March 3, 1959 A. J. CANN 2,876,351

IONIC TIME-DELAY APPARATUS

Filed Aug. 29, 1955 3 Sheets-Sheet 1

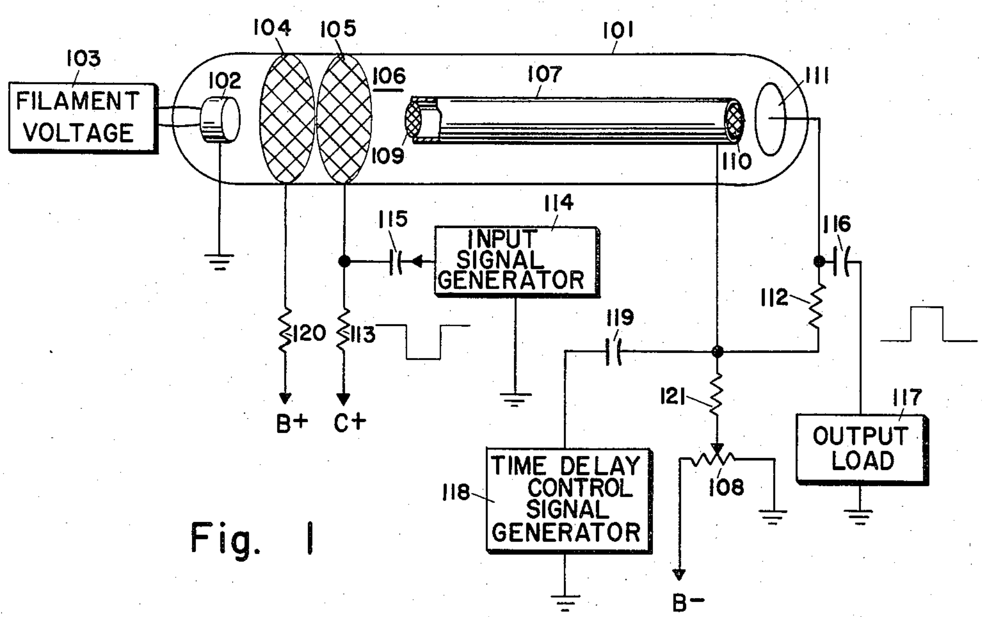

Fig. 1

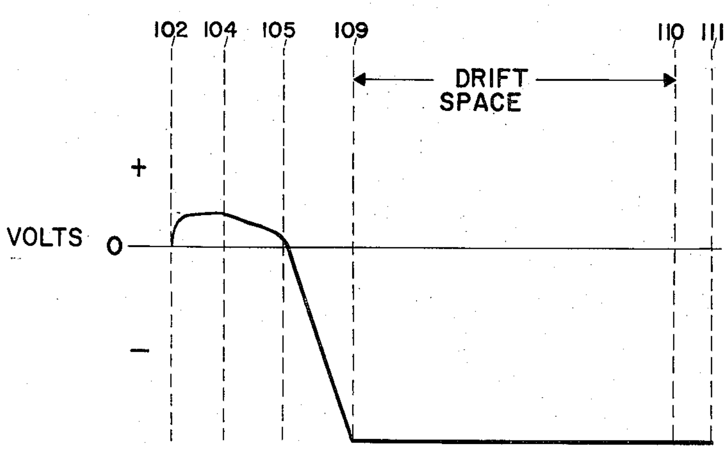

Fig. 2

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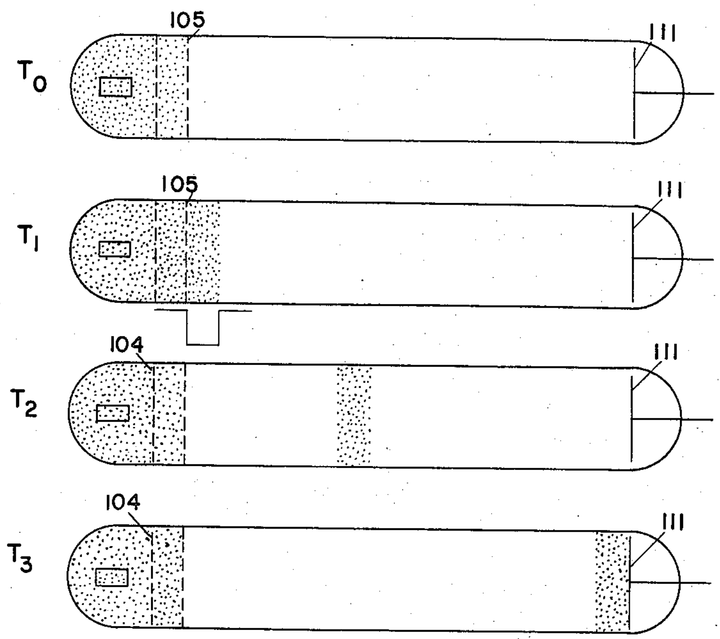

