April 28, 1953 A. H. REEVES 2,636,681

GASEOUS DISCHARGE TUBE

Filed July 25, 1947 5 Sheets-Sheet 1

FIG. 1.

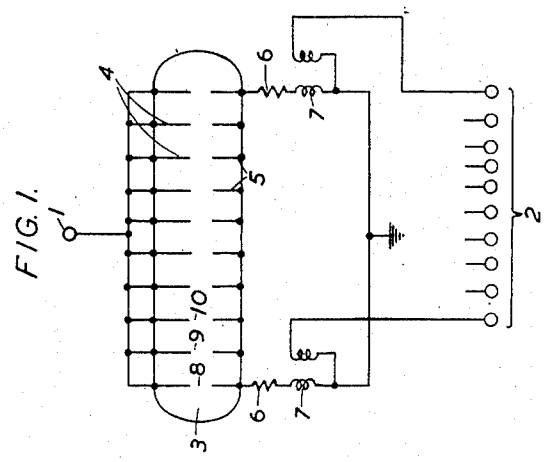


FIG. 2.

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GASEOUS DISCHARGE TUBE

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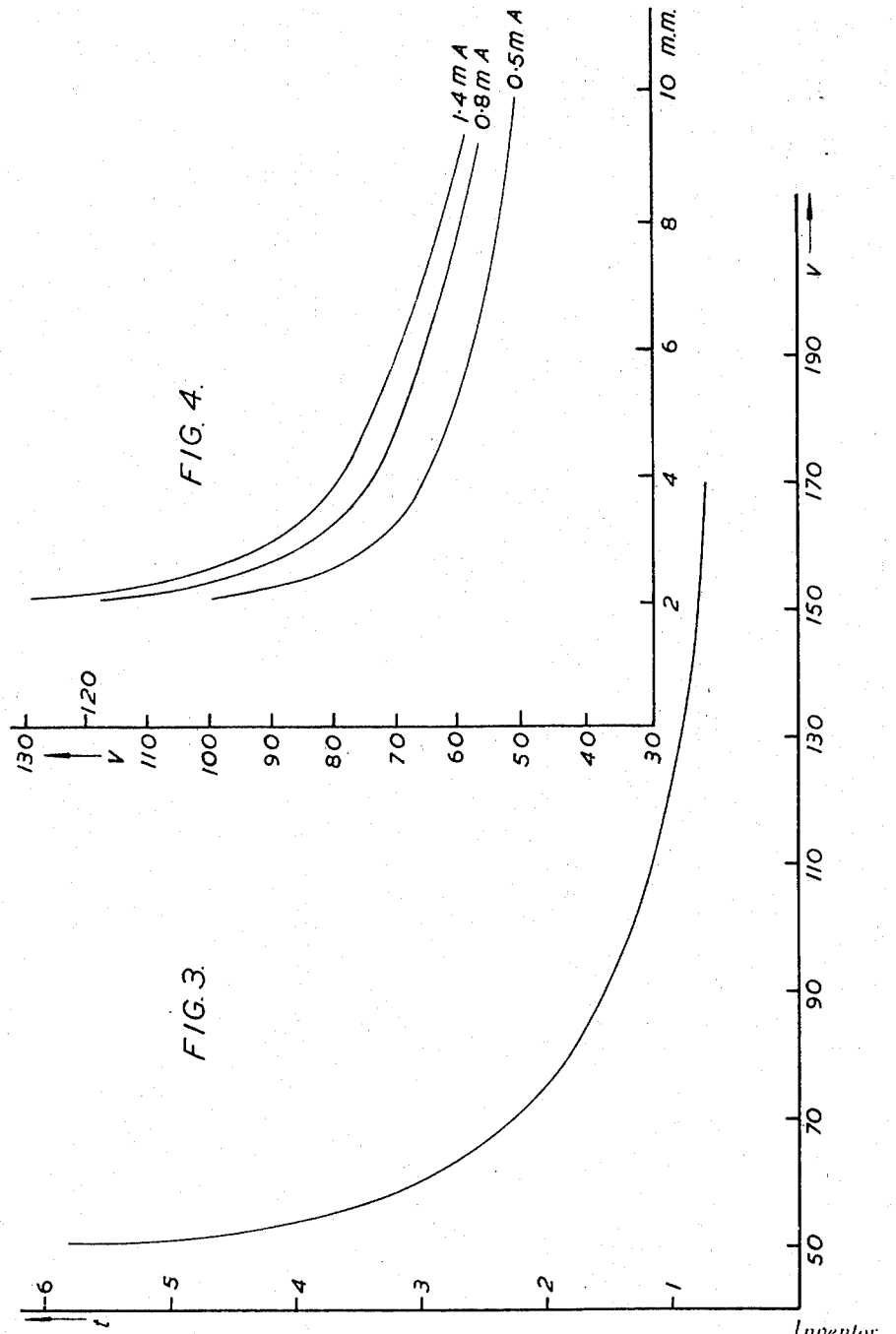


