Aug. 10, 1954 M. J. COHEN 2,686,275

ART OF STORING OR DELAYING THE TRANSMISSION OF ELECTRICAL SIGNALS

Filed March 31, 1951

Fig. 1.

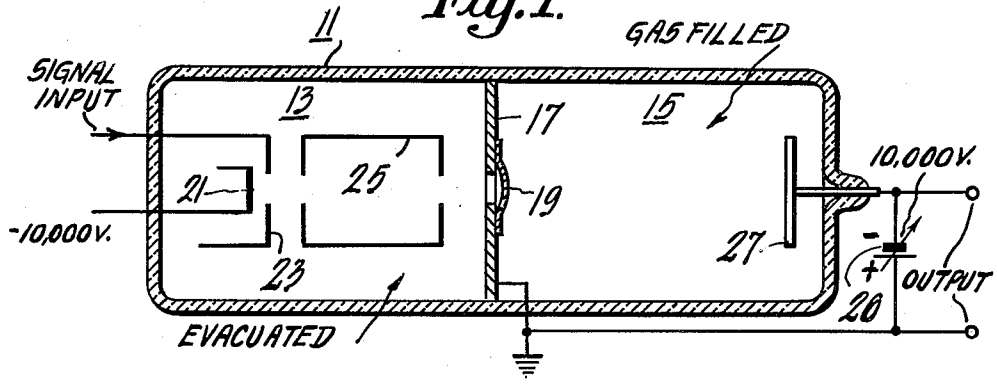


Fig. 4.

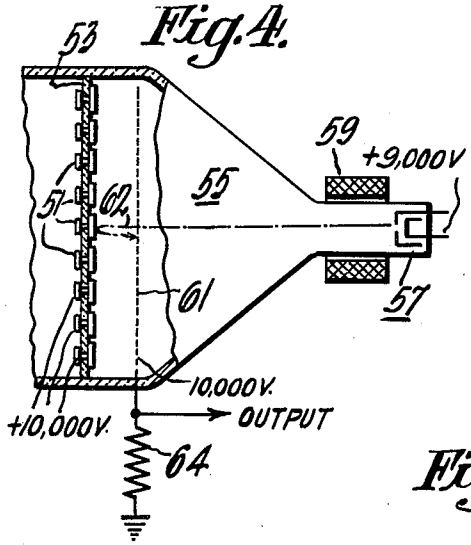


Fig. 2.

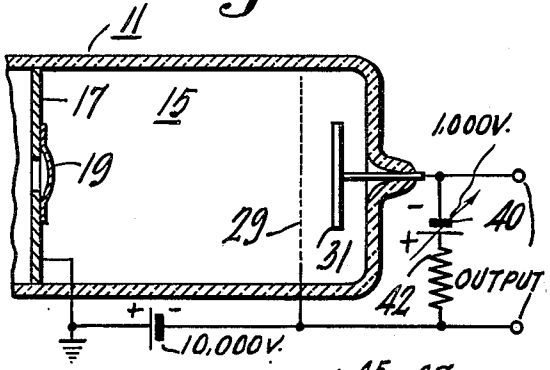
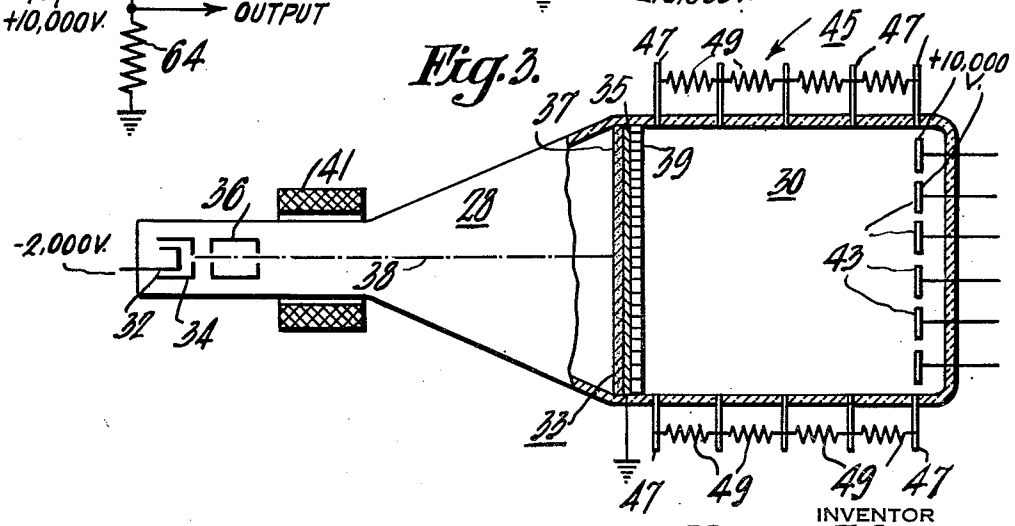


Fig. 3.



