shown; 9 is a priming cathode and forms a priming discharge gap with anode 4' in order that the cathodes 5, 5' may be the first to fire in the respective arrays. Anode 4' is connected to a constant voltage source 10 which is represented diagrammatically as a battery in series with a decoupling resistance. Anode 4' is also connected to a signal input terminal 11. Cathodes 5', 6' and 7' are shown connected to ground, through individual current limiting resistances 12, while cathode 8' also feeds a pulse output transformer 13. Cathodes 5, 6, 7, 8 are connected through individual resistances 14 to the negative terminal of stabilised supply 15, the positive pole of which is connected through the secondary winding of pulse input transformer 16 to anode 4. An earth connection is made to a tapping point on supply 15 to bias the cathodes 5, 6, 7 and 8 positively, if required, with respect to cathodes 5', 6', 7' and 8'. Cathode 9 is connected to ground through variable resistance 17 and biassing battery 18. All the cathodes may conveniently be nickel rods coated with alumina or other discharge inhibiting substance, except at the extreme end facing the co-operating anode. In practice the two cathode arrays are arranged parallel to one another below the anodes as shown very diagrammatically in the end view of Fig. 2. The voltage supplied by source 10 is adjusted so that it is not sufficient to initiate any discharges at gaps of either of the discharge arrays, but will maintain a discharge once established. Cathode 9 is arranged to discharge continuously.

The operation of the circuit is as follows: A train of positive pulses, which we will refer to as dialling pulses, is applied to the primary terminals of transformer 16. These pulses should be limited in amplitude and duration so that, the first pulse discharge takes place between cathode 5 and anode 4, this discharge gap being partially energised by the priming discharge at cathode 9. No other gap should fire on this first pulse. Due to the voltage source 15, this discharge may now be maintained indefinitely. A second pulse will cause cathode 6 to fire. A third will initiate discharge at cathode 7 and a fourth at cathode 8. At terminal 11 there are applied repeated trains of pulses of general waveform, as shown at 19. This waveform comprises a series of positive pulses followed by a negative pulse. The positive pulses set up discharges at the gaps of array 3—which we shall call the counting array—while the negative pulse takes anode 4' below the maintaining voltage for sufficient time to extinguish all discharges at this array. The positive pulses may each be modulated in time position or width, and may typically be one microsecond in mean width. The repetition rate for the positive pulses at terminal 11 may be of the order of 100 kc./s. while the dialling pulses may be applied to transformer 16 at a rate of 12 cycles per/sec. We shall assume that each of the positive pulses applied to the counting array is associated with a definite speech channel. Suppose now that two dialling pulses are applied to transformer 16. These should cause cathodes 5 and 6 to fire and remain glowing. Now, when the first pulse of pulse train 19 is applied to terminal 11 both gaps associated with cathodes 5' and 6' will fire if it be arranged that ionisation from the dialling gaps primes the immediately adjacent counting gaps. Thus, the second pulse of the train applied at 19 will initiate a discharge at cathode 7' and the third will fire cathode 8'. From the discharge at 8' a corresponding pulse will appear at the secondary terminals of transformer 13. The fourth and last positive pulse will have no effect, as all cathodes of the counting array are already glowing. The negative pulse then extinguishes the discharges and the sequence is repeated. Thus, in each successive pulse train, the third pulse appears at the output terminals of transformer 13. In the same way, had, say, four dialling pulses been applied to the primary of transformer 16, the first pulse of train 19 would have appeared at output cathode 8'. In general, if the tube had $m$ gaps in dialling and counting arrays and $n$ dialling pulses were applied to 16, pulse No. $(n-m+1)$ would appear on the output cathode. What is more, and this is one of the principal objects of such a circuit, if through interference or other temporary cause, the counting sequence is upset on any one train, it will be corrected for the next train because the selecting means—the dialling pulses—sets up a permanent selecting condition.



It is to be understood that the circuit shown in Fig. 1 has been introduced merely for general explanatory purposes and in practice alternative circuit arrangements may be provided. Similarly various modifications to the electrode arrangement of tube 1 are possible—such as providing a common internal connection for cathodes 5, 6, 7 and 8.

