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2,666,163

ELECTRON DEVICE WITH LONG ELECTRON PATH

Filed Dec. 29, 1951

3 Sheets-Sheet 1

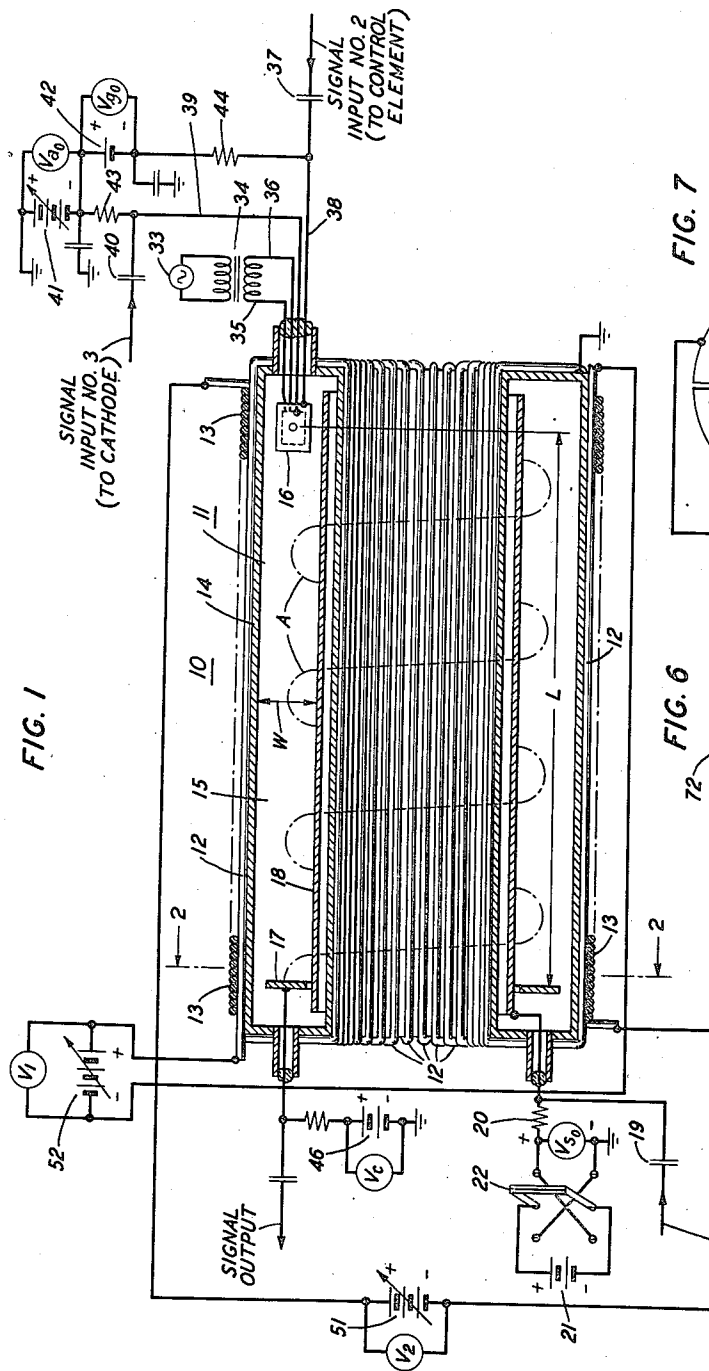


FIG. 1

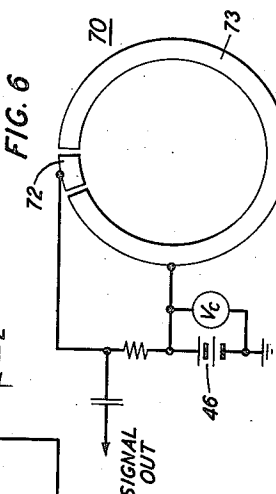
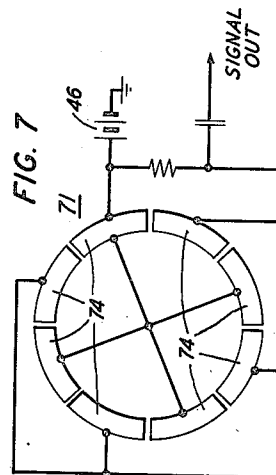