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ART OF STORING OR DELAYING THE TRANSMISSION OF ELECTRICAL SIGNALS

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9 Claims. (Cl. 315—10)

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This invention relates to improvements in the art of storing or delaying the transmission of electrical signals.

The prior art offers many examples of storage tubes of the "electro-mechanical" and "electrostatic" varieties. Irrespective of the advantages claimed for a given tube it may be said generally that it possesses certain disadvantages inherent to its class. Thus, if the device is of the "electro-mechanical" variety, its ability to handle electrical signals without distorting them is adversely affected by the necessity of translating the signals into mechanical vibrations, and back again. On the other hand, if a storage device is of the "electrostatic" type its ability to maintain a number of signals in storage is limited by the leakage characteristics of the material (e. g. mica) upon which the signal-bearing electrostatic charges are stored.

Accordingly, the principal object of the present invention is to obviate the foregoing and other less apparent objections to "electro-mechanical" and "electrostatic" types of storage devices and to provide a novel, relatively distortionless, method of and apparatus for storing electrical signals.

Another object of the invention is to provide a storage device having an adjustable storage or delay time, and one capable of handling a multiplicity of discrete signals without "cross-talk" or leakage.

Stated generally, the foregoing and other objects are achieved in accordance with the invention by producing small groups of ions, say at one end of a gas-filled tube, and then collecting the ion groups at the other end after they have travelled the length of the tube. The delay due to the transit time of the ions, and consequently the "memory" or delay time of the tube, depends upon the choice of operating parameters such as; applied voltages, nature and pressure of the transit medium, etc. It may range from a fraction of a second to several seconds, or even longer if output signals are fed back into the input in a continuous process.

The invention is described in greater detail in connection with the accompanying single sheet of drawings wherein:

Fig. 1 is a longitudinal section of a storage device constructed in accordance with the principle of the invention and including an evacuated gun-chamber and a gas-filled storage chamber;

Fig. 2 is a longitudinal section of the "storage" or ionization chamber of the device of Fig. 1, said storage chamber containing an alternative form of output electrode-assembly;

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Fig. 3 is a side view of a tube, cut away in part to show a schematic presentation of the electron gun, and a longitudinal section of the ionization chamber which affords many simultaneous "corridors" of information; and

Fig. 4 is a fragmentary view, partly in section, showing an alternative output electrode assembly for the tube of Fig. 3.

The tube shown in Fig. 1 comprises a gas-tight envelope 11 divided into a first chamber 13 and a second chamber 15 by an hermetically sealed-in wall 17 with an electron permeable window 19.

The wall 17 is constructed of copper so that it may serve as an electrode offering a conductive path to ground. The electron-permeable window 19 is of the Lenard type, i. e. it holds a vacuum but is permeable to an electron beam. It may comprise a thin sheet of aluminum foil. The first chamber 13 is evacuated and contains an electron-beam source comprising: an electron emitter 21, a control electrode 23, and an accelerating and focusing electrode 25. These members are so positioned that the electron beam produced by them is directed toward the electron permeable window 19. The second chamber 15 contains under pressure a pure gas (argon is suitable), and has a collector electrode 27 situated at the opposite end from, and directly in line with, the electron permeable window 19. The pressure of the gas is in the neighborhood of one atmosphere, but it may be varied over wide ranges consistent with other properties and functioning of the tube.

