Aug. 15, 1967 T. R. O'MEARA 3,336,499

DISPLAY DEVICE WITH PLASMA DISCHARGE PROPAGATING DELAY LINE READ-IN

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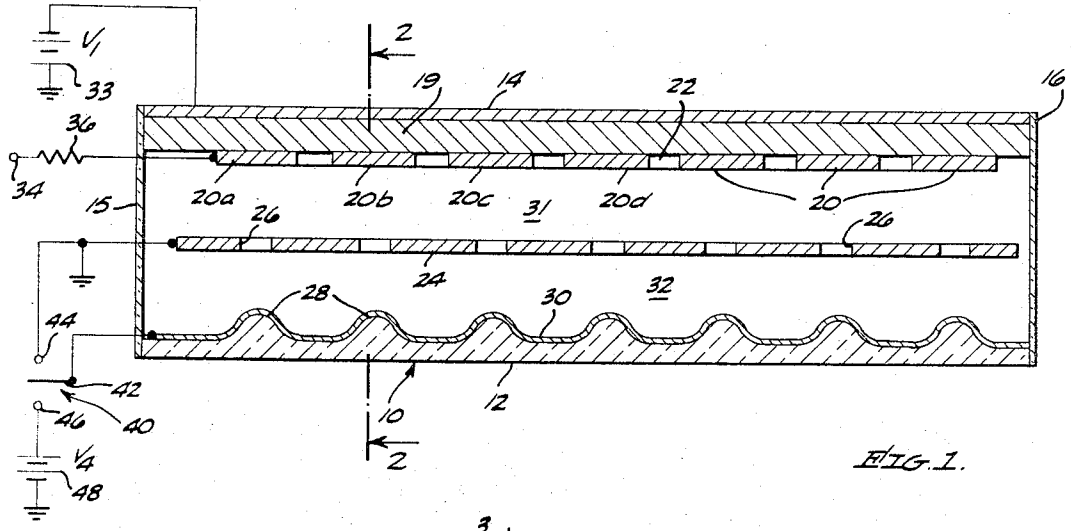


FIG. 1.

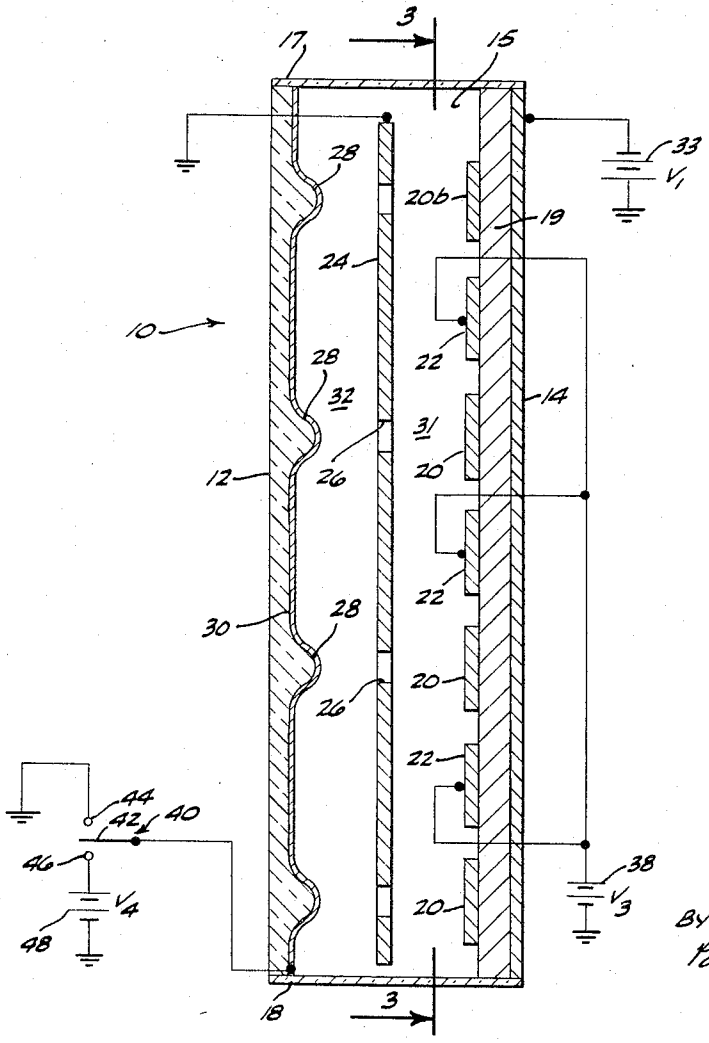


FIG. 2.