FIG. 6

FIG. 7

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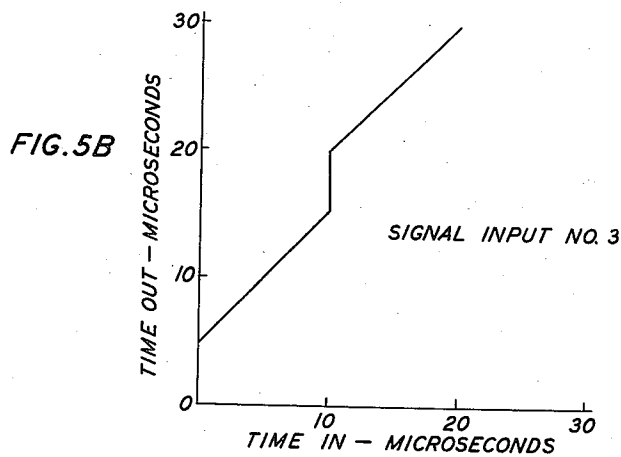
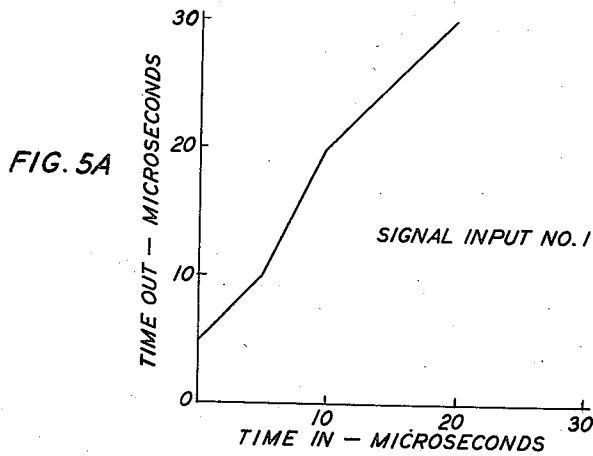
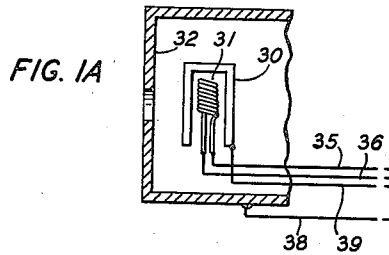
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FIG. 2