We can now consider the practical difficulties which must be overcome in connection with the discharge tube before a circuit such as has been described may work. In the first case, there is a large difference between the operating speeds required for the two discharge arrays; one is to operate at dialling speed—12 cycles/sec.—and the other at a pulse repetition rate of 100 kc./sec. As explained in copending application No. 763,655, gap dimensions and spacings in sequence discharge tubes are largely determined by the counting rates required; on the other hand, in order to provide coupling between corresponding gaps in the two arrays, the gap spacing should be the same for each. In order to avoid what we call "self-running"—sequential firing due to ionisation spread without the additional potential supplied to the gap by signal pulses—the spacings between cathodes in the dialling array must be made as large as possible and the cathode currents as small as possible for a given gas mixture and pulse voltage. Before quoting suitable dimensions for the discharge gaps, it is advisable to consider the other difficulties to be overcome.

Assuming that we have solved the problem of providing a pair of discharge arrays having similar inter-cathode spacings but capable of satisfactory individual operation at widely different counting speeds, we must next consider the question of interaction between the two discharge arrays, when they are operating simultaneously. The first problem is that of priming the gaps of the counting array from the discharges being maintained at the dialling array without discharges at the counting array priming the dialling array and thus increasing the tendency for self-running or an unstable registering condition in the dialling array. Thus, consider the case when a dialling count of 2 has been set up in the dialling array. We require that cathode glow shall be maintained on cathodes 5 and 6 of array 2. When during the counting pulse train applied to array 3, cathode 7' and 8' are fired, there is a danger that the discharges here may prime either or both of the last two gaps defined by 7 and 8 with anode 4 of the array 2 so that discharges at this array tend to step along with the discharge sequence at array 3. Some assistance in this direction may be obtained by biassing the cathodes of array 2 so that they are always positive with respect to those of array 3. In this way positive ions will tend to be attracted to the cathode of lower potential, while electrons will tend to keep to the direct discharge path from cathode to anode. This in itself, however, will tend to aggravate a further difficulty, that of cross-coupling. Thus, we must prevent discharges occuring between, say, cathode 7 and anode 4', or between cathode 7' and anode 4, otherwise self-running may also occur on the counting array. Careful consideration must, therefore, be given to these related problems and the present invention resides largely in their solution.

Referring now to Fig. 2, which shows diagrammatically two pairs of electrodes in a discharge tube of the type described with reference to Fig. 1, let us consider the general double-gap system there represented. For this purpose anodes 4, 4' and cathodes 5, 5' may represent the electrodes of any pair of gaps having unidirectional coupling properties according to the present invention, but their relative positions as shown are not necessarily such as will result in a practicable tube.

The systems shown in Fig. 2 presents four principal discharge paths, namely the direct paths 5—4 and 5'—4' together with the cross-paths 5—4' and 5'—4. Let the maintaining voltages for these paths be $V_{45}$, $V_{4'5'}$ and $V_{45'}$, $V_{4'5}$ respectively. As a rough guide it may be stated that the maintaining voltage $V_m$ for gaps of different length varies according to an equation of the form

$$V_m=V_0+kd$$

where $k$ and $V_0$ are constants and $d$ is the gap length. Since it is required that the gaps 4—5 and 4'—5' are to remain discharging once a discharge has started, external battery voltages may be assumed to provide polarising potentials of $V_{45}$ and $V_{4'5'}$ across the gaps 4—5 and 4'—5'. In order to ensure that no discharge can be maintained in the gaps 4'—5 when cathode 5 is conducting, we must have $V_{4'5}>V_{4'5'}+P_4$, assuming the cathodes to be substantially at the same potential where $P_4$, is the pulse voltage applied to anode 4', while to ensure that no discharge may occur under these conditions across the gaps 4—5' we must have $V_{45'}>V_{45}$. Thus, for a given value of $P_{4'}$, the minimum distance $d_{4'5}$ is determined as is also the minimum value of $d_{45'}$.

Taking into account the fact that we wish to bias the dialling cathode positive with respect to the counting cathode in order to make the ionisation coupling from dialling to counting gap greater than in the reverse direction, the above considerations will, in general, lead to different gap lengths for dialling and counting gaps. Another method of achieving the desired relationship between the electrodes is to stagger the anode wires so that gaps 4—4 and 4'—5' are no longer parallel to one another.

In order to assist in making the coupling unidirectional, we have made use of the fact that, during discharge, a large part of the potential fall between anode and cathode occurs in the cathode dark space, which, in the tubes under consideration, extends a very short distance from the cathode and terminates in the cathode flow. In and around the cathode glow there is an ionic space charge, while the current from the cathode to this space charge region is largely electronic. Thus, if the cathode of the counting gap cannot be "seen" by the dialling gap anode, there will be a minimum of electronic coupling in the direction from counting gap to dialling gap, while by making the dialling cathode positive with respect to the counting cathode, ions will tend to migrate from the dialling gap to the counting gap.