The electron beam from the first chamber 13 travels at sufficient velocity to pass through the window 19 into the second chamber 15 and, by knocking electrons from their orbits within individual gas molecules, produces positive ions in the immediate vicinity of the window 19. The extent of this ionization is explained more fully below under the heading, "Transit Time, Diffusion, etc." The electrons which the beam drives out of the gas molecules are collected on the electrode 17, and the resulting positive ions drift in a substantially straight path through the gas toward the collector electrode 27 under the influence of an electro-static field set up by a source of variable potential, represented by the battery 26, between the wall electrode 17 which is at ground potential and the collector electrode 27 which is at a negative 10,000 volts. The time that it takes these ions to complete their transit through the gas depends upon variable factors and may be calculated by formula in a manner which will be more fully explained below. It is this drift time which introduces into the tube

the delay that makes it useful as a memory device. The electron beam which creates the ions in the chamber 15 is controlled by input signal voltages applied to the control grid 23 of the beam source in chamber 13.

Standard techniques are used to detect the arrival of ions at the collector electrode 27 and derive output signals therefrom, e. g. differentiating circuit external to the tube and not shown in the drawing.

Instead of the single electrode shown in Fig. 1, Fig. 2 shows the combination of a screen electrode 29 and a solid electrode 31 as a signal pickup means. The screen electrode 29 is located slightly in front of the solid electrode 31 in the path of approaching ions. The output from the tube is taken across the resistance 42 in the circuit connecting these two electrodes. This circuit includes a variable source of potential indicated by the 1000 volt battery 40 which keeps the solid electrode 31 more negative than the screen electrode 29. While the ions are in the area between the electron permeable window 19 and the screen electrode 29 there is no signal current in this circuit, but when ions pass through the region between the screen electrode 29 and the solid electrode 31 current flows in the circuit between them and a signal voltage appears across the resistance 42.

The tube shown in Fig. 3 comprises an evacuated compartment 28 and a gas-filled compartment 30. The evacuated compartment 28 has an electron beam source comprising: an electron emitter 32, a control electrode 34 and an accelerating and focusing electrode 36 which function in conventional manner to produce an electron beam 38. The two compartments 28 and 30 are separated by a target electrode 33 which comprises a light-transparent supporting member 35 with a fluorescent coating 37 on the side presented to the beam 38 and a photo emissive coating 39 on the side presented to the ionizable gas. Deflecting elements 41 associated with the evacuated compartment 28 cause the electron beam 38 to scan the fluorescent surface 37 of the target 33.

Instead of the single collector electrode shown in Figs. 1 and 2, this tube has a plurality of collector electrodes 43. Six are shown but any convenient number may be used within limitations which are discussed below under the heading, "Multiplicity of Information."

As the electron beam 38 scans successive areas of the phosphor side 37 of the target electrode 33, it causes the phosphor immediately under electron bombardment to give off light. This light passes through the transparent supporting member 35 and when it arrives at the photo emissive side 39 of the target 33 it causes the photoemissive material in that area to emit electrons which attach themselves to the gas molecules in the immediate vicinity, thereby creating negative ions. These negative ions then drift in separate groups toward the collector electrodes 43 which are at a positive 10,000 volts with respect to the target electrode 33. As the electron beam 38 scans across the target 33, many such paths or "corridors" are activated. The maximum number of "corridors" available depends upon crosstalk due to lateral diffusion of the ionized gas. This lateral diffusion is discussed below under the heading, "Multiplicity of Information."

Because ions travel in a straight line toward the closest electrode of opposite potential under the influences of a uniform potential field, this type of structure can be utilized to provide any number of "corridors" of ion travel and consequently of electrically stored information.

The field in which the ions travel is kept uniform by means of a potential gradient device 45 comprising alternate electrically conducting rings 47 and resistance elements 49. The effect of this device is to divide the potential drop between the target electrode 33 and the collector electrodes 43 into even steps and keep straight the lines of potential gradient between the target 33 and the collector electrodes 43. The rings 47 are embedded into the walls of the chamber 30 so that they have a surface exposed to the interior. An alternative method of securing an even distribution of potential is to coat the inner surface of the envelope with a high resistance conductive material.