Fig. 3

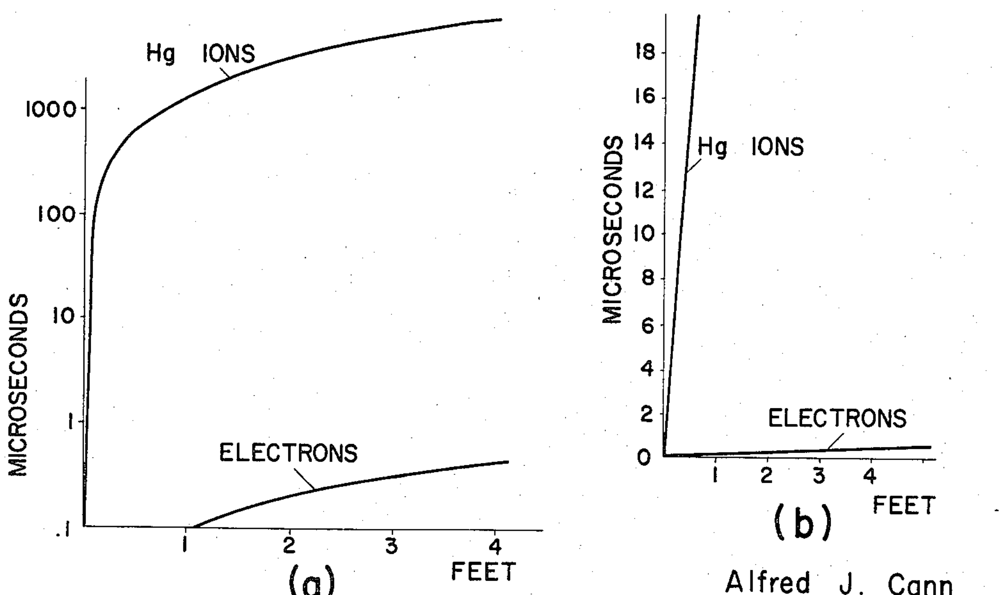

Fig. 4

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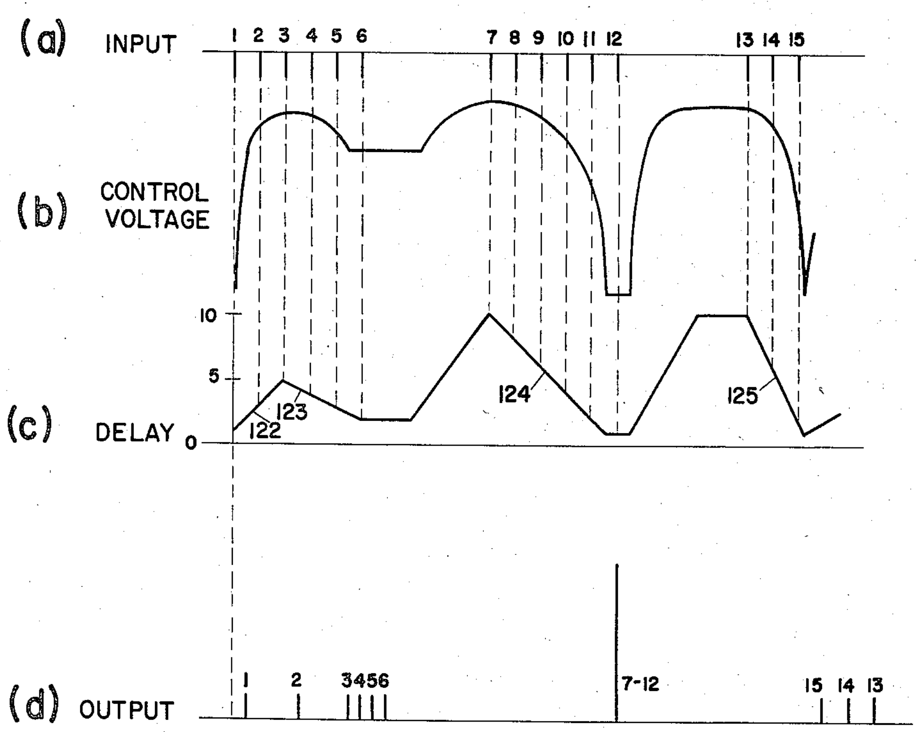

Fig. 5

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IONIC TIME-DELAY APPARATUS

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Application August 29, 1955, Serial No. 531,175

3 Claims. (Cl. 250—27)

This invention relates to time-delay apparatus. More particularly, this invention relates to time-delay apparauts of the type in which an ionic beam is utilized.

In U. S. Patent 2,456,466 issued to D. C. Sunstein, December 14, 1948, there is disclosed a variable time-delay electronic apparatus which utilizes an electron beam. Time-delay devices such as this are severely limited either in the total delay time available, the frequency bandpass characteristic, or the ability to vary delay time at a high speed. For example, the length of a time-delay tube utilizing an electron beam becomes impracticably great as the required time-delay is increased. The time-delay which can be realized from an electron beam device is a function of its beam velocity. The velocity of the electron can be derived from the equation for kinetic energy:

(1) $$W=\tfrac{1}{2}mv^2$$

where W is the kinetic energy, m the mass of the particle and v its velocity. The energy gained by particles accelerated in an electrostatic field, for example, in the field between a cathode and an anode, can be expressed by the relation:

(2) $$W=qE$$

where q equals the charge of the particle and E the accelerating voltage. Substituting in Equation 1 above, the velocity v is then expressed:

(3) $$v=\sqrt{2q\,E/m.}$$

For electrons, v_e equals 593,000 $\sqrt{E}$ meters per second.