FIG. 4.

FIG. 3.

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GASEOUS DISCHARGE TUBE

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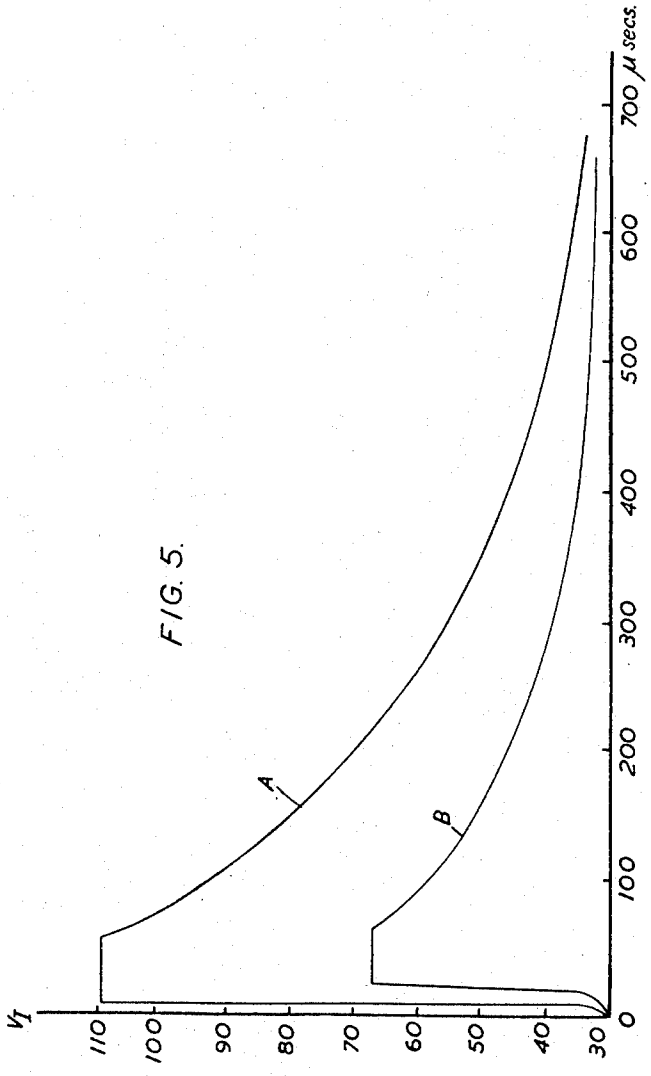


FIG. 5.