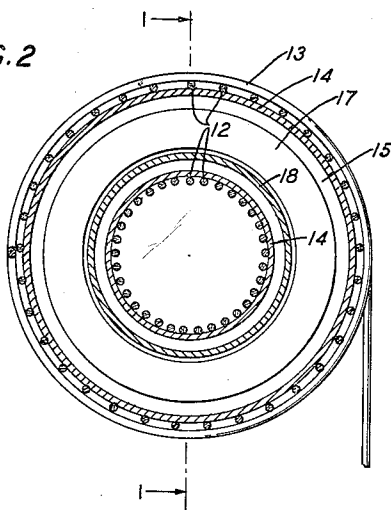


FIG. 4

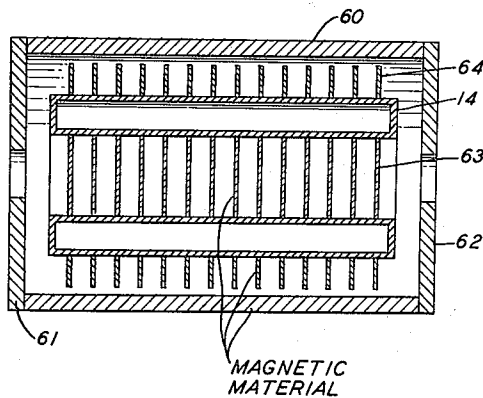
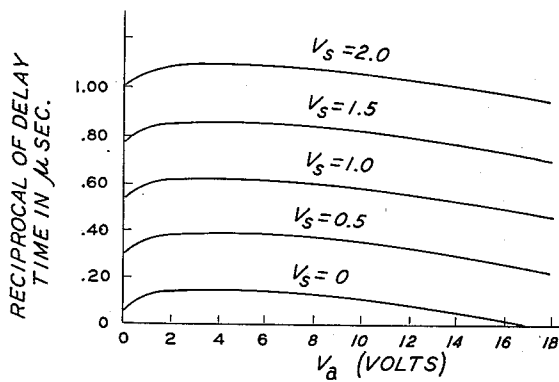
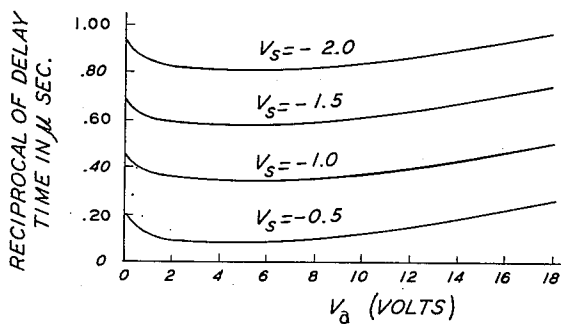


FIG. 3A



$B = 100$ GAUSS
 $B_z = -5$ GAUSS

FIG. 3B



$B = -100$ GAUSS
 $B_z = -5$ GAUSS

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ELECTRON DEVICE WITH LONG ELECTRON PATH

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13 Claims. (Cl. 315—21)

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This invention relates to apparatus for delaying electrical signals and more specifically to cathode-ray delay devices.

It is an object of this invention to improve the versatility of devices for delaying electrical signals.

It is another object of this invention to make readily variable the electrical time delay in cathode-ray delay tubes.

It is still another object of this invention to vary the length of the physical path traveled by a beam in a cathode-ray tube.

There has long been a need in the communication and other electrical arts for a device which produces an elastic time delay for applied signals, that is, a delay which can be varied quickly and easily. Such a device would be of considerable importance in electric circuits for delaying electrical pulses by varying amounts. Moreover, such a device would be of great value in encoding systems where it is desired to change the order and/or spacing of pulses in a series and in a variety of other systems in which signal time delay is required.

Passive delay circuits have been used to a great extent in various circuit arrangements but they are not generally variable and, for relatively large delays, require considerable apparatus. Acoustic delay lines have also been suggested for various circuit arrangements but they also have the disadvantage that the delay of the signal cannot readily be varied and the attenuation is very large.

Various electronic devices have been used in circuits requiring time delays, the electronic storage tube being the best known example of this type of device. In such a tube, a signal modulated beam is caused to scan a target to build up charges in various elemental portions thereof which can be stored for a limited period of time. These charges are removed by a second beam or by the storing beam if appropriate switching circuits are provided. The output signal available in tubes of this character is limited because of the relatively small cross-sectional area of the beam (made necessary by the small size of the elemental storage area). Moreover, the time delay imparted to the signal by tubes of this type cannot be simply varied nor is it an easy matter to change the order of the signal pulses in the reading (output) circuit compared to the order of signals in the writing (input) circuit.

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In accordance with the present invention, there is provided a cathode-ray tube in which the path of the electrons in the beam therein is made very long compared to the length of the axis of the tube. This is accomplished by causing the electrons to travel a curved path in the tube, such a path being in the form of a helix extending from the cathode to a collecting electrode, for example. Four fields act upon the electron beam: a magnetic circumferential field, a magnetic longitudinal field, an accelerating electric field, and a transverse electric field. Any one of these fields can be varied but as a practical matter it is easier to vary the two electric fields than it is to change the value of the two magnetic fields once they have been adjusted to predetermined values for the particular installation. The two magnetic fields in combination tend to restrict the path of the beam in the tube to a helix but this helical path is changed somewhat by the two electric fields. Variation of the accelerating electric field varies the delay mainly by altering the speed of the electrons in the stream, while variation of the transverse electric field changes the delay time chiefly by changing the pitch of the helix. The number of electrons in the beam can be made very large since it is not necessary to restrict the cross-sectional area of the beam to the area of an elemental area of a target because the target in the present invention serves only as a collector electrode and is relatively large compared to an elemental area in a storage tube target.