In an electron beam there inevitably exists a distribution of electron velocity due to the emission process. For thermionic emission the distribution of thermal energy has a range of approximately 0.3 electron volt. Consequently, the leading and trailing edges of a group of electrons representing a signal pulse randomly shift with thermal energy changes and gradually diffuse. This disturbance affects the rise time of a pulse. It has been determined that the rise time is a function of the thermal energy range divided by the accelerating voltage. Since both the time-delay and rise-time are functions of the voltage E, the delay/rise-time ratio R has been found to be:

(4) $$R=\sqrt{E}/.3 \text{ for electron beam devices}$$

For a typical ratio of 10-to-1, E is 30 volts and the corresponding electron velocity is 3.25×10^6 meters per second. Thus, for a delay time of 10 micro-seconds, the beam must travel 32.5 meters, an impractical length.

It is, therefore, an object of the present invention to provide an improved time-delay apparatus for producing a wide range of time delays.

It is a further object of the invention to provide an improved time-delay apparatus for introducing a variable time-delay to encode signals.

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A still further object of the invention is to provide an improved time-delay apparatus utilizing an ion beam for introducing a variable time-delay.

It is a further object of the invention to provide an improved time-delay apparatus for producing time delay effects with relatively high delay/rise-time ratios.

Other and further objects of the invention will be apparent from the following description of a preferred embodiment and method of practicing the invention, taken in connection with the accompanying drawings.

