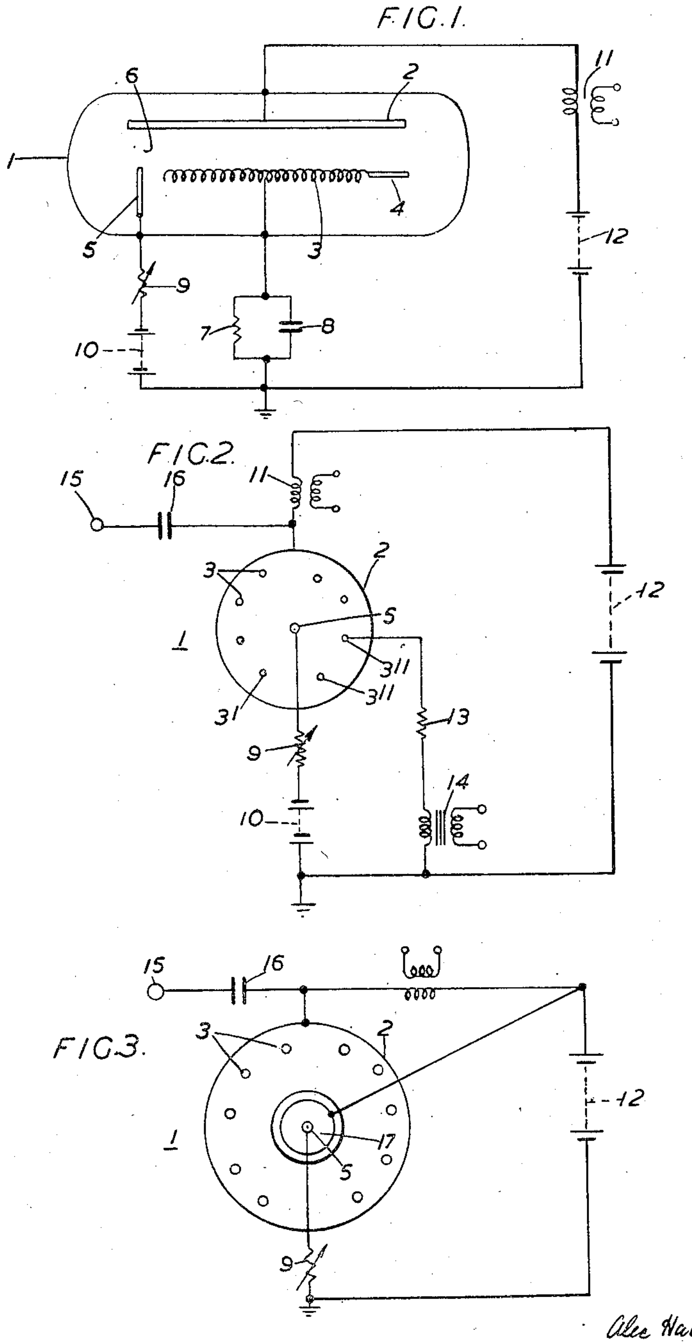
Aug. 29, 1950 A. H. REEVES 2,520,171

ELECTRIC DISCHARGE DEVICE

Filed April 5, 1948 3 Sheets-Sheet 1

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ELECTRIC DISCHARGE DEVICE

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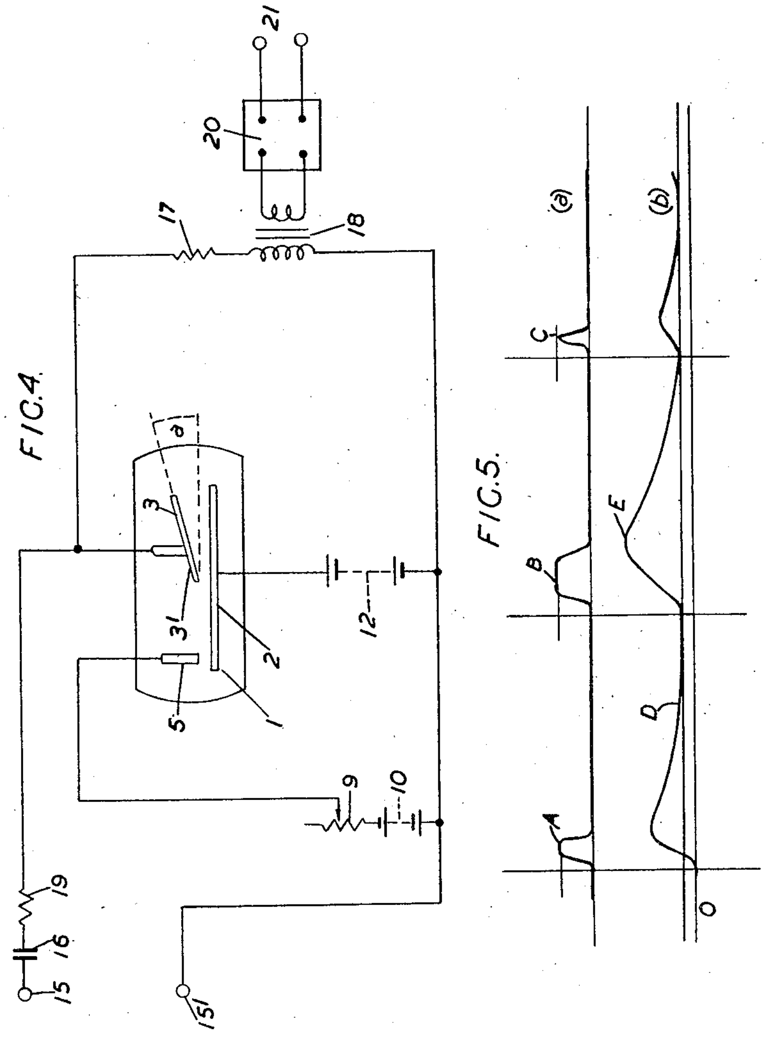