The invention will be more readily understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof, in which:

Fig. 1 is a schematic longitudinal sectional view of a cathode-ray device in accordance with the invention for producing elastic time delays;

Fig. 1A is a schematic enlarged view of the electron source in the arrangement of Fig. 1;

Fig. 2 is a cross-sectional view of the tube in the arrangement of Fig. 1 taken in a plane through the line 2—2 in the latter figure;

Figs. 3A and 3B are diagrammatic representations to aid in understanding the invention;

Fig. 4 is a longitudinal view of a modification of the arrangement of Fig. 1;

Figs. 5A and 5B are graphical representations to illustrate the effects caused by varying the transverse electric field and the accelerating electric field, respectively;

Fig. 6 shows one collector arrangement for the invention; and

Fig. 7 shows another form of collector.

For a more detailed description of the invention, reference will now be made more specifically to the drawings. In these drawings, Fig. 1 shows a cathode-ray device 10, in accordance with the invention, for imparting elastic time delays to signals applied thereto and which comprises a tube 11 and various associated circuit elements. Specifically, these circuit elements include three input circuits identified in the drawing as Signal Input No. 1, Signal Input No. 2, and Signal Input No. 3, respectively, an output circuit identified in the drawings as Signal Output, and circuits for applying potentials to magnetic coils 12 and 13 for forming circumferential and longitudinal magnetic fields, respectively. Biasing sources are included in the respective input and output circuits.

The tube 10 comprises a grounded hollow cylindrical metallic envelope 14 serving as an anode and having an annular evacuated chamber 15 in which there are positioned at opposite ends an electron source or gun 16 and an annular collector electrode 17. A beam of electrons, represented by the dash-dot line A, is caused to travel a helical path in the tube between the members 16 and 17 (by means of magnetic and electric field producing means to be described below in detail), and, by means of signals applied to the various input circuits, the mode of travel of the electrons in the beam can be controlled in any of a variety of ways.

Within the chamber 15 is a cylindrical conductor or shell 18 which is connected to the Signal Input No. 1 through an appropriate coupling condenser 19. A biasing transverse electric field E between the envelope 14 and the shell 18 is obtained by connecting the member 18 to ground through a resistance 20 and a potential source 21. This biasing voltage, which is of the order of 10 volts, for example, may be poled in either direction by the reversing switch 22 connected in circuit with the source 21. A signal applied to Signal Input No. 1 varies the intensity of the field E and thus varies the time delay of the electrons in the beam between the members 16 and 17 by varying the pitch of the helical path between the gun 16 and the collector 17.

Signal Inputs Nos. 2 and 3 control the electron gun 16, a specific illustrative embodiment of which is shown in Fig. 1A. The gun 16 comprises a cathode 30, a cathode heater 31, and a control element 32. Current for the heater cathode is obtained from a source 33 by means of transformer 34 and wires 35 and 36. The Signal Input No. 2 is connected through the coupling condenser 37 and wire 38 to the control element 32 while the cathode 31 is connected by means of wire 39 and coupling condenser 40 to the Signal Input No. 3. Bias for the control element 32 is obtained by means of sources 41 and 42 through resistors 43 and 44. Signal Input No. 2 controls the number of electrons in the beam and signals modulating the intensity of the beam are applied at this point. Signal Input No. 3 controls the speed of the electrons and signals applied there vary the delay of the electrons in the beam A by said control. The intensity of the accelerating electric field V_a is determined by the sum of the voltage V_{a0} from source 41 and the voltage applied to Signal Input No. 3. The intensity of the transverse electric field E is determined by the sum of the voltage V_{e0} from

source 21 and the voltage applied to Signal Input No. 1.