A preferred arrangement for counting and dialling gaps is shown in Fig. 3, in which the dimensions are considerably exaggerated to show the main features. All electrodes are of nickel, the anodes being round wires running the length of each array and the cathodes being rods of say, 1 m. m. diameter coated with alumina except for the actual discharge surfaces 20, 20'. The surface 20' on cathode 5' is inclined so as to be shielded by the top edge of the cathode from anode 4. The anode 4' is arranged to lie on a normal to surface 20', while the two gaps are also staggered in vertical position with respect to one another. For a gas mixture of 92% neon 7% hydrogen and 1% argon at a pressure of 100 m. m. of mercury, and for dialling and counting speeds of 12 cycles/sec, and 100 kc./s. respectively, dialling and counting cathodes are placed 2 m. m. between centres while the gaps 4—5 and 4'—5' are each 1 m. m. long. The cathode-cathode separation along the two arrays may be made 1 m. m.

A further alternative arrangement is shown in Fig. 4 in which they are so mounted that cathode 5 effectively shields anode 4 from cathode 5' and hence prevents electron coupling from gaps 4' and 5' to gap 4—5.

A practical construction for a discharge tube according to the presnt invention is shown in Fig. 5. In this tube there are two cathode arrays 21 and 22, each comprising four 1 m. m. diameter nickel rods 23 welded to valve pins 24 in a conventional glass-based envelope 25. The cathode rods are spaced apart by and form supporting means for a pair of mica discs 26 and 27. These, in turn carry three support rods 28, to which two top mica discs 29 and 30 are secured. The top mica discs form support for the two anodes 31 and 32 which are formed of smooth nickel rods bent around three sides of a rectangle and locked in mica discs 29 and 30. Leads from the two anodes are taken to the top caps 33 and 34 respectively. The general arrangement of the electrodes is similar to that shown in Fig. 4. The rods 23 in each cathode array are spaced on 3 m. m. centres, while the gap length between anode 31 and the cathodes of array 21 is 1 m. m. The gap length for array 22 is 1.5 m. m. Array 21 is spaced 4 m. m. from array 22. Anode 32 is vertically above its cathode array 22 while the anode 31 is displaced slightly from its array 21 and in a direction distally from array 22. The discharge surfaces of rods 23 are ground flat and electrolytically polished, while all other surfaces and internal leads except the anodes 31, 32 and their connecting leads, are coated with alumina to prevent unwanted discharges. After evacuation through the exhaust tubulation 35, the tube is filled with the neon, hydrogen argon mixture mentioned previously.

In this particular tube, no separate priming cathode is provided, as the tube was designed for three-channel operation, therefore an end cathode of either array 21 or 22 may be used for this purpose.

In the arrangements so far described, the present invention has been put into effect by means of suitable geometrical design of the discharge gaps. It will be appreciated that this involves rather close tolerances both in the tube construction and in the circuit operating conditions. In the embodiments now to be described, novel constructional elements are incorporated in the design which result in simpler construction and wider design tolerance.

As has been pointed out above, a major difficulty in connection with unidirectional coupling between discharge gaps is the phenomenon of "cross-firing" between an anode of one main gap and the cathode of another. This cross-firing difficulty may be overcome as in the previously described embodiments, by one or other of the two cathodes acting as a screen. We find that a more direct method is to interpose an insulating screen between the two gaps, leaving a direct path between the two cathodes so that ionisation coupling may take place, this coupling being made unidirectional by biassing one cathode with respect to the other. One such arrangement which has been found to give satisfactory operation in a tube such as described with reference to Fig. 1 is shown in Fig. 6 in which the gaps 36 and 37 are made of equal length and a sheet of mica 39 is interposed between the two anodes 40 and 41. The mica does not extend to the level of the tops of the cathodes 42 and 43. In a satisfactory tube (otherwise similar to that shown in Fig. 5), the mica sheet projected 2 m. m. below the level of the anodes and within 0.5 m. m. of the level of the cathode discharge surfaces; the two cathode arrays were spaced on 2 m. m. centres while the cathode rods of the individual discharge arrays were mounted on 3 m. m. centres. We have found that still better results are obtained, with but little effect upon the "ionisation coupling," if the mica sheet is extended between the cathodes and an aperture be left just sufficient for one cathode discharge surface to be "seen" from the other. This arrangement is shown in Fig. 7 in which the electrodes are indicated by the same reference numerals as in Fig. 6 and the insulating sheet 44 has a circular hole 45 in line with the tops of cathodes 42 and 43 and of the same diameter as the discharge surfaces hole 45 permits migration of positive ions between the two gaps.