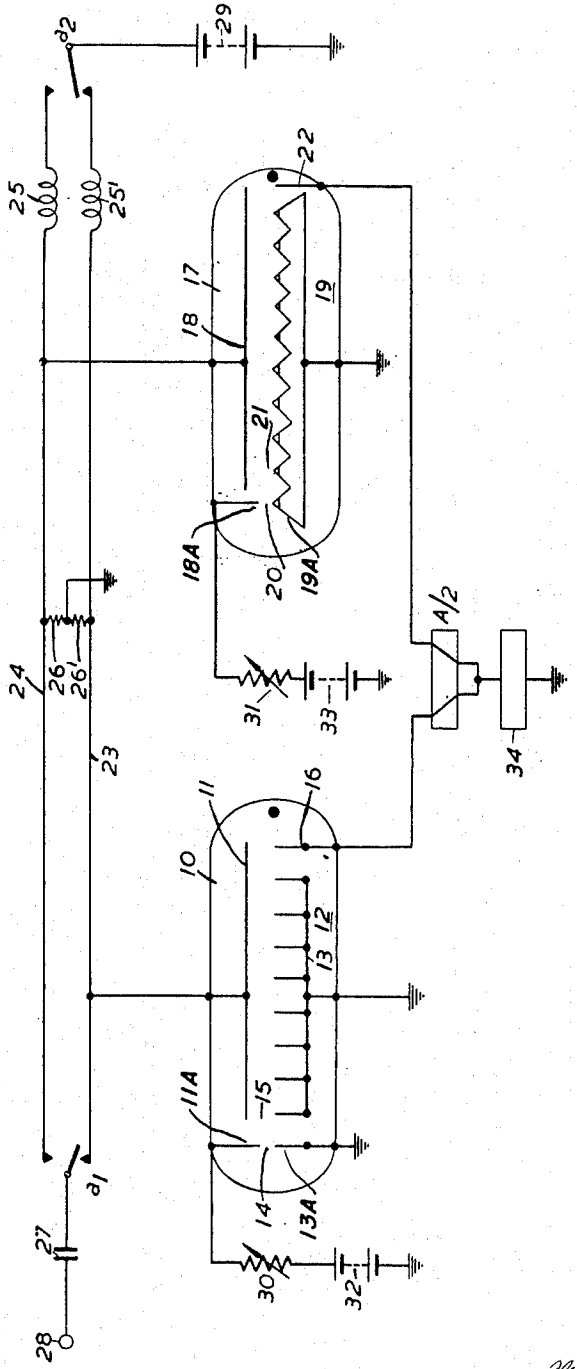
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GASEOUS DISCHARGE TUBE

Filed July 25, 1947 5 Sheets-Sheet 4

FIG. 6.



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GASEOUS DISCHARGE TUBE

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FIG. 7

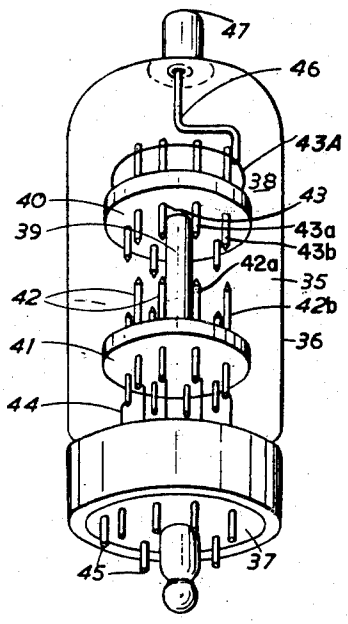


FIG. 7A.

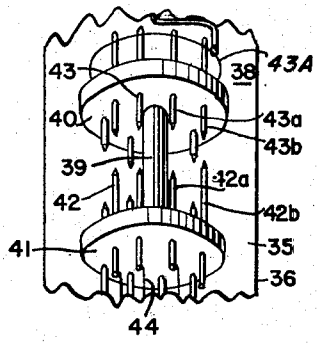
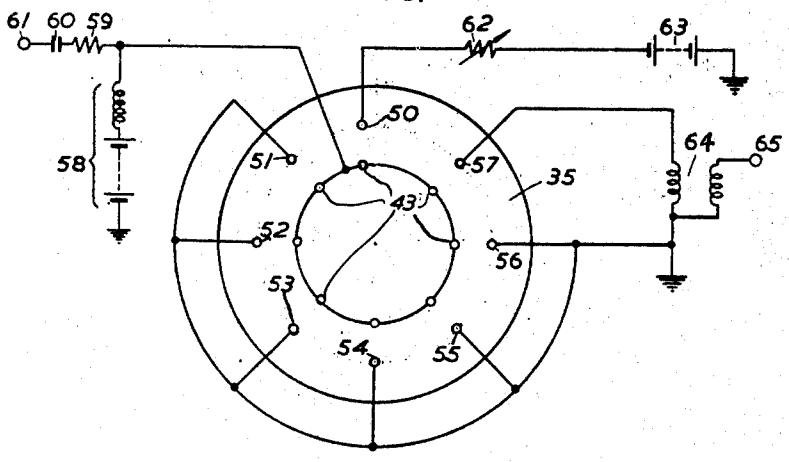


FIG. 8.



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UNITED STATES PATENT OFFICE

2,636,681

GASEOUS DISCHARGE TUBE

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Application July 25, 1947, Serial No. 763,655
In Great Britain July 25, 1946

20 Claims. (Cl. 235—92)

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The present invention relates to cold cathode gas discharge tubes in which the initiation of a discharge between a pair of electrodes is conditioned by ionization coupling from another discharge gap and is particularly concerned with the construction of tubes employing several gaps.