The arrival of ions at the collector electrodes 43 may be detected by a differentiating integrating circuit, as mentioned in connection with the description of Fig. 1. Alternatively, a "take-off" cathode ray beam may be used, as shown in Fig. 4. In the latter case, the electrically separate electrodes 51 upon which the ions are collected are individually sealed into the glass wall 53 of the gas-filled chamber with an exposed surface on each side of the wall. Sealed against this wall 53 is an evacuated envelope structure 55 containing an electron gun 57, deflecting means 59 and a signal electrode 61. Following a known technique in the pickup tube art, the electron beam 62 travels from the gun 57 and bombards the target or wall 53 at a voltage above first crossover. The effect is to raise the potential of the elements 51 to that of the screen 61 (10,000 volts). Once the elements 51 are so charged, the entire beam 62 is reflected back to the screen 61. Its electron content is affected by the negative ion charges which have accumulated on the individual electrodes 51. In the circuit between the signal electrode 61 and ground is an output resistance 64. The changes in electron content of the beam 62 as it is intercepted by the electrode 61 and conducted to ground cause voltage variations across the resistance 64 and become the signal output of the tube.

Multiplicity of information

The amount of information which can be stored per electron beam in a tube of the type shown in Fig. 3 is limited by three factors: (*a*) the number of storage paths available, (*b*) the amount of information which can be stored in each path, and (*c*) the number of individual ion groups which the scanning electron beam can start down the separate "corridors" of the tube during the transit time of an ion between electrodes. In this specification the storage paths (separate parallel paths of ion travel) are referred to as "corridors" and each time or space division capable of carrying information within a "corridor" is termed a "channel." As previously mentioned, ions travel in substantially straight lines to their collector electrodes making possible a great number of parallel "corridors" in a single tube. One limitation on the number of corridors which is practicable is a possible lateral diffusion of the ions in transit. This makes some physical separation between neighboring circuits necessary to prevent crosstalk. Co-axial magnetic fields (not shown) around the tube, or insulating partitions within the tube (also not shown) can be used to cut down on the physical separation necessary between "corridors." As demonstrated later in the specifica-

tion under the title, "Transit Time, Diffusion, etc.," however, even without the co-axial fields and insulating partitions suggested above, the physical separation necessary to prevent cross-talk is not too serious a limitation. In argon, for example, an ion will diffuse only ~.036 cm. in .01 second which is a practicable transit time between electrodes.

The number of separate items of information which can be written into a tube of the type shown in Fig. 3 is a function of the transit, or drift time, of an ion in the tube, and the scanning speed of the electron beam which produces the ions. The separate items can be written in separate corridors or they can be channeled into a single, or relatively few corridors. In any event their number, for a given scanning speed, can be calculated from the formula:

$$n=\frac{t}{w_1+w_2}$$

where:

n=the number of items of information possible.

t=the transit time of ions travelling between electrodes down a "corridor." (This is the effective time available for laying down or "writing" signals in a total number of corridors, because there is no point in having more corridors than can be used simultaneously.)

t=.01 is selected as a desirable delay time.

w_1=the time it takes the "writing" electron beam to ionize sufficient molecules of gas within a corridor to produce a signal.

$w_1=0.5\times10^{-6}$ is convenient to secure a satisfactory band width and an ample signal-to-noise ratio at the collector electrode. It is also consistent with a suitable size for the instrument and accepted scanning techniques.

w_2=the time it takes the writing electron beam to traverse the space between corridors (or the spacing between pulses within a corridor).

$w_2=0.5\times10^{-6}$ is selected as representative, if, in order to get adequate separation, the space between corridors (or pulses) is to equal approximately the width of a corridor, or the time it takes to "write" a signal.

When the values suggested above are applied to the formula,

$$n=\frac{t}{w_1+w_2}=\frac{.01}{(0.5+0.5)\times10^{-6}}=10^4$$

or 10,000 possible items of information.

If the 10,000 separate items of information referred to above are to be carried in separate corridors within the tube, the question of physical size of the tube required arises. This question involves such considerations as the diameter of the ion groups as they are initially created by the writing electron beam and the extent to which they diffuse in transit down a corridor.

The electron beam spot area on the target may be assumed to be approximately .008 sq. cm. (Cf. Spangenberg, "Vacuum Tubes," page 427.) As a result, an ion group as it starts through the drift medium is .008". If, as is mentioned above, ions will diffuse only about .036 cm. in a transit time of .01 second, then 1 sq. cm. of area would provide ample cross section to contain a single corridor. This would permit 10,000 different corridors to be carried with a margin of safety in a 12 cm. diameter tube. The number of "corridors" available in a tube of a given diameter is a function of the tube's cross-sectional area and may be calculated from the formula:

$$\text{Number of "corridors" available}=\frac{\pi r2}{.01}$$

where r is given in cm. and the .01 is the area of a .1 cm. square "corridor."