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ELECTRIC DISCHARGE DEVICE

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FIG. 6.

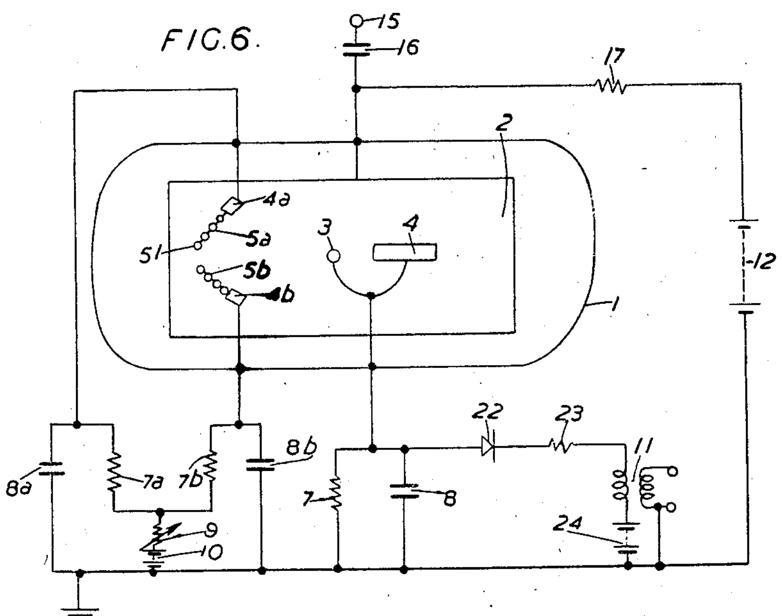



FIG. 8.

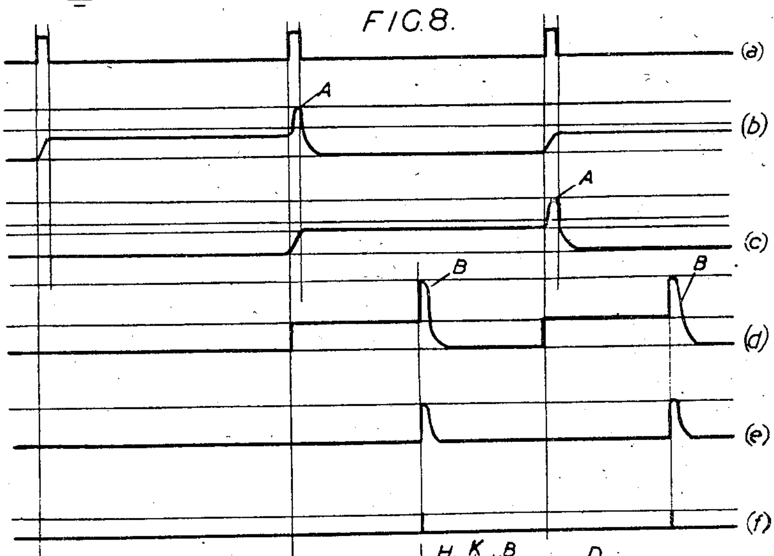



FIG. 7.

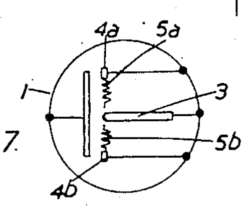
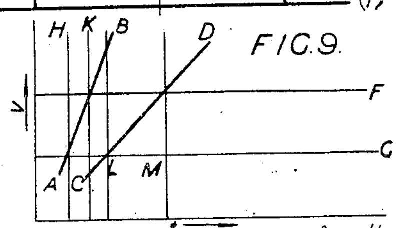



FIG. 9.

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Patented Aug. 29, 1950 2,520,171

# UNITED STATES PATENT OFFICE

2,520,171

## ELECTRIC DISCHARGE DEVICE

Alec Harley Reeves, London, England, assignor to International Standard Electric Corporation, New York, N. Y., a corporation of Delaware

Application April 5, 1948, Serial No. 19,084
In Great Britain May 5, 1947

14 Claims. (Cl. 315—261)

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The present invention relates to cold cathode electric discharge tubes of the sequence discharge and related types and is particularly concerned with means for adjusting the ionisation level in such tubes.