It is characteristic of cold cathode gas filled discharge tubes that the voltage required to initiate a discharge between two electrodes depends upon the nature and pressure of the gas, its state of ionization, the shape and material of the discharge electrodes and the distance between them—the gap length. At low interelectrode voltages, negligible current will flow if the gas is initially deionized. As the voltage is increased slowly the molecules of the gas become ionized, until eventually a discharge is set up with a rapid increase in current flow which may typically rise from microamperes to milliamperes at a critical voltage which is the static "striking" or "firing" voltage for the discharge gap. The discharge is characterized by a glow which appears at the cathode and may extend towards the anode and beyond the immediate neighbourhood of the gap, depending upon the degree of ionization, and is associated with the migration of ions, which term is taken to include all ionization products. When once a discharge has been established, a much lower voltage in general is required to maintain it. The critical voltage below which the discharge dies away, neglecting a slight rise just before extinguishing is called the "maintaining" voltage. If the discharge current be limited so that the whole cathode surface is not covered with glow, the interelectrode voltage tends to remain constant, and independent of the discharge current, at a value approximately the same as the maintaining voltage. When once the discharge current is increased beyond the value at which the whole of the cathode surface is covered with glow, the interelectrode voltage rises again. In the familiar neon tubes used as voltage regulators and the like, the striking potential may be designed of the order of 100 volts or more, while the maintaining voltage may be arranged to be in the region of 80 volts.

As mentioned above, ions tend to diffuse from the immediate neighbourhood of the discharge. This phenomenon has been extensively used to lower the static striking potential of another discharge gap in the same tube envelope. In one known device there is provided a main discharge gap between a main anode and a trigger gap between an auxiliary anode and the said cathode. The auxiliary anode is much closer to the cathode than the main anode so that the initial striking voltage of the trigger gap is considerably below that of the main gap. The trigger gap is used to lower the striking voltage of, or to "prime" the main gap by ionization coupling.

These trigger tubes are finding increasing application in electrical counting circuits, for switching purposes and the like and in some of

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these applications batteries of trigger tubes are used in tandem. For many applications it would be of great assistance if, instead of being in separate tube envelopes, an array of discharge gaps were placed in a single envelope so that the gaps could be fired in sequence, the ionization coupling between gaps performing the priming function of the trigger gaps of the ordinary trigger tubes. It is the object of this invention to provide such a tube, which we propose to call a "sequence discharge tube."

In its more general aspect, the present invention consists of a cold cathode sequence discharge tube comprising an array of three or more discharge gaps so arranged that, upon a discharge being initiated at one of said gaps, ionization from said discharge may lower the striking potential of its neighbouring gap, whereby said gaps may be fired in sequence along said array.

Although other modes of operation and use are obviously possible, sequence discharge tubes are naturally particularly adapted for use in connection with pulse operated systems, and in the present specification embodiments of the invention will be described with reference to pulse operation.

From this aspect, the invention provides a cold cathode sequence discharge tube comprising an array of three or more discharge gaps so arranged that the first pulse of a train of voltage pulses applied to said tube may initiate a discharge at a given gap and subsequent pulses may initiate discharges at successive gaps in sequence along said array. Reference is hereby made to applicant's copending application, filed even date herewith and bearing Serial Number 763,656 (now abandoned).

The invention will now be more fully described with reference to the accompanying drawings in which:

Fig. 1 is a diagrammatic representation of a tube according to the present invention which may be used in a pulse separator circuit.

Figs. 2 to 5 show curves illustrating the factors influencing the operation of discharge tubes according to the invention.

Fig. 6 is a schematic diagram of a pulse recording circuit using two tubes according to the present invention.

Fig. 7 shows a practical embodiment of an eight point counting tube according to the present invention.

Fig. 7A is a view of the part of a tube of the type shown in Fig. 7 slightly modified.

Fig. 8 is a diagrammatic view of the discharge tube of Fig. 7 together with a circuit to illustrate its manner of operation.

It may be stated in general, that the design of a sequence discharge tube as regards its gap dimensions will depend very largely upon the dynamic operating characteristics required—thus for the same gas mixture and electrode materials closer electrode spacings are required for satis-

factory operation at higher pulse repetition frequencies than for slow operation. These, and other design factors will be better appreciated by considering some examples in connection with specific applications.