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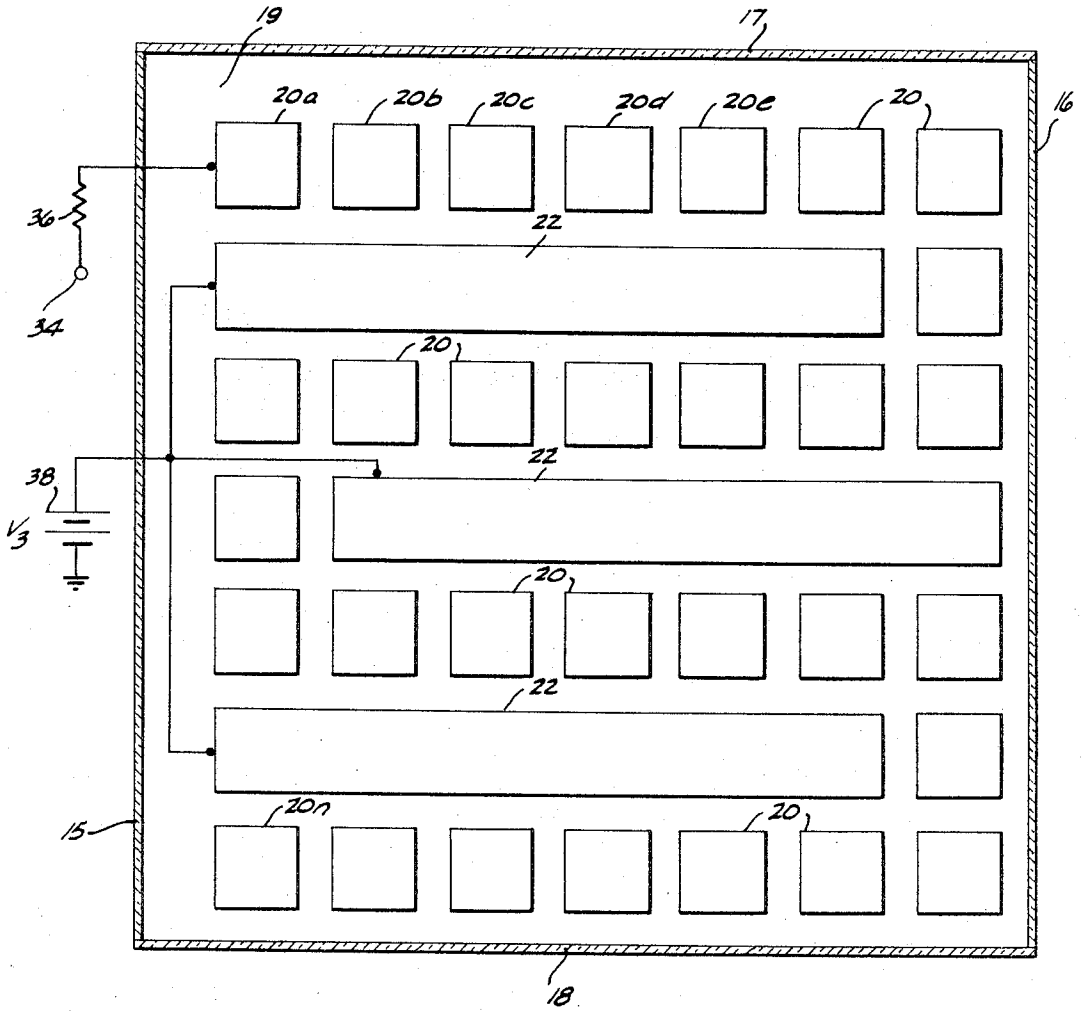


FIG. 3.