The meaning of the term "sequence discharge type" and the other terms used in this specification will become apparent in the following discussion of the general principles of these tubes.

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 and its state of ionisation, 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 deionised. As the voltage is increased the molecules of the gas becomes ionized until eventually a discharge is set up with a rapid increase in current flow which may typically rise from microamps to milliamps at a critical voltage which is the "striking" or "firing" voltage for the discharge gap. The discharge is characterised by a glow which at first appears at the cathode and may extend to the anode and beyond the immediate neighborhood of the gap, depending upon the degree of ionisation. When once a discharge has been established the interelectrode voltage tends to fall and becomes to a large extent independent of the discharge current. This approximately constant voltage is called the "maintaining" voltage. Thus in the familiar neon tubes used as voltage regulators and the like, the striking potential may be of the order of 100 volts or more, but the maintaining voltage tends to be constant in the region of 80 volts.

Ions and electrons tend to migrate from the immediate neighbourhood of the discharge. This phenomenon has been extensively used to lower the striking potential of another discharge gap in the same tube envelope. In one known device there is provided a main discharge gap between main anode and a cathode 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 ionisation coupling.

It is also well known that whereas when striking voltage is applied to a gap, ionisation takes place in a very short time, measured in microseconds, if the voltage across a discharging gap be removed, deionisation is not complete until after a substantial period of time which may often amount to milliseconds.

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In my copending application Ser. No. 763,655, filed July 25, 1947, the phenomenon of ionisation coupling is utilised to provide a cold cathode discharge tube having an ordered array of gaps in which the "starting" gap is arranged to have a lowered striking voltage than the remainder so that a recurrent voltage applied to each gap in turn or to all gaps together fires first the starting gap and then the remainder in order. Due to the finite deionising time, it is not necessary that a priming gap be discharging simultaneously with the application of the recurrent voltage to a neighbouring gap. Thus such a "sequence discharge tube," as it may be called, may be operated by a train of pulses applied between a common anode in the form of a plate or wire and an array of cathodes, each mounted independently, or forming the hills of a corrugated plate facing the anode, or, perhaps, taking the form of rods mounted upon a common plate or wire like the teeth of a comb, and having the gap length for a given gap, usually the first, shorter than the remainder. Then the first or starting gap may be fired by the first pulse, while the second pulse reignites the starting gap and the next adjacent gap simultaneously. The third pulse will fire the first three gaps and so on. On the other hand, if a maintaining battery be connected across the gaps, once fired each gap will remain discharging indefinitely. Thus such a sequence discharge tube has been used, with suitable circuits to extract the information and to restore the initial conditions as to ionisation, as a counter or/and as an information storage device.

Applicant has found with high ionisation coupling that the striking voltage of a gap may be reduced to or even below the maintaining voltage so that ionisation spread from a discharge proceeds at a definite rate, depending upon the conditions in the discharge tube. These phenomena have been utilised to provide sequence discharge tubes in which, after discharge has been established at a starting gap, the other gaps of an array may be made to fire automatically in order at definite time intervals, thus providing means for generating pulse trains. Sequence discharge tubes utilising the time aspect of ionisation migration form the subject matter of my copending application bearing Serial No. 14,184, filed March 11, 1948.

We have found that the rate of spread of ionisation from a discharging gap depends, inter alia, upon the discharge current passed. Thus the amount by which the striking potential of a neighbouring gap is reduced, and the rate of such reduction, depends in part upon the priming discharge current. In the past it has been proposed to stabilise the operation of electric discharge tubes for illumination purposes by regulating the general level of ionisation in the tube, by means of an auxiliary discharge which is maintained continuously. The present invention is primarily concerned with the use of such an auxiliary discharge to regulate the ionisation level in sequence discharge and related tubes, and thus to alter in some cases their mode of operation, or again to effect the time constants of the discharges.

According to one aspect, the invention provides a cold cathode gas filled electric discharge tube comprising a plurality of main discharge gaps forming an ordered array, and one or more auxiliary discharge gaps placed in relation to one or more of the main gaps in such manner as to permit regulation of the ionisation level at the said one or more of the main gaps by the maintenance of a discharge at the auxiliary gap or gaps.

According to another aspect, the invention provides a cold cathode gas filled electric discharge tube comprising one or more main discharge gaps and a sequence of auxiliary discharge gaps so placed in relation to the main gap or gaps as to permit a variable control of the ionisation level at the main discharge gap or gaps in accordance with the number of auxiliary gaps which are discharging.

According to still another aspect the invention provides a cold cathode gas filled electric discharge tube comprising electrodes forming an extended discharge gap along which a discharge is adapted to spread, and one or more auxiliary discharge gaps so placed in relation to the said electrodes as to permit regulation of the ionisation level in the neighbourhood of the said electrodes by the maintenance of a discharge across the auxiliary discharge gap or gaps.