As an alternative to the above arrangements, a very considerable improvement in unidirectional coupling may be obtained by using electronic, as opposed to ionic coupling. To assist in the understanding of the phenomenon involved, consider the effect on the electric field in the region of a glow discharge if a conducting plate be placed parallel to the discharge gap and held at a potential between that of anode and cathode of the gap. Fig. 8 shows roughly the way in which the equipotentials are distorted under static discharge conditions. Anode 40 and cathode 42 are polarised so as to maintain a discharge between them, conducting plate 46 being parallel to gap 40—42 and being held at a potential below that necessary to maintain a discharge from cathode 42. As previously explained, most of the anode-cathode potential fall is localised a very short distance from the cathode surface. Equipotentials 47 are shown in Fig. 8 much further away from the cathode surface than they would in practice, but the diagram does show they are distorted by the neighbouring plate 46; in particular, there is a steep potential gradient near the cathode on the side adjacent plate 46. In consequence, the discharge path itself is considerably distorted as shown by the dotted line 48. Some electrons from the area of the cathode glow will tend to be drawn off towards plate 46. In particular, if an aperture 49 be drilled through the plate opposite of the steepest potential gradient and an accelerating field is set up on the other side of the plate, electrons will tend to be focussed through the holes and in the direction of the gradient of the accelerating field. For a given thickness of plate 46 and a given potential distribution to the left of the plate, there is a critical value of accelerating field—or rather of the gradient of this field—to the right of the plate below which the number of electrons which penetrate the aperture 49 is negligible, and above which a focussed stream may be obtained.

Applying this phenomenon to the problem of unidirectional coupling, it is found that a high degree of unidirectional coupling is obtained by employing an electrode arrangement such as is shown in Fig. 9, in which anodes 40 and 41 with corresponding cathodes 42 and 43 form a pair of discharge gaps as, in the previous examples, but conducting screen or baffle plate 46, placed closer to gap 40—42 than 41—43, isolates these gaps from one another except for coupling through the aperture 49. It may thus be arranged that discharge of gap 40—42 is virtually independent of the conditions at gap 41—43, but that when a sufficiently high pulse voltage is applied to anode 41, the electrons travelling in the path 50 ionise the gap 41—43. On the other hand it may also be arranged that discharges may take place at the counting gap 41—43 without priming the dialling gap 40—42.

A sequence discharge tube using an electrode arrangement such as described briefly with reference to Fig. 9 has been used with some success, but fuller description of an arrangement at present preferred will be given rather than a detailed discussion of the Fig. 9 arrangement.

In Fig. 9, the plate 46 merely serves as an auxiliary electrode to the discharge gaps 40—42 and 41—43. It is found, however, that it is possible to dispense with anode 40 and to make plate 46 function as the dialling anode. The preferred electrode arrangement is illustrated by the cross-sectioned view shown in Fig. 10 and a circuit diagram is given in Fig. 11. In Fig. 10, a counting anode 41 is shown with one of the counting cathodes 43 as previously described.

Cathodes 42, constituting the cathodes of the dialling array, are mounted perpendicularly to plate 46 while the counting cathodes 43 are parallel thereto. Corresponding individual cathodes 42 and 43 are mounted so that a plane perpendicular to the plane of the drawing would pass through a cathode 42, an aperture 49 and the corresponding cathode 43 slightly below the upper surface of the latter. On the side facing the dialling cathodes, plate 46 is backed with a mica sheet 51 having apertures 52 approximately twice the diameter of apertures 49 and exposing an annular surface of plate 46 opposite each dialling cathode. The purpose of mica sheet 51 will be explained later, its use is not essential to the invention but is preferred when low dialling pulse repetition frequencies are employed.

In the circuit of Fig. 11, the electrodes are denoted by the same reference numerals as in Fig. 10. Each counting cathode 43 is connected to ground through a resistance 53, the output cathode also including a pulse transformer (not shown) or other suitable means for passing the discharge pulse to a further circuit. The counting anode 41, which serves all dialling counting gaps, is connected directly to the cathode of a vacuum tube arranged as a cathode follower 54, the anode of which is connected to a suitable polarising source 55. The grid of cathode follower 54 is supplied with a pulse voltage of waveform similar to that shown at 56, which, however, represents the waveform of the anode 41. The dialling anode plate 46 is kept at a steady positive potential $V_2$ with respect to ground by battery 57. Cathode 42 is connected via resistance 58 to lead 59 which connects to the remaining dialling cathode resistances "58" (not shown). From lead 59 a connection is made through a stabilised D. C. potential source 60 and the secondary of dial pulse input transformer 61 to anode 46. Source 60 serves as a maintaining battery for the dialling array and provides a constant mean voltage $V_3$ between anode 46 and lead 59. Dialling pulses are fed in through the primary of transformer 61 from terminals 62. Anode 41 is maintained by the cathode current of 54 at a D. C. potential $V_1$ with respect to ground which is increased to $V_1+P$ during the counting pulses. The counting pulse train 56 contains a negative extinguishing pulse 63 for the purpose of extinguishing discharges at the counting array after each cycle of operation.