The signal output circuit is connected to the control electrode 17. The collector is placed at an appropriate positive potential with respect to the electron gun 16 by means of the source of potential 46. This source may be, for example, of the order of five or six volts above ground and ten or twelve volts with respect to cathode potential. There is nothing critical about the voltage between the cathode and the collector except that it should not be high enough to produce more secondary electrons from the collector 17 than there are primary electrons in the beam striking it.

To provide a longitudinal magnetic field B_z , the coil 13 is wound in the form of a solenoid around the envelope 14. A voltage V_2 is applied to the coil 13 by means of a suitable source 51 which may be varied to give the desired field intensity B_z . A circumferential magnetic field B is obtained by means of toroidal voltage coil 12 wrapped as shown in Figs. 1 and 2. A voltage V_1 is applied to this coil by means of source 52 to produce the desired intensity of circumferential field B. The source 52 may be varied to produce any desired field strength.

The operation of the device shown in Figs. 1 and 2 will now be described. The sources 51 and 52 are adjusted so that they tend to direct the beam from the cathode 30 in a helical path to the collector 17. This helical path is varied somewhat (but it is still helical) by the accelerating electric field V_a and the transverse electric field E. A signal applied to Signal Input No. 1, which varies the intensity of the transverse electric field E, will vary the pitch of the helix of the beam and hence varies the delay time. Variation of the grid voltage V_g , either by changing the voltage V_{g0} of the source 42 or by applying a signal to the Signal Input No. 2, will vary the number of electrons in the beam A. Variation of the cathode voltage, either by varying the potential V_{a0} of the source 41 or by applying signals to the Signal Input No. 3 will vary the potential of the accelerating electric field V_a and hence the speed of the electrons. Summarizing, then, there are four field values which can be varied, that is, the accelerating electric field V_a , the transverse electric field E, the longitudinal magnetic field B_z , and the circumferential magnetic field B. Since in practice, it is more difficult to vary the magnetic fields than it is to vary the electric fields, control signals are applied, as shown in the drawings, to the elements which vary the electric fields only, but it is to be understood that the magnetic fields can be varied by control signals as well.

The formula for the delay in seconds can be written:

$$\frac{B}{\tau} = -\frac{1}{L} \left[\frac{2V_a}{R} - \frac{V_s}{W} + \sqrt{\frac{2eV_a}{m}} B_s \right] \quad (1)$$

where B is the circumferential field (Webers/meter²), L is the distance from gun 16 to collector 17 (meters), V_a is accelerating voltage (volts), R is radius of the helical orbit (meters), V_s is the voltage on the cylindrical shell electrode 18 (volts), W is the distance from shell electrode to outer envelope (meters), e and m are charge and mass of electron in coulombs and kilograms respectively, and B_z is the longitudinal magnetic field (Webers/meter²).

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If some of the constants in the above equation are given the following values by way of example:

$$B=0.01 \text{ Webers/meter}^2$$

$$B_z=-5 \times 10^{-4} \text{ Webers/meter}^2$$

$$L=0.21 \text{ meter}$$

$$R=0.028 \text{ meter and}$$

$$W=0.001 \text{ meter}$$

the equation becomes

$$\frac{1}{\tau}=0.478V_a-.0354V_a-.145\sqrt{V_a} \quad (2)$$

where τ has been expressed in microseconds.

Figs. 3A and 3B are graphs which have as coordinates the reciprocal of the delay time in microseconds

$$\left(\frac{1}{\tau}\right)$$

and accelerating voltage V_a for different values of voltage V_s , the set of curves in Fig. 3A being taken for magnetic field strengths of B of 100 gauss and B_z of -5 gauss while the lower curves are taken for negative values of V_s and B is -100 gauss, B_z remaining at -5 gauss.

The device shown in Figs. 1 and 2 has many advantages. Due to the size and shape of the collector electrode, there is no electro-optical problem of making a beam of accurate size and, moreover, the output signal available is not limited to a narrow beam (as in many other electronic storage tubes) and, as a matter of fact, the beam can have a relatively large intensity. The information "write in" is continuous and no erasing is required, nor is it necessary to switch between two tubes, one of which is "writing" the information to be stored and the other of which is "reading" the stored information. The time delay is measured by the length of time the beam takes to cover the path between the cathode and the collector but this can be made relatively large such as of the order of 100 microseconds, for example. To obtain such delays the path length is made very long, that is, tens or hundreds of feet although it is obvious that the tube itself is by no means this long.