In Fig. 1, a sequence discharge tube is arranged to divert positive pulses in a repeated pulse-train applied to terminal 1 to individual circuits connected to terminals 2. Sequence discharge tube 3 is represented as having a number of anode wires or rods 4 and an equal number of cathode rods 5. The cathode rods are connected through current limiting resistances 6 and pulse transformers 7 to ground. Only the first and last of these resistances and transformers have been shown on the drawing. One end of the secondaries of transformers 7 is connected to ground and the other ends are each connected to one of the output terminals 2. All the gaps of tube 3 are assumed to be of equal length, except the first gap 8, which is slightly shorter than the others. Thus, in the absence of ionization, all the gaps except 8 will require the same static striking voltage Vs to initiate a discharge. As stated above, this static striking voltage is a function of the nature and pressure of the gas, the gap length and the electrode materials. As is well known, by applying cathode coatings to reduce the work function, the striking voltage may be varied considerably. At the present time, however, to ensure long life and consistency of operation, I prefer to use cathodes of homogenous material and usually I employ pure nickel for both cathode and anode. The choice of gas mixture not only affects the striking voltages but also the maintenance voltage and, a very important factor, the deionizing time. At the present time for most applications I use a mixture of 92% neon, 7% hydrogen and 1% argon at a total pressure of 100 mm. of mercury. It should be mentioned that this gas mixture has been chosen to give a short deionizing time. With this gas and pressure, the maintaining potential, V_m is about 185 volts, and for 2 mm. gap lengths with nickel electrodes the static striking potential Vs is about 340 volts. Thus, assuming deionized condition within tube 3, a pulse of amplitude greater or equal to 300 volts with respect to ground would fire any gap of the array (assuming also the gas and gap lengths given above) provided it is of sufficient duration, as will be explained later. It will of course, be almost impossible to ensure such uniformity that all the static striking potentials are exactly the same, so that even if gap 8 were not made shorter, the gaps would not fire simultaneously.

In order to appreciate the dynamic sequence discharge conditions within the tube, we will assume, for the moment, that the electrodes of gap 8 are isolated from the remainder and that a steady discharge is maintained at this gap. Then charged particles which we shall refer to generally as ions, will spread out from gap 8 and will be effective in reducing the striking potential of other gaps in the tube. When considering the quantitative aspects of ionization coupling it will be an advantage to think in terms of energy levels, expressed in volts, at various points in the tube. Thus, under static conditions, the energy level for any gap must be Vs volts before a discharge can take place; the ionization due to a discharge at gap 8 will contribute an energy of V_I, say. There will also be a contribution due to the electric fields associated with the electrodes which will provide an energy level contribution of V_E say. Thus, neglecting any other contribution, and still assuming static conditions, the voltage required to initiate a discharge at another gap is now

$$V_S-(V_I+V_E)$$

V_I will depend upon the number of ions produced by the discharge at 8, i. e. upon the discharge current. It may be mentioned at this point that, to control the discharge conditions, we ensure that the cathode glow is confined to a definite area on each cathode by coating part of the cathode rods—and also any other electrode leads which we do not want to act as cathodes—with a discharge inhibiting substance such as alumina, which may be painted or sprayed on or may be applied by a colorizing process.

Before considering the dynamic conditions in the tube, it is necessary to appreciate an apparent variation of striking voltage which is encountered when the tube is operated under pulse conditions. For any given ionization level in a gap, in order to initiate glow discharge we have observed that a discrete amount of work must be performed to raise that energy to a critical level, which we call the striking point. From this consideration, it can be seen that if the work to initiate a glow is to be performed in a limited amount of time, then the rate of working must be greater than when a longer time is available. Hence for short pulses of 2 microseconds duration, the pulse amplitude required to strike a glow is much greater than that required in a pulse of 10 microseconds duration.

The preceding discussion implies that on the application of a given voltage across a gap, there is a necessary delay before the glow is initiated. These two effects are illustrated in Figs. 2 and 3 for a typical sequence discharge tube. Fig. 2 shows for a given ionization level the variation in pulse amplitude (volts, V_A anode to cathode), with variation in pulse width (w microseconds), in order that the striking point may be attained. For the same conditions, and using a pulse width of 10μ secs., the variation in delay time, t, in microseconds, is plotted in Fig. 3 as a function of pulse amplitude V, superimposed upon a steady potential of 185 volts, anode to cathode.