In one mode of operation, individual priming discharge gaps (not shown) such as described in connection with Fig. 1 are provided for both dialing and counting arrays. The pulse amplitude P is then adjusted so that the counting array operates normally without discharges occurring at the dialling array. The potentials $V_1$ and $V_2$ are arranged to be such that, in the absence of counting pulses, no current is drawn from the dialling cathodes when the dialling gaps are discharging. In other words, the potential gradient between 46 and 41 is insufficient to focus electrons through the apertures 49. This is assisted by having the cathodes 43 a millimetre or so above the level of the respective apertures 49 so that they tend to set up a retarding field. During the counting pulses, however, the increased potential of anode 41 is arranged to be sufficient to draw current through any aperture 49 opposite a discharging dialling cathode. The potential $V_1+P-V_2$ must then be greater than the anode fall of potential for a gap of length $d$, and having the geometry shown in Fig. 10, where $d$ is the distance between 41 and the corresponding aperture 49. A stream of electrons then passes between cathode 42 and anode 41 and ionises the gap 41—43 so that a discharge takes place whether or not the gap is ionised due to discharge at a neighbouring counting gap (or at a priming gap). Thus, at the first pulse of pulse train 56 those counting gaps opposite discharging dialling gaps will fire, the remaining counting gaps, if any, then firing in normal sequence discharge manner at successive pulses of the counting train.

At first sight it might appear that the unstruck dialling gaps might be fired by the pulse potentials applied to anode 41. This might conceivably occur were a steady potential $V_1+P$ to be applied to anode 41. However, it is to be remembered that in a gaseous discharge, the gap potential difference must be applied for a finite time—the formative delay time—before the gap energy has built up to a value sufficient to initiate the discharge. The pulse amplitude P is chosen so that the formative delay time for the gap 41—42 is longer than the duration of a counting pulse. The dialling array gaps cannot then be fired by the counting pulses. On the other hand, when a dialling gap is discharging no further energy need be provided by the potential of anode



41 other than that required to draw sufficient electrons through aperture 49 to ionise the gap 41—43; there is then virtually no formative delay time involved in the extension of the discharge from plate 46 to anode 41.

Due to the high repetition frequency of the counting pulses and to the fact that the gap distances are chosen to suit the slower dialling speed, no difficulty arises in the counting array due to self-running. This difficulty does tend to occur in the dialling array, however, due to causes:

(1) The current drawn to anode 41 through aperture 49 tends to increase the ionisation coupling along the dialling side of the tube, and

(2) In the absence of mica sheet 51 a long-term ionisation coupling occurs between gaps of the dialling array, apart from the operation of the counting array; this is, in a slightly different form, a recurrence of the original problem mentioned in the description with reference to Figs. 1 to 5. The fact that the anode is a plate instead of a wire aggravates the problem, due to there being a less concentrated field across the anode cathode gaps of the array and hence a wider diffusion of ionisation products.

The effect of (1) is less serious than (2) and can largely be eliminated by the geometrical design of the gaps and the electric field employed: this design is materially assisted by the cure for (2). The long term ionisation coupling (2) manifests itself as a tendency to instability of the dialling number registered after a tube has been in operation two or three minutes. The provision of mica sheet 51 (Fig. 10), which localises the discharge to a definite region of the anode, effects a satisfactory cure. Sheet 51 acquires a considerable static charge, particularly at the rim of aperture 52 surrounding aperture 49 which charge reduces the ionisation coupling between dialling cathodes thereby limiting the effect of the long term ionisation coupling.

In the design to eliminate effect (1) it can be arranged, for example, that the whole of the current at the dialling gap is transferred from the dialling anode to the counting anode. Thus, with a suitable field on the other side of the plate, all the electrons go through the aperture 49 rather than being collected by plate 46. This is illustrated in the following table in which electrode voltages and currents are compared. In the table:

$I_{DC}$ denotes dialling cathode current (electrode 42 in Figs. 10 and 11).