In addition to its value for delaying signals by a time period which can be quickly and readily changed by varying the potential of the accelerating voltage or of the transverse voltage, the device of this invention is very useful in encoding systems. For example it can be used to open up "time gaps" at the transmitting and receiving ends of a system by varying the velocity of some electrons more than others.

In order to understand this last statement, it should be noted that a change of V_a or E affect a chain of pulses going through the delay tube in different ways. When E is varied by a changing signal in Signal Input No. 1, all pulses in the drift space between the gun 16 and the collector 17 are affected, while a change in V (by changing the voltage in Signal Input No. 3) affects only those pulses that enter the drift space after the change. This difference is illustrated in Figs. 5A and 5B where the time period between the start of the pulse chain and the time when a particular pulse in the chain reaches the collector (time out) is plotted against the time period between the start of the pulse chain and the time the particular pulse modulates the stream (time in), Fig. 5A represents an illustrative condition when signals are applied to Signal Input No. 1 (changing E) and Fig. 5B shows the condition when similar signals are applied by way of Signal Input No. 3 (changing V_a). In

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each case a change is made at $t=10$ microseconds that changes the delay through the tube from 5 to 10 microseconds. In Fig. 5A, it can be seen that the time between successive pulses emerging from the tube is increased slightly for a period long enough to accumulate 5 microseconds. In Fig. 5B, however, an interval of 5 microseconds is suddenly inserted in the chain of pulses. This last type of change is a particularly desirable one.

Stating it somewhat differently, the impulse entering upon the helical path between the cathode and the collector can be caused to arrive at the collector end of the tube ahead of other impulses which originally preceded it. By this means a complete distribution or shuffling (in time) of a sequence of impulses can be accomplished.

Various alternative forms of the arrangement shown in Fig. 1 are possible and some of these changes will now be described. The exterior solenoid coil 13 can be replaced by a permanent magnet such as that shown in the arrangement of Fig. 4. For simplicity of the drawing, only the annular envelope 14 has been shown but it is to be understood that the electron gun elements 16, the collector electrode 17, the means for obtaining the electric fields and the toroidal coil 12 are the same as the corresponding elements in Fig. 1. The permanent magnet structure comprises a cylindrical permanent magnet 60, magnetic end plates 61 and 62, and a multiplicity of discs 63 and annular plates 64 to reduce transverse components of the magnetic field. The arrangement of Fig. 4 produces a field B_z as in the embodiment 10 of Fig. 1 although it is more difficult to make changes in the magnetic field strength than in the previously described embodiment.

Another alternative is to replace the toroidal coil 12 in the arrangement of Fig. 1 by a solid conductor or by a series of concentric conductors carrying heavy currents.

The collector ring 17 can have one or more insulated sectors to reduce the effects of velocity dispersion and to achieve a quantized time delay. One of the main problems connected with the delay tube is the dispersion of a transmitted pulse due to the thermal spread of velocities at the cathode. In considering means of improving this situation, it is to be noted that electrons with different initial velocities not only arrive at the collector at different times but follow different orbits. Thus, a group of electrons of different velocities will arrive at the collector along different paths and will strike different portions thereof. A group of electrons confined to a particular velocity range can be selected by dividing the collector ring 70 as shown in Fig. 6 and taking the output signal only from a small section 72 thereof. The pulse observed in this way will be less dispersed. Furthermore, the delay through the tube will be quantized by this arrangement. Thus, as the accelerating voltage is changed, transmitted pulses will be observed only at certain spaced intervals of delay. The intervals can be made as small as desired by spacing several active segments 74 around the collector (as shown in Fig. 7), these being connected together.

In some embodiments the shell 18, the effect of which is to assist in establishing the proper physical path A by its repelling effect upon the electrons therein can be omitted, and in some embodiments the solenoid winding 13 for pro-

ducing the longitudinal magnetic field B_z can also be omitted.