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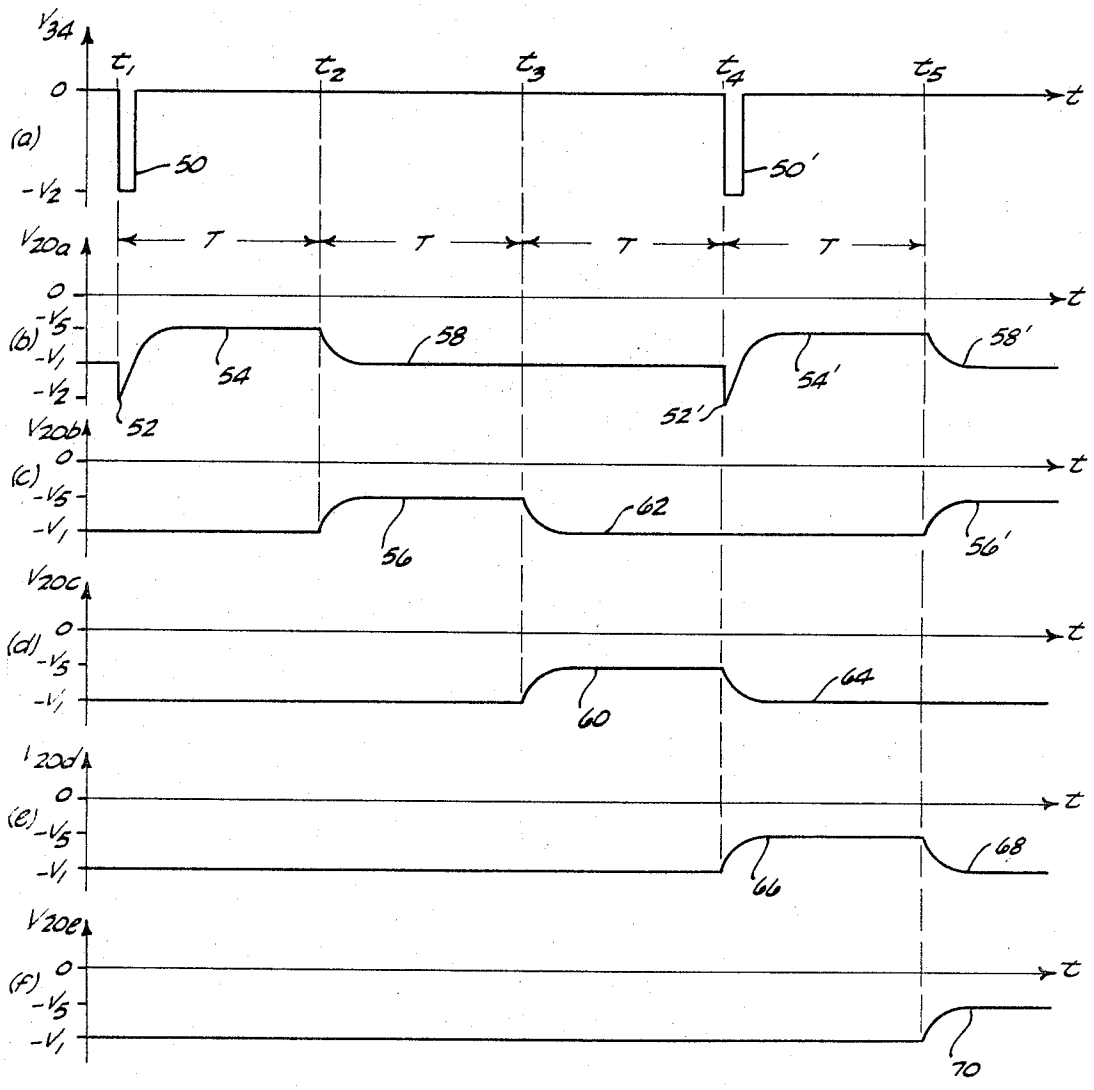


FIG. 4.