The invention also covers circuit arrangements which include means for producing ionisation control, discharges across the auxiliary discharge gaps of such tubes.

For brevity we shall refer to these auxiliary gaps and discharges as priming gaps or priming discharges.

The nature of the invention as regards the above aspect and others to be discussed later will be more easily understood from the following description of embodiments of the present invention having reference to the accompanying drawings in which like parts, in the different figures are indicated by like reference numerals and in which:

Fig. 1 is a diagrammatic drawing of a device according to the present invention connected in a simple utilisation circuit.

Fig. 2 illustrates another form of sequence discharge tube used as a generator of pulse trains in a multichannel pulse modulation system.

Fig. 3 shows an alternative arrangement to that of Fig. 2.

Fig. 4 shows another type of device and circuit utilising the invention.

Fig. 5 shows explanatory curves relating to the circuit of Fig. 4.

Fig. 6 shows a further type of device and circuit utilising the invention.



Fig. 7 shows the electrode arrangement of the device of Fig. 6.

Figs. 8 and 9 show explanatory curves in connection with the circuit of Fig. 6.

It has been explained above that in the gap arrays of sequence discharge devices it is usual to provide a starting gap by making this gap of shorter length than the remainder of the gaps of the array. In Fig. 1 a device 1 is shown in which the starting gap may be of the same length as the others. The device 1 comprises an anode 2 in the form of a smooth plate or rod and a cathode formed as a wire helix. Except for a narrow strip facing the anode, the helix is coated with material, such as alumina, which inhibits the spread of cathode glow around the turns of the wire and confines the glow to the uncoated portions. Thus each turn of the helix forms a separate discharge gap with anode 2. The right hand end of the helix terminates in a length of smooth rod 4 which forms an extinguishing squeg tab as described in my copending application bearing Serial No. 19,083, filed April 5, 1948, and whose function is explained below. Near the other end of the helix an independent cathode 5 is provided to form with anode 2 a priming gap 6. Cathode 3 is connected to ground through resistance 7 shunted by condenser 8. Cathode 5 is connected via variable resistance 9 to the negative pole of battery 10, whose positive pole is connected to ground. Anode 2 is taken via the primary winding of pulse transformer 11 to the positive pole of battery 12 whose negative pole is connected to ground.

The voltage of battery 12 is insufficient to initiate a discharge from any cathode but is sufficient to maintain any or all discharges from cathode 3. Battery 10 assists battery 12 in initiating and maintaining permanently a priming discharge at gap 6, the discharge current being regulated by resistance 9. Assuming that the gas in device 1 is in a deionized condition and that battery 10 is put into circuit a continuous discharge will commonce at gap 6. With suitable spacings, gas pressure and other conditions as described in the above-mentioned application bearing Serial No. 14,184, after a definite time the striking potential for the first gap formed by cathode 3 will be reduced to the voltage of battery 12 and a discharge will be set up across to anode 2. After a further time interval the next gap formed by the turns of the helix will fire, and then the next in order from left to right. The total current through the primary of transformer 11 will then increase in steps separated by definite time intervals. Hence a train of voltage pulses will appear at the secondary terminals of transformer 11. When the cathode glow reaches the smooth rod 4, the total discharge current rises rapidly but the resistance 7 limits the discharge current to a value insufficient to produce enough ionisation to maintain the increased discharge. Hence all discharges from cathode 3 will be extinguished and de-ionisation will set in until the charge on condenser 8 has leaked away sufficiently through resistance 7, when the sequence of discharge will be recommenced from the left hand end of cathode 3 which is nearest to the ion source 6.

It will be seen that the priming gap 6 ensured that the left hand turn of the helix 3 functions as a starting gap. Furthermore the variation in the amount of current passed by the priming discharge when the resistance 9 is varied will affect the rate of spread of ionisation throughout the tube. In the position shown in Fig. 1, however, the priming discharge has a greater effect at the left hand end of the cathode arrays. In certain types of sequence discharge tube it may be advantageous to provide each individual main gap with an auxiliary priming gap to control the general ionisation level throughout the tube. Alternatively the main gap array may be arranged symmetrically about the priming gap.

An increase in the general ionisation level in a sequence discharge tube has four principal effects on the gaps of the main array:

1. A reduction of the minimum striking voltage.
2. A reduction of the difference between the striking and maintaining voltages;
3. A reduction in the minimum extinguishing time; and
4. An increase in the rate of spread of cathode glow along each cathode when the discharge is struck.

Effect No. 2 is very useful when it is desired to reduce the interval between pulse trains in a pulse train generator such as described above, while effect No. 4 may be utilised, for example, in a pulse time modulated signalling system to determine the relation between signal voltage and the resulting time modulation, and can be used to adjust this relation.