It is to be understood that the above-described embodiments are illustrative of the application of the principles of the invention. Numerous modifications may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A cathode-ray device comprising an annular evacuated chamber, an electron gun near one end of said chamber, a collecting electrode near the other end of said chamber, and means for directing electrons from said gun to said collecting electrode in a helical path through said chamber, said means including a metallic cylinder within said chamber extending from the vicinity of said gun to the vicinity of said collector.

2. The combination of elements as in claim 1 in further combination with means for applying a signal to said cylinder.

3. A cathode-ray device comprising an annular evacuated chamber, an electron gun near one end of said chamber, a collecting electrode near the other end of said chamber, and magnetic means for directing electrons from said gun to said collecting electrode in a helical path through said chamber, said magnetic means including means for establishing a longitudinal magnetic field and means for establishing a circumferential magnetic field.

4. A cathode-ray device comprising an annular evacuated chamber, an electron gun near one end of said chamber, a collecting electrode near the other end of said chamber and magnetic means for directing electrons from said gun to said collecting electrode in a helical path through said chamber, said last-mentioned means including a solenoid around said evacuated chamber and a toroidal coil associated therewith.

5. A cathode-ray device comprising an annular evacuated chamber, an electron gun near one end of said chamber, a collecting electrode structure near the other end of said chamber and means for directing electrons from said gun to said collecting electrode structure in a helical path through said chamber, said collecting electrode structure having a segment therein which is insulated from the rest of the collecting electrode structure.

6. A cathode-ray device comprising an annular evacuated chamber, an electron gun near one end of said chamber, a composite collecting electrode structure near the other end of said chamber, and means for directing electrons from said gun to said collecting electrode structure in a helical path through said chamber, said collecting electrode structure having a multiplicity of segments therein which are structurally spaced and insulated from each other, alternate segments being connected together.

7. A cathode-ray device comprising an annular evacuated chamber, an electron gun near one end of said chamber, a collecting electrode near the other end of said chamber, and magnetic means for directing electrons from said gun to said collecting electrode in a helical path through said chamber, said magnetic means comprising

a permanent magnet structure surrounding said evacuated chamber.

8. A cathode-ray device comprising an annular evacuated chamber, an electron gun near one end of said chamber, a collecting electrode near the other end of said chamber, and magnetic means for directing electrodes from said gun to said collecting electrode in a helical path through said chamber, said magnetic means comprising a permanent magnet structure surrounding said evacuated chamber, a multiplicity of annular rings within said permanent magnet structure and surrounding said evacuated chamber, and a plurality of discs outside said evacuated chamber but within the confines thereof.

9. In a variable time delay electronic device, an evacuated envelope having an axis, means within said envelope for forming an electron beam, electrical means for causing the electrons in said electron beam to follow a substantially helical path about said axis, means for inducing a circumferential magnetic field about said axis in the space through which said electrons travel, means to control the radial force acting on said electrons, and means for collecting the electrons from said electron beam.

10. An electronic device as set forth in claim 9 in which said electron collecting means is a segmented electrode having its active portions located symmetrically about said axis.

11. In combination, an evacuated envelope, two substantially coaxial electrodes forming a passageway within said evacuated envelope, electrical means coupled to said electrodes for varying the radial electrical field therebetween, electron gun means adjacent one end of said passageway for introducing an electron beam into said passageway, induction means providing a magnetic field having substantial circumferential components in said passageway, and means adjacent the other end of said passageway for collecting the electrons from said electron gun.

12. The device as set forth in claim 11 in which means are provided for varying the output velocity of the electrons emitted by said electron gun.

13. In a cathode ray tube, an evacuated chamber including an annular passageway of generally cylindrical configuration, first induction means for providing a magnetic field generally parallel with the axis of said cylindrical passageway, second induction means for providing a magnetic field having substantial circumferential components within said passageway, electrical means within and adjacent one end of said passageway for providing a stream of electrons in said passageway, and a collector electrode within and adjacent the other end of said passageway.

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