In accordance with the invention there is provided an ionic, time-delay apparatus. The apparatus includes an ion discharge device having a source of ions and a drift tube means responsive to the ions for directing the flow thereof. Control means are provided in the path of the ions for varying the density of the ionic flow in accordance with an input signal. Input generator means are coupled to the control means for providing an ordered sequence of input pulses spaced apart by predetermined time intervals. A time-delay control signal generator means is coupled to the drift tube means for varying the time intervals between input signal pulses with respect to the predetermined time intervals.

In the accompanying drawings:

Fig. 1 is a schematic, partially fragmentary, three-dimensional view of a time-delay tube embodying the present invention;

Fig. 2 is a voltage gradient curve illustrating an aspect of the operation of the embodiment of Fig. 1;

Fig. 3 is a series of diagrams further illustrating the operation of the embodiment of Fig. 1;

Fig. 4 is a graph comparing the available time delays for devices utilizing ion and electron beams; and

Fig. 5 is a series of graphs further illustrating the operation of the embodiment in Fig. 1.

Referring now to the drawings, and with particular reference to Fig. 1 representing one embodiment of time-delay apparatus in accordance with the present invention including an ionic time-delay tube **101**, the tube **101** comprises an hermetically sealed shield or envelope enclosing a gas generally indicated at **106**, for example mercury vapor at a pressure of 2×10^{-3} millimeters of mercury and surrounds a plurality of electrodes. An emitter cathode **102** including an internal filament, which is connected to a source **103** of filament voltage, provides a source of electrons. The tube **101** includes between the cathode **102** and a collector anode **111**, a perforated anode **104** connected through a voltage dropping resistor **120** to a source of positive voltage labeled B+, for example 100 volts. A control grid **105** comprises means for varying the density of ion flow in the tube. The grid **105** is connected through a voltage dropping resistor **113** to a source of positive bias voltage labeled C+, for example 2 volts. A drift-tube **107** is connected through a resistor **121** and a potentiometer **108** to a source of relatively high negative voltage labeled B—, for example 450 volts. The tube **107** is utilized to direct the flow of the ions. The drift-tube **107** has grids **109** and **110** enclosing its ends to minimize the effect of fringing fields. The collector **111** is connected through a load resistor **112** in parallel with the drift-tube **107** to B—, as shown. The collector **111** comprises means for discharging the ions and for producing an electron current flow to develop an output signal delayel with respect to the input signal. An input signal generator **114** is coupled through a capacitor **115** to the control grid circuit, as shown, one side of the generator **114** being grounded. The output of the device is coupled from the collector **111** through the capacitor **116** to an output load **117** which is connected to ground as shown. The output load may typically be a resistor or a transformer. A time-delay control signal generator **118** has one side grounded and the other coupled through a capacitor **119** to the drift-tube cathode **107** as shown.

The operation of the invention will now be discussed with particular reference to Figs. 1 through 5. In Fig. 2, a voltage-gradient curve illustrates the static accelerating potential present in the tube **101**. Thus, it will be seen that electrons are accelerated from the emitter cathode **102** to the perforated anode **104** by the relatively positive potential on the anode **104**. When the voltage on the anode **104** is of the order of 15 to 20 volts, the electrons gain sufficient velocity to ionize mercury vapor atoms as in a conventional mercury vapor rectifier. In the static condition a small positive biasing voltage on the ion control grid **105** electrostatically shields the ions from entering the accelerating region between the grid **105** and the drift-tube **107**. When in input signal in the form of a negative pulse is applied to the grid, positive ions are admitted to the accelerating region. The differential voltage between the grid **105** and the drift-tube **107** determines the velocity of the ions entering the drift-tube **107**. The tube **107** provides a Faraday cage or field-free region. The ions consequently travel through the tube at their initial velocity as determined by the potential difference between the ion control grid **105** and the drift-tube **107**. At pressures on the order of 2×10^{-3} millimeters of mercury, the mean free path of the ions is of the order of the length of the tube and there is a minimized tendency for ions to collide. Ions which do collide are generally deflected to the walls of the drift-tube. Only undisturbed ions contribute to the output.