As an example of this aspect of the invention the case, illustrated in Fig. 2 may be considered in which device **1** comprising a circular anode plate **2**, and an array of separate cathodes **3** formed by rods mounted normally to the plane of anode plate **2** symmetrically about an auxiliary cathode rod **5**. All the cathodes **3** except that indicated **3'** form gaps of equal length with anode **2**. Sufficient distance is provided between cathodes **3'** and **3''** to ensure that the discharge sequence shall proceed clockwise around the tube with **3''** being the last cathode to fire. Each cathode rod is connected to ground through a limiting resistance and the secondary of a speech transformer associated with a respective separate speech channel. To avoid complicating the drawing, only one cathode **3''** is shown connected to its limiting resistance **13** and transformer **14**. Connections to the auxiliary cathode **5** and anode **2** are similar to those previously described in connection with Fig. 1, except that a further connection is made from the anode to terminal **15** through blocking condenser **16**.

A master pulse generator (not shown) is connected to terminal **15** and supplies positive starting pulses and negative extinguishing pulses to the anode. The starting pulse is arranged to fire the first gap from cathode **3'**. Assuming that no speech currents are flowing in any of the transformers **14**, a train of equally time-spaced pulses will be obtained from the secondary of transformer **11**. After the last cathode **3''** has fired, an extinguishing pulse is applied at terminal **15** and quenches all the discharges except that from the priming cathode **5**. In the presence of speech currents in the primary of a transformer **14**, however, the potential of the associated cathode varies in accordance with the speech, so that the time of firing is retarded or advanced. Furthermore, the unmodulated position of each pulse will depend upon the time positions of all the preceding pulses in the train and therefore depends upon the modulation of the previous channel pulses. In consequence the output of transformer **11** will consist of trains of pulse-period modulated pulses of the type disclosed in copending application Ser. No. 756,262, filed June 21, 1947. The "depth of modulation" of the pulse may be adjusted by control of the priming discharge current by means of variable resistance **9**.



As an alternative to the device of Fig. 2, the device illustrated diagrammatically in Fig. 3 may be used. The arrangement is similar to that of Fig. 2 except that an auxiliary anode **17**, in the form of a disc insulated from anode **2**, which is now annular, co-operates with cathode **5**. The battery **10** of Fig. 2 may be omitted.

As applied to a discharge device comprising a pair of smooth opposed electrodes forming the main discharge gaps, an embodiment of the invention is illustrated in Fig. 4 which is concerned with a device and circuit for de-modulating a pulse modulated signal and forming part of the subject matter of my copending application bearing Serial No. 14,185, filed March 11, 1948.

In a multichannel electric pulse communication system, the usual method of demodulating pulses which are signal modulated either as to amplitude, duration, or time of occurrence, is to pass the pulses of a given channel, or pulses derived from them, through a low pass filter. As the pulse durations are usually very small compared with the repetition period, this method has the serious disadvantage of giving an output power very small compared with the pulse input peak power (unless a valve amplifier is used, which is often to be avoided). The circuit shown in Fig. 4 gives an output power comparable with the peak input power, without hot-cathode valve amplifiers. For a 100 channel system, this may give an output power gain of up to 10,000 over the usual system.

In Fig. 4 the circuit comprises a tube **1** containing a gas, or suitable mixture of gases, at a suitable pressure. **2** is an anode, which may be, for example, a rod, flat strip or flat plate, connected to the positive terminal of battery **12**. **3** is a cathode which may also be a rod, strip or plate, connected to the negative terminal of battery **12** through resistance **17** and one winding of transformer **18**. **3** is set at an angle *a* with respect to the anode **2**. **5** is an extra ionisation control cathode, at a suitable distance from **2**, and connected to the negative terminal of **12** through variable resistance **9** to the negative terminal of battery **10** the positive terminal of which is connected to the negative terminal of battery **12**. This auxiliary battery **10** provides an increased potential for the gap between **2** and **5**, so that a permanent discharge is produced in this gap.

The pulses to be demodulated are applied between terminals **15** and **15'** through blocking condenser **16** and decoupling resistor **19**, to the cathode **3** in such a sense as to make **3** more negative with respect to **2**. The potential of battery **12**, the nature and pressure of the gas, the nature of the electrode surfaces, and the smallest gap at end **3'** between cathode **3** and anode **2**, are arranged so that in the absence of pulses at **15**, a glow discharge is not struck at the end **3'** to the anode **2** but the pulse voltage at **15** is adjusted so that when the pulse arrives, a glow discharge does occur between **3** and **2**. This discharge will first strike at end **3'** of **3**.

For the duration of the pulse, the ionisation will spread rapidly from the end **3'** along the surface of **3** from left to right, at a speed depending chiefly on the gas constants, the sum of the pulse voltage and the voltage of battery

12, resistance 17, angle $a$, the degree of roughness of cathode surface 3, the control current between cathode 5 and 2, and the spacing between 5 and 3. These various constants are adjusted so that a modulated pulse of maximum duration or of maximum amplitude just enables the glow to spread over the whole length of cathode 3 before the pulse disappears.