$I_{DA}$ denotes dialling anode current (electrode 46 in Figs. 10 and 11).

$I_{CA}$ denotes counting anode current (electrode 41 in Figs. 10 and 11).

$V_{CA}$ denotes counting anode voltage with respect to ground.

$V_{DA}$ denotes dialling anode voltage with respect to ground.

| $I_{DC}$ | $I_{DA}$ | $I_{CA}$ | $V_{CA}$ | $V_{DA}$ |
|---|---|---|---|---|
| μamp. | μamp. | μamp. | Volts | Volts |
| 400 | 400 | | 160 | 100 |
| 450 | | 450 | 193 | 100 |
| 550 | −60 | 610 | 260 | 100 |

It will be seen that there is an increase of only 150 μ amp. in the dialling cathode current for a 100 volt pulse on the counting anode. Since the gap spacings—which are similar to those given in connection with Fig. 5—are such that there is but little variation in ionisation coupling between gaps with discharge currents for discharges of the order of 400 $\mu$ amp., the tendency for self-running is largely eliminated.

It was mentioned above, that in one mode of operation, both dialling and counting arrays could be provided with priming discharge gaps to control the general ionisation level in both arrays and so ensure that sequence discharges commenced at the first gap in each array. The voltages of pulse train 56 (Fig. 11) were thus arranged so that the counting array counted normally in the absence of discharges at the dialling array. Such a mode of operation is set satisfactorily when only a small number of gaps—say four—are involved in each array. With arrays capable of dialling and counting higher numbers, some difficulty is liable to be experienced in the counting array, due to the fact that the general level of ionisation decreases exponentially with distance away from the permanently discharging priming gap at the end of the array. In consequence, due to the phenomenon of formative delay time, when several dialling gaps are discharging, the corresponding counting gaps do not all fire at exactly the same instant on application of the first pulse of train 56, it is found that there is a tendency for them still to fire in sequence with consequent detriment to the exact time at which the output counting gap discharges due to the variation of formative delay time. Where this effect is of importance, it is preferred to dispense with a priming gap associated with the counting array. It follows then, that counting occurs only when discharges are present on the dialling array, the coupling from dialling to counting gap being sufficient to start the counting process, and, at the same time, all counting gaps opposite discharging dialling gaps then fire simultaneously.

Although the discharge tubes described with reference to Figs. 9, 10 and 11 were devised with a view to meeting the requirements of a sequence discharge tube as discussed with reference to Fig. 1, the phenomena involved in the electronic coupling between gaps through aperture 49 may be utilised with advantage in a tube other than of the sequence discharge type. Thus, Figs. 9 and 10 may be taken to illustrate electrode arrangements for tubes having single pairs of coupled gaps to utilise the electron coupling phenomenon. Thus, it may be arranged that, if anode 41 be maintained at constant D. C. potential and the potential of plate 46 be raised, the current flowing to anode 41 may be decreased in spite of the extra current drawn from cathode 42 to electrode 46. Similarly, if electrode 46 be maintained at a steady potential and that of electrode 41 be raised, the current to electrode 46 will decrease. It follows that the tube may be made to act as a negative resistance. For many purposes cathode 43 could be dispensed with and the tube could then be regarded as a triode having a negative mutual conductance—electrode 41 functioning as anode and 46 as control grid, or vice versa. Such a structure is not dissimilar from those previously described in connection with a tube utilising what is termed a "Plasma" cathode in which an apertured screen constricts the cross-section of the discharge and enables an impoverishment of positive ions to occur in the anodic space with consequent negative resistance properties between the "Plasma" cathode and the anode. The operation of such tubes is, however, very different from those with which we are concerned and involves currents of the order of 50 amperes or more compared with the microamperes or millamperes which can be used in embodiments of the present invention.



According to this further aspect of the present invention, is provided a gas-filled electric discharge tube comprising a cold cathode discharge gap between solid electrode surfaces, and a metal screen having an aperture separating the cathode of said gap from a further anode or control electrode, the electrodes being arranged so that electrons from the discharge at said cathode may be drawn through said aperture to said further electrode under the influence of the potential field between said screen and said further electrode.

It will be evident that such a tube may be made to fulfill many of the functions heretofore performed with thermionic valves and that other additional electrodes may be inserted to simulate the various multi-grid tube of the thermionic valve art.