Fig. 3 graphically illustrates the time-delay action. The time conditions T_0, T_1, T_2 and T_3 represent respectively the initial static condition; the insertion of a negative square-wave pulse from the generator **114** to the grid **105** and the consequent formation of a cloud of ions passing through the control grid **105**; the cloud of ions approximately half way along the length of the tube and the cloud of ions being discharged at the collector **111**.

As indicated by Equation 4 above, the delay/rise-time ratio is principally determined by two factors: the thermal distribution in electron volts and the accelerating potential. As is well known, the thermal distribution is a function of absolute temperature. Since the electrons are initially emitted at the cathode temperature, a greater range of initial velocities may be expected than is exhibited by the ions which are essentially at the much lower ambient temperature. The transmission of electron velocities to the ions because of electron-gas molecule collisions is substantially negligible since the ionic mass is so much greater than that of an electron. Thus, the energy distribution of the ions has a range of only .045 electron volt. From the Equation 4 above, the delay/rise-time ratio R for ions is expressed:

$$R=\sqrt{E/.045} \qquad (5)$$

Then, only a minimum of 4.5 volts are required for a delay/rise-time ratio of 10. Since the mass of a mercury ion is approximately 360,000 times that of an electron, the ionic velocity v_i for a given voltage is only approximately $\frac{1}{600}$ that of the corresponding electron velocity v_e. Thus, in accordance with the Equation 3 above, the ion velocity v_i equals approximately $980\sqrt{E}$. For E equal to 4.5 volts, the ionic velocity v_i turns out to be approximately 2000 meters per second. For the 10 microsecond time delay a tube length of 2000×10^{-5} or 2 centimeters is required as opposed to 32.5 meters for a time-delay device utilizing an electron beam. It will be apparent that suitable accelerating voltages and transit lengths may be chosen to provide an ionic time-delay device with an extraordinary range of time delay.

For a given tube length and a given delay/rise-time ratio, an ionic time-delay device embodying the present invention produces approximately 1500 times as much delay as a corresponding electron device. This is graphically illustrated in Fig. 4*a* where the ordinate is logarithmically calibrated in microseconds and the abscissa linearly calibrated in feet to present a plot of delay-time versus drift-space length. In the curve (*b*) of Fig. 4, the ordinate is linearly calibrated in microseconds as shown.

In the curves of Fig. 5 a series of pulses, numbered 1 through 15 and occurring in a time sequence as shown, are assumed to be applied to the ion control grid **105**. A suitable voltage as shown in curve 5(*b*) is developed by the time-delay generator **118** and coupled through the capacitor **119** to the drift-tube and through the resistor **112** to the collector **111** effectively to vary the time delay in accordance with the curve 5(*c*). It is to be noted that when the variation in time delay has a positive slope as at **122**, the time separation between pulses is expanded as illustrated by pulses **1**, **2** and **3** in the curve 5(*d*). The more positive the drift-tube **107** with respect to the grid **105**, the longer the time of travel for the ionic pulse through the drift-tube. When the delay is decreasing, in other words, the potential on the drift-tube going negative as at **123**, the pulses are compressed in time as illustrated by the pulses **3**, **4**, **5** and **6** as opposed to the pulses **1**, **2** and **3**. The pulses **7** through **12** coincide with a negative unity slope as shown at **124**. This has the unobvious effect of causing the pulses to occur simultaneously at the collector **111** at an enhanced amplitude as shown.

When the slope of the curve is negative and greater than unity as indicated at **125**, an actual inversion takes place. Thus, the pulses **13**, **14** and **15** in the curve 5(*a*) have their order completely inverted as shown in the curve 5(*c*) with the same time separation between them. The structure of the drift tube **107** permits such an extraordinary result to be realized. The ionic flow within the drift-tube **107** proceeds at substantially its initial velocity as determined by the differential potential between the control grid **105** and drift-tube **107**. A group of ions introduced to the drift-tube at a higher velocity than an earlier group can overtake the earlier group and actually pass through it. This result is not possible with any prior art device. The densities of the groups of ions are such as to permit a given cloud of ions literally to pass through another cloud of ions without losing its identity. Some distortion takes place due to collisions between ions of the two groups. The probability of such collisions, however, is sufficiently low that the resultant dispersion is negligible.