If then the modulated pulse has less than this maximum value of amplitude or duration, the glow will not have had time to cover the surface of 3 completely on disappearance of this pulse: experiment and theory both show that the rate of spread is definite quantity. Theory and experiment also show that on disappearance of the pulse the glow may be made to collapse again, and to remain only at the end 3'; and furthermore the rate of collapse may be made slower than the rate of spread during the period of the applied pulse. The collapse rate may generally be made such that for a pulse of maximum amplitude or duration the collapse is only just completed when the following pulse arrives. The principles involved in a device of this type are discussed in my copending application bearing Serial No. 15,582, filed March 18, 1948. It will be understood that the plate 3 may be corrugated or serrated to provide an array of separate gaps of increasing length.

The process is illustrated in the curves of Fig. 5. Curve $a$ shows three successive input pulses A, B and C of different duration and curve $b$ shows the corresponding variations of the current flowing to the cathode 3.

As shown by curve $b$ the cathode current corresponding to input pulse A rises rapidly from zero during the period of the pulse, and then falls slowly to a small steady value at D, continuing at the value of D until the arrival of the second pulse B of Fig. 5, $a$. During the period of the second pulse the current through 3 rises again to a higher value E as the input pulse is longer. It then falls again but to the value D, before the third input pulse C arrives. This third pulse causes the cathode current to rise again rapidly to a smaller value, as this third pulse is shorter than the first. The current then collapses gradually again, the rapid rise and slow collapse occur indefinitely as long as the input pulses occur.

The current from cathode 3 flows through transformer 18, of which the secondary winding is connected through a low-pass filter 20 to the output terminals 21. If 20 is arranged to pass the modulating signal frequencies but not the pulse frequencies, terminals 21 will receive the signal frequency components of the fluctuations of the total area of the curves of Fig. 5, $b$. The average area may for example, correspond to an average power of the order of $\frac{1}{15}$ of the peak pulse input power. In the usual demodulation system, in the case of 100 channels, the average output power, about which the signal fluctuations take place, will be only about $^1/_{4,000}$ of the peak input power. The present system thus has a relative power gain in this case of the order of 2,500.

In the example just described the priming discharge not only stabilises the operation of the tube, but acts as a variable volume control, determining the relation between the maximum input pulse width and the peak output power. The priming discharge has been used to control inter alia the amplitude of derived pulses. In this and the preceding example the priming discharge has been continuous. There is no reason, however, why the priming discharge may not itself consist of recurrent pulse trains, and instead of one priming gap an ordered array of gaps permitting a sequence discharge may be used to control the mean ionisation level in a discharge device.



As an example of this aspect of the invention, the circuit of Fig. 6 illustrates a method of obtaining a derived train of pulses, corresponding in time relationship with an applied train but with each derived pulse delayed by an adjustable time period from its corresponding input pulse. The device of Fig. 6 comprises an anode plate 2 and a main cathode 3, in a form of a rod mounted normally to the plane of the anode. Cathode 3 is joined to an extinguishing cathode 4 which is a flat plate mounted parallel to the anode 2 but closer to it than the tip of cathode 3. Mounted symmetrically with respect to the line joining the projection of 3 and 4 on the anode but nearer 3 than 4, are two auxiliary cathode arrays 5$a$, 5$b$ forming priming cathodes. Each of 5$a$ and 5$b$ comprises a comblike or serrated electrode with all projections except an end one 5' on 5$a$ forming gaps with 2 of the same length as formed by cathode rod 3. The arrangement is indicated more clearly in Fig. 7, in which electrode 4 has been omitted for clarity. The cathode arrays 5$a$ and 5$b$ are formed with extinguishing squeg tabs 4$a$ and 4$b$ such as described in my above-mentioned copending application bearing Serial No. 19,083 comprises smooth elongations of the array electrodes at their mutually remote ends. The priming cathodes are taken to ground through respective resistances 7$a$ and 7$b$, a variable resistance 9 and battery 10 and also through the respective condensers 8$a$ and 8$b$. Anode 2 is connected to input pulse terminal 15 via blocking condenser 16 and also via resistance 17 to the positive terminal of battery 12 whose negative terminal is connected to ground. Cathodes 3 and 4 are taken to ground through resistance 7 and condenser 8 in parallel. The primary winding of an output pulse transformer 11 in series with rectifier 22, resistance 23 and biassing battery 24 is connected across resistance 7. Condenser 8, which need only be a few micro-microfarads in capacity, is not large enough to shunt the output transformer circuit to any appreciable extent. The function of the components 22, 23 and 24 is to pass only the peaks of pulses to the output transformer 11. The voltages of batteries 10 and 12 are adjusted so that, while a discharge may be maintained from the cathodes 3 and 4 or from the projections of 5$a$ and 5$b$, no discharge may be initiated except on application of a positive pulse to terminal 15. Pulses to be applied to 15 are limited so that the joint voltage of both batteries plus input pulse may initiate a discharge from starting cathode 5', but from no other when the tube 1 is in a deionised state.