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DISPLAY DEVICE WITH PLASMA DISCHARGE PROPAGATING DELAY LINE READ-IN

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This invention relates to the visual display of electrical information, and more particularly relates to a display device in which binary electrical signals are sequentially read into the device by means of a plasma discharge propagating delay line, after which a plasma discharge display of the information read in is provided.

In the past the visual display of electrical information has been afforded by such devices as storage tubes and cathode ray tubes in which electrical information is read into the device by means of an electron beam. However, in order to provide display devices having longer life and lower power requirements, recent emphasis has been placed on solid state display arrangements which may, for example, take the form of a matrix of perpendicular transparent conductive strips disposed on opposite surfaces of a layer of electroluminescent material. Not only do such solid state display devices require a complex logic address system in order to energize the desired conductive strips, but also spurious illumination often occurs as a result of partial energization. Although such spurious illumination has been eliminated by reading information into the display device by means of an electrical delay line, the informational signals traveling along the delay line become attenuated as a function of distance along the line, resulting in distortion of the displayed image.

Accordingly, it is an object of the present invention to provide a display device which employs a delay line to read electrical information into the device without attenuating the informational signals traveling along the delay line.

It is a further object of the present invention to provide an electrical information display device which does not require a complex logic address system.

It is a still further object of the present invention to provide a device for visually displaying binary electrical information with greater resolution of image detail than prior art devices employing delay line read-in.

It is still another object of the present invention to provide a display device which, in addition to possessing a simple and accurate information read-in arrangement, displays the information with an intense, bright display.

In accordance with the foregoing objects, a display device according to the present invention includes a housing having an electrically conductive transparent wall along a portion thereof, and which housing contains a gaseous medium capable of sustaining plasma discharge. A plurality of electrodes are mounted in the housing in a plane spaced from the transparent wall, with electrical resistance being provided between each of the electrodes and an electrically conductive element. Electrically conductive means mounted within the housing between the electrodes and the transparent wall define a plurality of apertures aligned with respective ones of the electrodes. A first voltage of a magnitude less than the ionization potential of the gaseous medium is applied between the electrically conductive element and the electrically conductive

means. A second voltage is applied between one of the electrodes and the electrically conductive means to initiate plasma discharge in a region of the gaseous medium between the one electrode and the electrically conductive means. The plasma discharge so generated propagates to regions of the gaseous medium between other ones of the electrodes and the electrically conductive means. A third voltage is subsequently applied between the electrically conductive transparent wall and the electrically conductive means to develop plasma discharge in a region of the gaseous medium between the electrically conductive means and the transparent wall which is coupled via one of the apertures in the electrically conductive means to a region of the gaseous medium in which plasma discharge exists at the time of application of the third voltage.

Additional objects, advantages and characteristic features of the present invention will become readily apparent from the following detailed description of a preferred embodiment of the invention when considered in conjunction with the accompanying drawing in which:

FIGURE 1 is a sectional view illustrating a display device according to the invention;

FIG. 2 is a sectional view taken along line **2**—**2** of FIG. 1;

FIG. 3 is a sectional view taken along line **3**—**3** of FIG. 2; and

FIGS. 4(*a*)–(*f*) are graphs depicting the voltage at various locations in the device of FIGS. 1–3 as a function of time.

Referring with greater particularity to the drawing, a display device according to the present invention may be seen to include a housing **10** having a front wall **12** of a transparent material such as glass, a rear wall **14** of electrically conductive material such as aluminum or copper, and side walls **15**, **16**, **17** and **18** of electrically insulating material such as glass, although it is pointed out that the side walls need not be transparent. Disposed on the inner surface of the electrically conductive wall **14** is a layer **19** of electrically resistive material such as a vapor deposited nickel-chromium film. Disposed on the broad surface of the resistive layer **19** remote from the wall **14** are a plurality of electrodes which may be formed by vapor depositing a metal such as gold, aluminum or copper onto the layer **19**. As may best be seen from FIG. 3, included among the electrodes on the layer **19** are a plurality of like equally spaced dot-like electrodes **20** (some of which are given lettered suffix designations such as **20***a*, **20***b*, etc. to facilitate referencing to particular ones of the electrodes **20**) which are successively arranged in a chain-like zigzag pattern commencing with electrode **20***a* at one end of the chain and terminating with electrode **20***n* at the other end of the chain. Although the electrodes **20** are illustrated as being of square shape, it is pointed out that they may be of other geometries such as circular Also included among the electrodes on the layer **19** are a plurality of strip electrodes **22** which are interposed between adjacent non-successive ones of the electrodes **20** in the chain-like pattern.