From what has been said above, it will be evident that the voltage required to initiate a discharge at a given gap in a discharge tube operated under dynamic conditions may differ considerably from the static striking voltage defined earlier. Unless expressly stated otherwise, in what follows it will be assumed that when the term "striking voltage" is used, these other factors have been taken into account. Thus the pulse voltage required to fire a gap may still be written $V_S-(V_I+V_E)$.

V_I will naturally tend to vary with the distance d from the ionizing source, particularly under dynamic conditions; the reduction of striking voltage V volts, or different distances from a priming gap is shown in Fig. 4 for diffused values of priming current.

When the discharge of gap 8 is extinguished, deionization sets in; furthermore, some time must elapse before ionization reaches a given point in the tube when gap 8 is first fired. Hence V_I is a function of time. The ionization diffusion time is in general small compared with the deionizing time. The variation of ionization coupling V_I due to a 50 μ sec. rectangular current pulse through gap 8 as a function of time t from the leading edge of that pulse, may be represented

by curves of the general form shown in Fig. 5, in which curve A gives the variation of V_I for gap 9 while curve B shows the time variation corresponding to gap 10. In the case of the sequence discharge tube 3 of Fig. 1, all the anodes are at the same potential, while, provided the potential drops across resistances 6 are small, the cathodes are also approximately at the same potentials so that the field term V_E in the energy level may be made negligible compared to V_I.

Assume now that a pulse-train is applied to terminal 1 of Fig. 1, each pulse being of amplitude Vp, between Vs and Vs—V_I. The first gap 8, being shorter, has a striking voltage Vs, assumed less than V_P. Gap 8 is thus the only gap to fire on application of the first pulse; the discharge current through associated transformer 7 sends a pulse out from the corresponding terminal 2. The next gap 9 will be energized by ionization from 8 by an amount V_I which varies with time as shown in curve A of Fig. 5. At gap 8 the residual ionization after the passing of the first pulse will contribute an energy V_R which will decay with time similarly to the falling portions of curves A and B of Fig. 5, but starting at a higher level. The spacing between gaps must be chosen in conjunction with the pulse repetition frequency so that when the next pulse is applied, gap 9 still has an energy level greater than Vs—V_I, while gap 10, which has an energy level variation corresponding to curve B of Fig. 5 will not fire. Gap 8 will fire again on the second pulse, due both to its smaller initial striking potential and to its residual ionization energy V_R. When the third pulse arrives, gap 10 will be able to fire as its energy is now raised by ionization from both the preceding gaps. Gaps 8 and 9 will also be fired. Thus, at each successive pulse one more gap will fire until, finally, all gaps are fired. It may easily be arranged, by means well known in the art, that the circuits connected to the individual terminals 2 will pass on only the first pulse received at that particular terminal during a time equal to the pulse-train repetition time. Thus, the individual pulses of a pulse-train applied to terminal 1, which may be modulated in width or time, are effectively passed on to separate circuits.

When all gaps of the array in tube 3 have been fired, the energy level at each gap will tend to be the same, so that before any further pulse-train is applied, time must be allowed for deionization to set in. Arrangements using two tubes may be made, in similar manner to that to be described later, whereby during alternate pulse-trains, one tube may remain idle while the other is operating, so as to provide time for the deionization process.

It will be evident that in tube 3 of Fig. 1, the connections between anodes 4 could be made internally, and in practice I find it convenient to replace the separate anodes by a single wire, plate or strip.

In the circuit of Fig. 1, the discharge at each gap of tube 3 is extinguished between successive pulses. For many applications it is preferable that a maintaining battery be included in the circuit so that each gap, after being fired, remains discharging until the battery voltage is removed. In general the tube design is simplified and the tolerance enlarged if this be done, as we are not then concerned with the falling portions of the V_I curves of Fig. 5; the contributions from any one gap tending to remain constant, I am able to base the design more on the Fig. 4 curves, taking into account only the initial portions of the Fig. 5 curves. Again, in practical cases I have found it preferable, where possible, to stabilize the minimum level of ionization in sequence discharge tubes by providing an auxiliary discharge gap, a "priming" gap, which may be separate from the main array, so avoiding trouble due to random external ionizing sources such as cosmic rays, sunlight or the like. If desired, the array gap spacings might be adjusted to equalize the fall-off of the ionization coupling-distance curve, or, preferably, the array gaps may be arranged symmetrically. In practice, however, I may use a priming gap to give an asymmetrical ionization distribution so that the nearest array gap may function as a starting gap.