When a pulse is applied at terminal 15, a discharge will be initiated at 5' and glow will spread from point to point of 5$a$ to a number of cathode projections depending upon the amplitude and duration of the applied pulse and also upon this priming discharge current as regulated by battery 10 and resistor 9. After the pulse has passed, the discharge glow will remain stationary on the points of 5$a$ until a second pulse arrives. The next pulse will continue the discharge sequence further along 5$a$ so that extinguishing tab 4$a$

discharges. Due to the resistances 7a and 9, and battery 10, a squeg occurs and extinguishes all discharges in the manner discussed in my above-mentioned copending application bearing Serial No. 19,083. At the time, however, that the second pulse arrives at 15, ionisation migration from the neighbourhood of 5a will have primed the nearest gap associated with 5b; hence this second pulse will initiate a sequence of discharges on 5b which will be similar in character to that described above for 5a. The pulse trains involved are depicted in Fig. 8, in which curve *a* shows the pulses applied at terminal 15, curves *b* and *c* respectively the discharge currents from 5a and 5b with the discontinuous step by step rise of current smoothed out, but the extinguishing pulse shown at A. It will be appreciated that the mean discharge current through 5a and 5b may be regulated by resistance 9 and hence the general ionisation level in the tube—and particularly in the neighbourhood of cathodes 3 and 4. The discharge arrays of 5a and 5b thus furnish priming arrays for the gaps at 3 and 4.

Because of the ionisation coupling from the priming arrays, when the second pulse is applied to terminal 15, cathode 3 will fire, and it will remain discharging after the pulse has passed. Depending upon the amplitude and duration of the applied pulse and upon the general ionisation level in the tube, cathode glow will travel along rod 3 more or less rapidly as explained in for example, my above-mentioned application bearing Serial No. 15,582. The glow is prevented from travelling along the wire connecting 3 and 4 by coating it with alumina, or by making the connections externally of the tube envelope. After a further time, but before the arrival of the third pulse, extinguishing cathode 4 will start to discharge. As its projected surface area on anode 2 is so much greater than that of the rod 3, the cathode current will rise suddenly and set up a squeg due to the resistance 7 thus extinguishing the discharge from both cathodes. On arrival of the next pulse the sequence will be repeated. The curve of current passed by 3 and 4 will be similar to curve *d* of Fig. 8.

Due to the biassing circuit, 22, 23, and 24, only the peaks B will be passed through the primary of transformer 11, as shown by curve *e* whilst if it will be a differentiating transformer, the secondary voltage will consist of short pulses as shown by curve *f* of Fig. 8.

There will appear at the output terminals of transformer 11 a series of pulses having similar time intervals between them as those of the input train applied to terminal 15, but delayed by a constant time interval which depends upon the priming discharge current. Thus in effect we have here a pulse delay network the delay period of which may be varied by changing the priming discharge current.

It should be pointed out in connection with the above circuit, that it may be found necessary, due to the somewhat large current variations associated with the discharges to provide voltage stabilising circuits, for example, of the kind described in my copending application bearing Serial No. 19,086, filed April 4, 1948, now abandoned, which in order to simplify the drawing and circuit explanation, have not been shown.

In the foregoing discussion of the circuit of Fig. 6 we have directed attention to the time interval between the application of a pulse at terminal 15 and the onset of a squeg discharge at cathode 4 and have considered the circuit as a pulse time delay network. If we consider the time intervals between the commencement of discharge from cathode 3 and the squeg discharge of cathode 4, a further aspect of the priming discharge ionisation level control and another use for the tube of Fig. 6 will become apparent. If, as stated above, cathode 3 is in the form of a rod, and if the cylindrical surface of the rod be made smooth, then it can be considered that cathode 3 has a smooth surface inclined at an angle of 90 degrees to the anode plate 2. In my above-mentioned copending application bearing Serial No. 15,582 we have pointed out that for smooth opposed electrodes, cathode glow will spread along the surface of the cathode at a rate depending, inter alia, upon the applied voltage. Now the priming of the adjacent squeg gap (cathode 4-anode 2) will depend to a large extent upon the amount of cathode glow on cathode 3 as well as upon the ionisation level due to the priming discharge at 5a and 5b. Hence if a speech transformer be inserted between resistance 7 and ground, speech voltages will modify the glow spread on 3 and hence the time interval between the commencement of discharges on the two cathodes 3 and 4. Furthermore the law relating applied speech voltage and resulting time modulation of the output pulses may be controlled by adjusting the inclination and surface shape of cathode 3 to anode 2, so that we shall now remove the restriction that they be mutually perpendicular. Assuming a linear modulation law, two curves illustrating the relationship between total cathode-anode voltage $v$ and time interval $t$ between firing of cathodes 3 and 4 is shown in Fig. 9. The two curves refer to two different states of ionisation as determined by the priming discharges of 5a and 5b. Let the momentary speech voltage bring the voltage $v$ to some ordinate between F and G. Then on curve AB the time interval $t$ will vary between H and K, while on curve CD, corresponding to a smaller priming current at 5a and 5b, the same variation in $v$ produces a larger, but still linear variation of $t$. Hence device 1 may be used as a modulator with a "gain" or modulation factor control provided by the priming discharge current 5a and 5b.