A circuit utilising a three-electrode tube according to this further aspect of the present invention is shown in Fig. 12. In this circuit anode 41 is connected through the tuned secondary of transformer 63 to the positive terminal of battery 64 while apertured plate 46 is connected via the primary winding of 63 to the negative pole of battery 64 and to the positive pole of battery 65, the negative pole of which is taken through current limiting resistance 58 to cathode 42. An earth connection can be made where indicated or at any other convenient point. The operation is as follows:

Battery potentials 64 and 65 are adjusted to maintain a discharge between cathode 42 and plate 46 with an extension of the discharge to anode 41. Then if, momentarily, the potential of anode 41 increases, the current at plate 46 passing through the primary of transformer 63 decreases. It is arranged that the windings of 63 are so poled that the decrease in primary current causes an increase in the voltage of anode 41. The potential across the tuned secondary builds up to a limiting value determined by the circuit constants and the non-linearity of the voltage-current characteristics of the tube, after which it falls and reverses the direction of regenerative action between electrodes 41 and 46. Oscillations are thus set up across the tuned secondary circuit of transformer 63, and may be obtained for example through a tertiary winding 66 coupled to the primary and secondary windings.

The transformer 63 may be replaced by any other suitable type of four-terminal network or filter having the necessary frequency determining properties.

It should be pointed out that, for the operation of the circuit described with reference to Fig. 12, a considerably higher cathode current is desirable than the 400—500 $\mu$ amps. quoted in the above table. Increased current several times larger may readily be obtained by increasing the effective area of cathode 42 without incurring a correspondingly substantial increase in the voltages $V_{CA}$ and $V_{DA}$ quoted in the table. In view of the complete transfer of current between electrodes 46 and 41, for a comparatively small change in the voltage between these electrodes, it will be appreciated that numerous other applications of devices according to the present invention are possible particularly as limiters or relaxation oscillators.

While the principles of the invention have been described above in connection with specific examples 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.

What is claimed is:

1. A cold cathode gas-filled discharge tube comprising a plurality of electrode arrays defining thereamong at least two discharge gaps, a first of said gaps having a lower given firing potential than a second of said gaps, means to energy-couple said first gap with said second gap, whereby firing of said first gap lowers the given firing potential of said second gap, and means disposed between said gaps to inhibit energy-coupling between said second gap and said first gap.

2. A cold cathode gas-filled electric discharge tube as claimed in claim 1, wherein each of said arrays comprises an anode and a cooperating cathode, wherein said first gap is in ionization coupling relation with said second gap, and wherein said inhibiting means comprises a portion of the cathode of said first array, said portion lying in a plane with and disposed between the anode of said first array and the cathode of said second array.

3. A cold cathode gas-filled electric discharge tube as claimed in claim 1 wherein each of said arrays comprises an anode and a cooperating cathode, each of said cathodes having a discharge-inhibiting area except at the portion adjacent its respective anode, whereby glow discharge is confined to the portion of each of said cathodes adjacent the respective anode, the said portions lying in different planes and said cathodes being positioned closer together than said anodes.

4. A discharge tube according to claim 3 in which the discharge portion of said second cathode faces away from the said first gap, the cathode being shaped to shield the cathode glow thereat from the electric field of the said first anode.

5. A discharge tube according to claim 3 in which the said first cathode is positioned to shield the cathode glow at the discharge portion of the said second cathode from the electric field of the said first anode.

6. A cold cathode gas filled electric discharge tube as claimed in claim 1, wherein each of said arrays comprises an anode and a cooperating cathode, the cathode of said first array adapted to be biassed at a higher positive potential than the cathode of said second array and said inhibiting means comprises a baffle positioned to separate said gaps, a portion of said baffle lying in a plane traversed by a line taken between the anode of said first array and the cathode of said second second array, whereby positive ions may migrate from said first gaps to said second gaps.

7. A cold cathode gas-filled electric discharge tube comprising a plurality of electrode arrays each array having an anode and a cooperating cathode and defining a discharge gap therebetween, a first of said gaps having a lower given firing potential than a second of said gaps, the cathode of said first array adapted to be biassed at a higher positive potential than the cathode of said second array, baffle means positioned between said arrays, said baffle, having an aperture therethrough to communicate with each of said gaps, said aperture substantially on a line with the discharge surfaces of said cathodes.

8. A cold cathode gas-filled electric discharge tube as claimed in claim 7, wherein the anode of the array making up said first discharge gap comprises a sheet of conducting material forming a shield adapted to inhibit positive ionic coupling between said first and said second discharge gaps, said sheet having an aperture therethrough to communicate with each of said gaps, said aperture disposed in a plane substantially offset from a line taken between said second cathode and said first anode, whereby electrons travel from said first cathode through said aperture to said second anode to prime said second discharge gap.