The amount of information which can be channelled into each "corridor" depends upon several factors. The first limitation is the transit time of the ion groups through the tube. This determines how much the tube can "hold" at any given time. But within this period of transit time there may be a great number of pulses of information and each ion group can represent a separate channel of information within its own "corridor." If we assume a transit time of .01 sec., a great number (100 is practicable) of micro-second pulses with adequate spacing between them to prevent interference can be utilized. The spacing must be sufficiently wide to take care of diffusion of the ions in transit toward the collector electrode. (This diffusion problem is discussed below.)

A proper combination of "corridors," and channels within "corridors," makes it possible to store many times 10,000 different elements of binary information. Furthermore, since the collector electrode and its associated circuitry can be made sensitive to the degree of amplitude of a pulse as well as to its mere presence, intermediate information as well as binary "off-on" conditions can be indicated and stored. It has been explained above how 10,000 "corridors" can be contained in a 12 cm. diameter tube. This would call for a scanning speed of .01 second per raster. By increasing the speed of the scanning beam, however, so that it lays down a succession of ion pulses in each "corridor" before the first pulse has completed its transit to the collector electrode, it is possible to multiple these 10,000 "corridors" by a great number of channels within "corridors." The number of channels possible within a single corridor is in the hundreds as shown in the chart below. Thus it is conceivable that more than a million elements of information can be stored if the writing beam scans fast enough to complete a hundred or more rasters during the ion transit time. As explained above, this scanning time is limited among other things by the time necessary to give each ion group an adequate signal to noise ratio.

Transit time, diffusion, etc.

(References: Cork, Radioactivity and Nuclear Physics; Loeb, Fundamental Processes of Electrical Discharge in Gases.)

When ions are produced by bombardment through a Lenard window, the depth of ionization is a function of the energy excess of the electrons after they have penetrated through the diaphragm of the window. An excess of 2500 v. will ionize to a depth of about .04 cm. and 1000 v. to about .003 cm. (Ref. Cork). (A chart on page 293, vol. 4 of the RCA Review publication "Television" shows the percentage of available energy after a cathode ray pierces a Lenard window as a function of window thickness and beam voltage.) For each electron which penetrates into the gaseous region several electrons and positive ions are formed, and the excess energy (i. e. the energy above that which is necessary to pierce the window) is dissipated at a rate of approximately 30 electron volts per ionized pair. These are the factors which along with the time dura-

tion of the cathode ray beam determine the area of gas which is ionized to form a particular ion group.

The rate at which ions move through gas depends upon several variables: the particular gas involved, pressure, distance between electrodes, voltages applied etc. This transit time must be calculated and measured for each device in order to determine the number and the size of the ion groups which can be channeled through its "corridors."

As explained above, the depth of these groups is affected, not only by the time duration of the electron beam which accomplishes the ionization, but also by the degree to which that beam penetrates into the gaseous region to be ionized. There is another factor which has an influence on the depth of the ion group as it passes through the gas filled chamber. This is the tendency of the ionized gas molecules to diffuse gradually throughout the gaseous region. This tendency of gas ions to diffuse must be taken into consideration in calculating the amount of information which can be channeled along any given "corridor."

In performing these calculations the following approach is helpful. Let:

N=number of channels of information (pulses) per "corridors."

t=transit time (of an ion group from electrode to electrode along a gas "corridor").

T=collection time (i. e. the time between the leading edge and the trailing edge of the ion group at the collector electrode. This includes original group width plus diffusion).

V=voltage between electrodes across the gas.

d=distance between electrodes.

v=velocity of ions in gas.

$\bar{x}$=average diffusion width of the ion group (i. e. the extent to which the input pulse has been widened by diffusion of its ion (assuming pulse of zero width at beginning). $\bar{x}$ is the distance the pulse is widened from the central axis therefore the total widening is $2\bar{x}$).

$k=\frac{\text{cm./sec.}}{\text{volts/cm.}}$ at 1 atm. pressure

(k for argon$\sim$1.3 $\frac{\text{cm./sec.}}{\text{volts/cm.}}$, with positive ions)

(International Critical Tables, vol. 6, p. 111).