In continuous-wave applications the device can be used to transform an input wave form at the control grid **105** to quite a different wave form in its output by a suitable velocity modulation signal as produced by the time delay control signal generator **118**.

The ionic variable-time-delay apparatus of the present invention greatly enhances the art of time control in that larger variations in time delay at higher speeds are now possible. It will be apparent that the present invention has wide application in the art of electronic control.

While there has been hereinbefore described what is at present considered a preferred embodiment of the invention, it will be apparent that many and various changes and modifications may be made with respect to the embodiment illustrated, without departing from the spirit of the invention. It will be understood, therefore, that all such changes and modifications as fall fairly within the scope of the present invention, as defined in the appended claims, are to be considered as a part of the present invention.

What is claimed is:

1. An ionic, time-delay apparatus, comprising: an ion discharge device having a source of ions, a drift tube means responsive to said ions for directing the flow thereof, control means in the path of said ions for varying the density of said ionic flow in accordance with an input signal, and collector means responsive to the ions issuing from said drift tube for discharging said ions and

for producing an electric current flow to develop an output signal delayed with respect to said input signal; input generator means coupled to said control means for providing an ordered sequence of input pulses spaced apart by predetermined time intervals; and time delay control signal generator means coupled to said drift tube means for varying the time intervals between output signal pulses with respect to said predetermined time intervals.

2. An ionic, time-delay apparatus, comprising: an ion discharge device having a source of ions,, a drift tube means responsive to said ions for directing the flow thereof, control means in the path of said ions for varying the density of said ionic flow in accordance with an input signal, and collector means responsive to the ions issuing from said drift tube for discharging said ions and for producing an electric current flow to develop an output signal delayed with respect to said input signal; input generator means coupled to said control means for providing an ordered sequence of input pulses spaced apart by predetermined time intervals; and time delay control signal generator means coupled to said drift tube means for varying the time intervals between output signal pulses with respect to said predetermined time intervals for providing an output ordered sequence of pulses with at least one pair of pulses reversed in time with respect to said input pulses.

3. An ionic, variable time-delay apparatus, comprising: a housing-tube oriented along a given axis; a source of ions within said tube; a cylindrical drift tube means disposed within said housing-tube and oriented along said axis for directing an ionic flow therethrough, said drift tube having conductive grids enclosing its opposite ends; control means disposed within said housing-tube between said source of ions and said drift tube for varying the density of said ionic flow in accordance with an input signal; collector means disposed within said housing-tube in the path of said ions emanating from said drift tube for effecting their discharge and producing an electron current flow to develop an output signal delayed in time with respect to said input signal; direct current means coupled to said drift tube and said collector for applying a negative voltage to said drift tube and said collector to control the velocity of ionic flow and provide an adjustment to vary the time delay; input signal generator means coupled to said control means for producing a sequence of input pulses spaced apart by predetermined time intervals; and time delay control signal generator means coupled to said drift tube to vary said negative voltage further to control the velocity of ionic flow and vary the ordering of ions emanating from said drift tube in a predetermined manner to provide an output sequence of signal pulses spaced apart by time intervals varying from said predetermined time intervals.

References Cited in the file of this patent

UNITED STATES PATENTS

2,401,945	Linder	June 11, 1946
2,442,662	Peterson	June 1, 1948
2,508,228	Coeterier	May 16, 1950
2,683,251	Ramo	July 6, 1954
2,697,169	Emslie	Dec. 14, 1954
2,706,788	Wiley	Apr. 19, 1955
2,737,585	Wolff	Mar. 6, 1956
2,776,374	Iskenderian	Jan. 1, 1957