9. A cold cathode gas-filled electric discharge tube comprising a metal screen anode and a first cooperating cathode defining a first discharge gap therebetween, a second anode and a second cathode defining a second discharge gap therebetween, said first gap having a lower given firing potential than said second gap, said screen anode disposed between said two cathodes and having an aperture therethrough substantially on a line taken between said cathodes, whereby electrons travel from said first cathode through said aperture to said second anode to prime said second gap.

10. A cold cathode gas-filled electric discharge tube comprising a first metal screen anode having an aperture therethrough, a common cathode disposed on one side of said first anode, a second anode disposed on the other side of said first anode, said cathode, said aperture and said second anode being in substantial alignment, each of said anodes forming a discharge gap with said cathode, one of said gaps being through the aperture in said first anode.

11. An electric oscillation generator comprising a cold cathode electric discharge tube having a first conducting screen anode having an aperture therethrough, a common cathode disposed on one side of said anode, a second anode disposed on the other side of said anode, said cathode, said aperture, and said second anode being in substantial alignment, each of said anodes forming a discharge gap with said cathode, one of said gaps being through the aperture in said anode, and a resonant circuit coupled to said second anode.

12. A cold cathode sequence gas-filled electric discharge tube comprising a first electrode array having pairs of mutually spaced electrodes defining a first series of discharge gaps, a second electrode array having corresponding pairs of mutually spaced electrodes defining a second series of discharge gaps, said first series of gaps having a lower given firing potential than said second series of gaps, the cathode of said first array adapted to be biassed at a higher positive potential than the cathodes of said second array, means to energy-couple corresponding of said first series of gaps with corresponding of said second series of gaps, whereby firing of any of said first series of gaps lowers the given firing potential of corresponding of said second series of gaps, and means disposed between said arrays to inhibit energy coupling between said second series of gaps and said first series of gaps, whereby discharges may be maintained across a desired number of consecutive gaps of said first array independently of discharge sequences occurring across the gaps of said second array while a discharge sequence along said second array commences at that one of its discharge gaps determined by the said number of discharging gaps in said first array.

13. A cold cathode gas-filled electric discharge tube comprising two sets of cathodes, arranged in a pair of parallel lines, each set comprising the same number of equally spaced parallel rods mounted opposite the respective rods of the other set; a pair of anodes each cooperating with a respective of said cathode sets, each anode com-

prising a rod extending parallel to said parallel lines defining with its cooperating cathode set a series of discharge gaps and constituting an electrode array, a first of said arrays having a lower given firing potential than said second array, means to ionically couple gaps of said first array with gaps of said second array, means to inhibit ionic coupling between gaps of said second array with gaps of said first array comprising a baffle sheet interposed in parallel between said two arrays, said sheet having a plurality of spaced apertures therethrough, each aperture substantially on a line between the discharge surfaces of corresponding cathodes of the two sets.

14. A cold cathode gas-filled electric discharge tube as claimed in claim 13, wherein said baffle sheet is of insulating material.

15. A cold cathode gas-filled electric discharge tube as claimed in claim 13, wherein said baffle sheet is conducting material.

16. A circuit arrangement comprising a cold cathode sequence discharge tube having a first and a second electrode array each of mutually spaced electrodes defining discharge gaps adapted to fire in sequence along the array when energized by voltage pulses applied in common to the electrodes of that array, the gaps of a first of said arrays having a lower given firing potential than the gaps of said second array, the electrodes in the two arrays being positioned relative to one another to provide successive pairs of discharge gaps, the gaps of said first array being in ionization coupling relation with corresponding gaps of said second array, means for inhibiting ionization coupling from gaps of said second array with corresponding gaps of said first array comprising portions of like electrodes in each of the gaps of said first array, each of said portions lying in a plane with and disposed between the cooperating electrode of each of said gaps and the like electrode of said second array, means for maintaining discharge across fired gaps of said first array after the passage of said pulses, means for applying a recurrent train of pulses to the second array whereby the first pulse of each said train of pulses initiates discharge at the same number of gaps of the second array as there are gaps of the first array being maintained in discharging condition, the remaining unfired gaps of the second array being fired in sequence by succeeding pulses of said train; a utilization circuit coupled to the last gap of said second array; means for passing a signal to said utilization circuit when said last gap has been fired; and means for extinguishing the discharges of the fired gaps of said second array between each of said recurrent pulse trains.

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