D=diffusion parameter (.0235 k.) (Ref. Loeb supra).

(1) $N=\frac{t}{T}$

(2) $t=\frac{d}{v}$

(3) $v=\frac{V}{d}k$

(4) $T=\frac{2\bar{x}}{v}$

(5) $\bar{x}=\sqrt{\frac{4Dt}{\pi}}$

(6) $D=.0235\ K$

(7) $N=\left(\frac{d}{v}\right)\left(\frac{v}{2\bar{x}}\right)$ (dividing Equation 2 by Equation 4)

(8) $N=\frac{d}{2\bar{x}}=\left(\frac{d}{2\sqrt{\frac{4D}{\pi}}}\right)\sqrt{\frac{t}{1}}$ (using Equation 5)=

$\left(\frac{d}{2\sqrt{\frac{4D}{\pi}}}\right)\left(\sqrt{\frac{Vk}{d}}\right)$ (using Equations 2 and 3)=

$\frac{\sqrt{V\pi}}{2\sqrt{.0235(4)}}$ (using Equation 6)

Equation 8 shows that the number of channels within a "corridor" is independent of the size of the instrument and volume of the gas but increases with the square root of the voltage (V) between electrodes. This is based on the assumption that the pulse has a width << diffusion width upon formation.

The chart below shows the number of channels increasing $\sqrt{V}$ and approximately at the rate $N=2.9\sqrt{V}$

Voltage across tube	Distance between electrodes	Gradient, volts/cm.	Velocity, cm./sec.	Transit time, t sec.	Collection time, T	No. of Channels
	Cm.				*Microsec.*	
10,000	11	910	1.2×10^3	.0092	30	306
5,000	8	625	813	.0099	44	225
1,000	3.5	286	372	.0094	97	96

Using the first case stated in the chart the diffusion of an ion group in .0092 second is calculated as follows:

$\bar{x}=\sqrt{\frac{4Dt}{\pi}}=\frac{\sqrt{4(.0235)1.3t}}{\pi}=.19t^{1/2}$

$2\bar{x}$(for t=.0092 sec.) =

$2(.19)(.0092)^{1/2}$=.036 cm.

Gases

In the gas-filled tubes described above there are two different types of ionization calling for two different types of gas.

In the first type (Fig. 1) ionization is accomplished by electron bombardment through an electron permeable window which bombardment separates electrons from the gas molecules to produce positive ions. In order to prevent the free electrons from combining with other molecules of the gas to form negative ions, a gas is selected which has a small co-efficient for electron attachment. (E. g. the probability of a free electron attaching to a molecule with which it collides is less than 10^{-5} to one.) Some suitable gases are: the rare gases helium, neon, argon, krypton, xenon, hydrogen, nitrogen, carbon monoxide, and carbon dioxide. The excess electrons are eliminated by attraction to the wall-electrode 17.

In the second type (Fig. 3) ionization is accomplished by activating an electron emitter which sends forth electrons to combine with individual molecules of the gas to form negative ions. Here the situation is opposite to the above case where the object was to eliminate electrons. Instead, we want to add them to the gas molecules. So a gas is selected with a high co-efficient for electron attachment. (E. g. the probability of a free electron attaching to a molecule with which it collides is more than 10^{-4} to one.) Considerable portions of the gas should be one of the follow-

ing: a halogen, oxygen, water vapor, hydrogen sulfide, ammonia, and nitrous oxide. For the second type of operation only, gas selected from the above may be mixed with one of the gases suggested for the first type. But it is recommended that gases within the same group should not be mixed in either type of operation because this would result in ions of different gases with different characteristics and transit times.

The delays introduced in a device of the sort described are of the order of a few seconds or fractions thereof. Longer "memory" may be achieved by running information back through the tube by means of associated circuitry connecting output to input. In this manner a signal may be stored indefinitely. The effects of diffusion are offset by appropriate circuitry to sharpen the pulses each time they are fed back through the tube.

One of the "corridors," or given pulses within any of the "corridors," can be utilized for synchronization or control purposes indicating when one of the parameters should be changed in order to operate the device at the desired delay time. Thus voltage and temperature irregularities etc., can be compensated for. Response to the indicated change can by appropriate auxiliary devices be made automatic.