In Fig. 1, tube 3 has been shown with starting gap 8 of shorter length than the others. Besides proximity to a priming gap, there are other possibilities such as by providing the starting gap with its cathode coated with or formed from material of lower work function than the others in the array. Alternatively, a small D. C. bias may be applied to the starting gap.

In Fig. 6, a circuit is shown to illustrate other aspects of the present invention in a pulse recording circuit. Sequence discharge tube 10 is represented as having an anode 11 in the form of a wire, strip or plate, and a cathode array 12 with individual cathodes in the form of rods mounted on a common busbar 13 to form a comb. All the array gaps are of equal length and a separate priming gap 14 consisting of auxiliary cathode 13A and auxiliary anode 11A is included in the tube for stabilization and to control the ionization level of the tube and is adapted to prime a starting gap 15 at the left-hand end of the array. A separate cathode 16 is provided at the other end and is spaced similarly to the other array gaps as regards both gap length and separation from its neighbor. The gas filling may be the neon, argon, hydrogen mixture previously mentioned; the gap dimensions then depend upon the required operating conditions and will be suggested later on. Tube 17, is similar in function to tube 10, but rather different electrode arrangements are shown. Anode 18 is again a wire, strip or plate, but cathode array 19 is comprised of a serrated metallic strip, coated with alumina or similar substance except at the tips of the saw teeth. At one end, the first tooth 19A on 19 cooperates with a separate anode 18A to provide a priming gap 20 and which gap controls the ionization level of the tube and primes the starting gap 21. At the other end, a separate cathode 22 is provided, similarly to 16 in tube 10. Cathode arrays 12 and 19 are shown connected to ground and anodes 11 and 18 are connected via separate leads 23 and 24 to the respective side contacts of a non-biased bank *a1* of polarized relay A which has opposed windings. Leads 23 and 24 are also connected through individual pulse blocking chokes 25 and 25' to the side contacts of bank *a2* of relay A and through leak resistances 26, 26' to ground. With the armatures of *a1* and *a2* in the position shown, anode 11 is connected through condenser 27 to pulse input terminal 28 and through choke 25' to the positive pole of battery 29, the negative pole of which is grounded. Anode 18 of tube 17 is open circuited except for its leak connection via resistor 26 to ground. Priming gaps 14 and 20 are connected through variable resistances 30 and 31 respectively across batteries 32 and 33. The output cathodes 16 and 22 are connected through the opposing windings of relay A to a message register 34. It should be emphasised that relay A and message register

34 are merely convenient designations for circuits having similar functions which would in practice be electronic in nature, or comprise circuits employing further sequence discharge or other cold cathode tubes. Similarly the battery 29 is to be regarded as symbolic of any convenient voltage regulated source and should include discharge current limiting means.

The operation of the circuit is as follows. Battery 29 should supply sufficient and constant voltage to maintain discharges at the array gaps of tubes 10 and 17 without, however, causing any gap to fire other than the starting gap, except when pulses from terminal 28 are applied to the respective anodes and then only if gaps 14 and 20 are discharging by reason of the potentials thereacross furnished by batteries 32 and 33, respectively. Resistances 30 and 31 may be adjusted to control the priming currents of gaps 14 and 20. Assume now, that positive pulses are applied to terminal 28, the relay contacts at a_1 and a_2 being in the condition indicated in the figure. The first pulse will fire gap 15, which will remain discharging under the influence of the maintaining voltage from battery 29 after the pulse has passed. By the time the second pulse arrives, the energy level at the next gap is that due to the sum of the ionization potentials from the priming discharge at 14, the discharge recently started at gap 15, together with the voltage from battery 29; the spacings between gaps must be arranged so that either the ionization from gap 15 has not had time to be fully effective at the third and subsequent gaps. These gaps are sufficiently far removed for the ionization coupling from gap 15 to be too small to prime them; this matter will be discussed again further on. The gap spacings, then, being suitably arranged, the second pulse will fire the gap adjacent to 15, the third pulse will fire the next gap, and so on until discharge occurs at cathode 16. The discharge current through cathode 16 actuates relay A and also message register 34 so that the completion of the first discharge sequence is recorded. Due to the operation of relay A, anode 11 is disconnected from terminal 28 and battery 29; discharges at all gaps of tube 10, except the priming gap 14, will thus collapse, but some time must elapse before the ionization levels have returned to their initial values prior to the discharge sequence. To allow for deionization in tube 10 without interruption of the pulse recording process, tube 17 takes over until the discharge reaches cathode 22, when relay A will operate to isolate tube 17 and to reconnect tube 10 and at the same time message register 34 will be advanced one count.