An electrically conductive plate **24** is mounted within the housing **10** in a plane parallel to the resistive layer **19** a preselected distance away from the electrodes **20** and **22**. The plate **24** is provided with a plurality of apertures **26** which may have a circular, square, or other shape and which are aligned with the central regions of

the respective dot-like electrodes **20**. The transparent front wall **12** of the housing **10**, which functions as a display surface, is provided with a plurality of bump-like portions **28** which extend away from the plane of the wall **12** in a direction toward the plate **24** in regions aligned with the respective apertures **26**. A transparent electrically conductive film **30**, which may be of tin oxide for example, is disposed on the inner surface of the wall **12**. The interior of the housing **10** is filled with a gas which is capable of sustaining a plasma discharge. Examples of such a gas are lithium and the noble gases such as helium, neon and argon.

The region **31** between the electrodes **20** and the plate **24** functions in accordance with a plasma discharge propagation phenomenon to be described below as a delay line which sequentially reads electrical information into the device **10** and stores the information until the read-in operation has been completed. The gas located in region **32** between the plate **24** and the electrically conductive film **30** functions to provide a simultaneous plasma discharge display of the information read into the delay line region **31** after completion of the read-in operation.

In order to initially prevent plasma discharge from occurring in the gas contained in the delay line region **31**, a bias potential of a magnitude less than the ionization potential of the gas is provided between housing wall **14** and plate **24**. This may be accomplished by connecting the plate **24** to a level of reference potential designated as ground, while connecting the wall **14** to the negative terminal of a source of potential **33** which furnishes a voltage V_1 of -80 volts, for example.

Input pulses representative of electrical information to be read in are applied to the device at an input terminal **34** which is connected via a resistor **36**, to the electrode **20***a* at the input end of the chain-like electrode pattern. The input pulses applied to the terminal **34** should provide a voltage V_2 sufficient to initiate plasma discharge in the gas contained in the region between the electrode **20***a* and the plate **24**, a typical exemplary value of V_2 being -120 volts. In order to prevent plasma discharge propagation between non-successive electrodes **20** in the chain-like pattern in a manner to be described more fully below, the strip electrodes **22** are biased to a desired blocking potential which may be furnished from a potential source **38** providing a voltage V_3 of $+90$ volts, for example.

As has been mentioned above, after completion of the read-in operation in the delay line region **31**, a simultaneous plasma discharge display of the information contained in the region **31** is provided in the display region **32**. In order to initiate the plasma discharge display a switch **40** is provided which in practice would be an electronic switch which is automatically triggered at the completion of the read-in operation. However, for purposes of illustration the switch **40** is shown as a mechanical switch having a contact arm **42** connected to the conductive layer **30**, and which contact arm is movable between a grounded terminal **44** and the positive terminal **46** of a source of potential **48** which provides a display control voltage V_4 of $+80$ volts, for example.

In the operation of the display device of the present invention, now to be described with reference to waveforms of FIG. 4, under quiescent conditions the contact arm **42** of the switch **40** is in contact with the ground terminal **44** so that no potential difference exists between the plate **24** and the transparent conductive layer **30**. Moreover, since no current flows through the resistive layer **19**, the electrodes **20** reside at a potential of $-V_1$ which is smaller in magnitude than the ionization potential of the gaseous medium in the chamber **10**. Thus, no plasma discharges occur within the device at this time.