A further modification of the circuit of Fig. 6 and described fully in my copending application Ser. No. 24,953, filed May 4, 1948, now abandoned, may be made by rectifying a part of the modulating speech voltages and applying the smoothed voltage in series with battery 10—or even replacing. The latter the "gain" control is thus automatic. As described above, cathodes 5a and 5b are serrated and parallel to anode 2. The gain control thus proceeds in steps which may be made to follow any desired law. It will be evident that many modifications may be made in the arrangement and shape of the priming arrays, thus in some circumstances it may be convenient to incline them to the anode 2, or even to make them smooth. If the latter case, however, the glow would tend to collapse down to the shortest gap after passage of the input pulses at terminal 15.

I claim:

1. A cold cathode gas filled electric discharge tube comprising a plurality of main electrodes defining at least one main gap and a plurality of auxiliary electrodes spaced from said main electrodes and defining a source of sequentially firing auxiliary discharge gaps positioned with respect

to said main gap to permit a variable control of the ionisation level at said main discharge gap in accordance with the number of said auxiliary gaps which are discharging.

2. A cold cathode gas filled electric discharge tube comprising a plurality of main electrodes defining a plurality of main discharge gaps and a plurality of auxiliary electrodes spaced from said main electrodes and defining a series of sequential firing auxiliary discharge gaps positioned with respect to said main gaps to permit a variable control of the ionisation level in the neighborhood of at least one of said main gaps in accordance with the number of said auxiliary gaps which are discharging.

3. A cold cathode gas filled electric discharge tube comprising a plurality of cathodes arranged in a circle, a plate anode co-operating with the said cathodes to form a sequence of discharge gaps, and ionisation level control electrode means spaced from said anode and said cathodes and defining an auxiliary discharge gap placed at the center of the circle for controlling the ionisation level in the neighborhood of said cathodes by the maintenance of a discharge across the auxiliary gap.

4. A discharge tube according to claim 3 in which the auxiliary discharge gap is constituted by an additional cathode co-operating with the said anode.

5. A discharge tube according to claim 3 in which the said anode is annular in form, and in which the auxiliary discharge gap is constituted by an additional cathode co-operating with an additional circular anode arranged in the circular space at the centre of the annular anode.

6. A cold cathode gas filled electric discharge tube comprising two electrodes inclined to one another to form a tapered discharge gap, and an ionisation control electrode co-operating with one of the first mentioned electrodes to form an auxiliary discharge gap controlling the ionisation level in the neighborhood of said tapered discharge gap by the maintenance of a discharge across said auxiliary gap.

7. A discharge tube according to claim 6 in which the said further electrode is arranged adjacent to the smaller end of the tapered discharge gap.

8. A discharge tube according to claim 6 in which one of the first mentioned electrodes is corrugated or serrated.

9. A discharge tube according to claim 6 in which one of the main cathodes comprises a rod arranged perpendicularly to the anode, and the other comprises a plate arranged parallel thereto, the two cathodes being connected together.

10. A discharge tube according to claim 6 in which each array of auxiliary cathodes has a squeg tab connected at one end thereof.

11. A cold cathode electric discharge tube comprising two main cathodes co-operating with an anode to form two main discharge gaps having an ionisation coupling therebetween, and two similar arrays of auxiliary cathodes co-operating with said anode and symmetrically placed with respect to said main cathodes for controlling the ionisation level in the neighborhood of the main discharge gaps in accordance with the number of auxiliary cathodes which may be discharging.

12. An electric circuit arrangement comprising a cold cathode gas filled electric discharge tube including an anode and a main cathode inclined to one another to define a tapered discharge gap, an ionisation level control cathode positioned adjacent the small end of said tapered gap and spaced from said anode to define an auxiliary discharge gap, a source of potential connected across said anode and main cathode, and voltage means coupled to said ionisation control cathode for establishing a permanent discharge between said anode and said last mentioned cathode to control the level of ionisation in the neighborhood of said tapered gap.

13. An electric circuit arrangement comprising a cold cathode gas filled electric discharge tube including a plurality of electrodes defining two main discharge gaps and ionisation level control electrode means defining a sequence of auxiliary discharge gaps to control the ionisation level in the neighborhood of at least one of said main discharge gaps, and first voltage applying means connected to said plurality of electrodes for applying a maintaining potential across said main gaps of insufficient magnitude to initiate a discharge there-across, and second voltage applying means coupled to said level control means for establishing sequential discharges across said auxiliary gaps effective to fire said main gap after a predetermined delay.

14. An arrangement according to claim 13 further comprising means connected to said second voltage means for adjusting the auxiliary discharge current for the purpose of varying said delay.

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