The storage tubes and delay devices of the invention have been described as feeding into differentiating circuits for deriving a signal output. It will be understood that they may also be fed into other types of circuits and used for other purposes, e. g. they can be used as counting devices in cooperation with integrating circuits.

The invention has been presented as embodied in a gas filled discharge tube. The disclosure in this respect is to be interpreted as being illustrative and not in a limiting sense. The ionizable medium may comprise any fluid material wherein the elementary particles or molecules are capable of changing their electrical charge characteristics (i. e. add or subtract an electron relatively easily). Among such ionizable media are dust particles in air, oil droplets in various emulsions, etc.

What is claimed is:

1. A storage device for electrical signals comprising, an envelope containing an ionizable medium at a pressure of the order of one atmosphere, a plurality of electrodes mounted to define the terminals of a path in said ionizable medium, means for creating a signal-modulated localized-discharge in said ionizable medium adjacent to one of said terminals, means for establishing a potential difference between said electrodes of an intensity and sign calculated to draw said localized-discharge in a substantially straight path away from its area of origin through said ionizable medium in the direction of said other terminal electrode, means including said other terminal electrode for deriving signals from said signal-modulated localized discharge, and at least one other electrode intermediate said terminals of said path.

2. The invention as set forth in claim 1 and wherein means are provided for varying the potential-difference between said terminal electrodes, whereby to regulate the transit time of said signal-modulated discharge through said ionizable medium.

3. The invention as set forth in claim 1 and wherein said means for creating a signal-modulated localized discharge in said ionizable medium comprises an electron-gun.

4. The invention as set forth in claim 1 and wherein said envelope comprises an electron-permeable gas-tight partition which divides said envelope into a gas-chamber and an evacuated chamber, and wherein said first-mentioned means comprises a grid-controlled electron-gun mounted within said evacuated chamber in line with said electron-permeable partition.

5. An electrical delay device comprising a gas-tight envelope having two chambers having a common gas-tight wall, an electron permeable window in said wall, a beam-source of electrons mounted in one of said chambers in a position to bombard said window, the other of said chambers containing a gas of a type and pressure capable of localized ionization in response to the impress thereon of said electrons, a collector electrode in a part of said gas-filled chamber remote from said electron permeable window, and a foraminous auxiliary electrode mounted in the gaseous space between said window and said collector electrode.

6. The invention according to claim 5 wherein said ionizable fluid consists essentially of a gas having a low coefficient of electron-attachment.

7. An electrical delay device comprising an envelope having a translucent gas-tight partition dividing the interior thereof into an evacuated compartment and another compartment containing an ionizable fluid, a beam source of electrons mounted in said evacuated compartment in a position to scan said translucent partition, an electron-sensitive photo-emissive coating on the scanned surface of said partition, a photo-sensitive electron-emissive coating on the opposite surface of said partition and within said other compartment, a plurality of collector electrodes immersed in the ionizable fluid in said other compartment remote from said partition, means for establishing a potential difference between said partition and at least one of said collector electrodes of an intensity and sign calculated to draw a localized-discharge in a substantially straight path away from said partition through said ionizable fluid in the direction of said collector electrodes, means including said collector electrodes for deriving signals from said localized discharge, and at least one electrode intermediate said partition and said collector electrodes.

8. The invention according to claim 7 and wherein said ionizable fluid consists of gas having a high coefficient for electron attachment.

9. An electrical discharge device comprising an envelope containing two spaced apart gas-tight partitions dividing the interior of said envelope into a central compartment and two oppositely located evacuated compartments, an ionizable fluid in said central compartment, a beam source of electrons mounted in each of said evacuated compartments in a position to scan the adjacent surface of its partition, the scanned surface of one of said portions comprising an electron-sensitive, light-emissive coating, the opposite side of said partition having an electron-emissive coating sensitive to the light emitted by said first mentioned coating, the scanned surface of the other partition comprising a plurality of discrete electrodes for collecting ions resulting from the release within said gas of electrons from said light sensitive electron emissive surface means for establishing a potential difference between said partition having said electron emissive coating thereon and at least one of said electrodes of an intensity and sign calculated to draw a localized-discharge in a substantially straight path away

from said partition through said ionizable fluid in the direction of said electrodes, means including said electrodes for deriving signals from said localized discharge, and at least one electrode intermediate said partition having said electron emissive coating thereon and said electrode.

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