As stated above, the spacings between gaps must be arranged to suit the pulse repetition rate. For a high counting rate, if the gaps are too far apart, the ionization from one discharge will not have had time to reach the adjacent gap before the arrival of the next pulse. On the other hand, if the spacings are too close it is possible for the total gap energy to build up to a value such that the battery voltage is sufficient to fire gaps without any added pulse voltage. In general, I may say that, for a given gas mixture and pressure, for a given gap spacing, and with rectangular pulses of given width, a tube can be made to function satisfactorily for all counting rates up to a certain maximum, but if the inter-pulse interval is never more than a given time, then the counting rate may be increased to a higher maximum which depends upon that given time.

Using nickel electrodes and the gas mixture and pressure mentioned above, I find that the design data given below results in optimum tube and circuit tolerances.

Anode-cathode spacing	2 mm.
Striking voltage	V_S=300 volts
Maintaining voltage	V_M=185 volts
Maximum pulse repetition frequency	100 kc./s., 60 kc./s., 40 kc./s.
Cathode-cathode spacing (including priming cathode)	2 mm., 3 mm., 5 mm.

These counting rates were obtained using a stabilized maintaining battery voltage of 195 volts measured between anode and cathode, rectangular pulses of 1 μ sec. duration and 40–50 volts amplitude, and discharge currents of 1 ma. per cathode, including priming cathode.

It will be evident that several alternative electrode arrangements besides those so far specifically mentioned are possible in sequence discharge tubes. Furthermore, although the tubes represented in Figs. 1 and 4 are shown with 10 counting gaps, many more gaps may be provided. It is envisaged that tubes having one hundred or more gaps in an array will be used, possibly with smaller gap spacings and higher gas pressures, to enable the electrodes to be fitted into envelopes of sizes comparable with ordinary radio receiving tubes.

In Fig. 7 a practical embodiment of an eight point counting tube with separate cathodes is shown. The tube 35 comprises a normal glass envelope 36 sealed to a conventional 8-pin glass base 37 and is filled with the neon, argon, hydrogen mixture previously mentioned. The electrodes are carried on an insulating member 38 made of lavite or other suitable material. Member 38 comprises a central cylindrical rod 39 joining parallel circular discs 40 and 41 at their centers. The electrodes comprise a set of eight nickel wires forming cathodes 42 secured perpendicularly through disc 41 around a circle near the circumference of the disc. Except for one slightly wider spacing, separating the first and last cathodes of the array, the cathodes are all substantially equally spaced. Disc 40 carries a similar set of wires forming anodes 43. Corresponding anode and cathode wires are in line with each other and form an array of gaps of equal length. Cathode wires 42 are secured on the lower side of the disc 41 to supporting wires 44 securing them to respective contact pins 45 sealed in the glass base 37 and serving to support the whole electrode structure and member 38. The anode wires 43 are joined together on the upper side of disc 40 by a common bus lead 43A which is connected by lead 46 to the top cap 47 of the tube. To restrict discharges to the ends of wires 42, these wires are coated with alumina except at the tips.

One mode of operation for tube 35 is shown in Fig. 8 in which the individual cathodes 42 of Fig. 7 are represented by the circles 50, 51 . . . 57, the corresponding anodes by the circles 43 drawn for convenience in the same plane. Anodes 43 are connected to a stabilized voltage supply represented by battery and choke 58, and also through a resistance 59, and blocking condenser 60 to pulse input terminal 61. Cathode 50 is connected as a priming cathode through variable resistance 62 to a source of potential represented by battery 63.

The cathode-cathode spacings 50—51—52 . . . 57 are all substantially equal, but the spacing