As is shown in FIG. 4(*a*), at a time t_1 an input pulse **50** is applied to the input terminal **34** to read the first item of information into the delay line portion **31** of the display device. In an exemplary information code which may be employed in connection with the display device of the invention, input information may take the form of binary electrical signals such as pulse **50** in which the presence of a pulse **50** indicates a binary "1," for example, while the absence of such a pulse during a time which would otherwise be a pulse time designates a binary "0," for example. Upon the commencement of the pulse **50** the potential V_{20a} of the first electrode **20***a* in the chain-like pattern assumes the input pulse level $-V_2$ as shown at **52** in FIG. 4(*b*). The potential difference between the electrode **20***a* and the plate **24** thus becomes sufficient to initiate a plasma discharge in the region between the electrode **20***a* and the opposing surface of the plate **24**, thereby generating electrons, ions and photons in the discharge region. Electron and ion current flow rapidly commences in the space between the plate **24** and the electrode **20***a*, causing an electron current to also flow through the resistive layer **19** between the electrode **20***a* and the conductive wall **14**. These currents are sufficient to raise the potential of the electrode **20***a* to a level $-V_5$, which may be around -40 volts for example, as shown by the waveform portion **54** of FIG. 4(*b*).

As some of the ions, electrons and photons travel laterally in the space **31** between the plate **24** and the electrodes **20** lateral expansion of the plasma discharge occurs. At a time t_2 which occurs a predetermined characteristic plasma discharge propagation time T after the time t_1, sufficient plasma particles (e.g. photons, electrons and ions) have entered the space between the second electrode **20***b* in the chain-like pattern and the plate **24** to initiate a plasma discharge in region between the electrode **20***b* and the opposing surface of the plate **24**. Upon commencement of the plasma discharge in the region between plate **24** and electrode **20***b* the plasma discharge in the region between plate **24** and electrode **20***a* ceases, thereby causing the plasma discharge to effectively propagate from the region adjacent the electrode **20***a* to the region adjacent the electrode **20***b*. The theory underlying this plasma propagation phenomenon is not completely understood at this time. However, in order to gain greater familiarity with the principles and mechanisms involved reference may be made to H. J. Hamilton, "Use of Gas-ion Processes in Modeling Excitable Membrane" Neural Theory and Modeling, Proceedings 1962 Ojai Symposium, pages 213–231 and especially pages 215–218.

During the time interval t_1–t_2 when a plasma discharge is present in the region between plate **24** and electrode **20***a*, positive ions which attempt to propagate in the direction of the strip electrode **22** are repelled by the relatively high positive potential $+V_3$ on the electrode **22**, while electrons propagating in this direction are absorbed by the electrode **22**. Thus, the electrode **22** prevents the plasma discharge from propagating to the electrodes **20** on the other side of the electrode **22**, thereby further channeling the plasma propagation into the next successive electrode **20** in the chain-like pattern.

Upon commencement of the plasma discharge in the region adjacent the electrode **20***b* and cessation of the plasma discharge in the region adjacent the electrode **20***a* the potential V_{20b} of the electrode **20***b* is raised to the level $-V_5$ as shown by the waveform portion **56** of FIG. 4(*c*), while the potential V_{20a} of the electrode **20***a* returns to the quiescent level $-V_1$ as shown by the waveform portion **58** of FIG. 4(*b*). After the plasma discharge in the region between the plate **24** and the electrode **20***a* becomes extinguished, this region is rendered incapable of sustaining a new plasma discharge for a recovery time which is greater than the plasma propagation time T but less thn twice the plasma propagation time 2T.

At a time t_3, which occurs one plasma discharge propagation time T subsequent to the time t_2, a plasma dis-

charge is initiated in the space between the next electrode **20***c* in the chain and the opposing surface of the plate **24**, while the plasma discharge in the region adjacent the electrode **20***b* terminates. Although some of the plasma particles from the region between plate **24** and electrode **20***b* may propagate back into the region between plate **24** and electrode **20***a*, the gas in this latter region is still in a recovery condition and at this time is incapable of sustaining a new plasma discharge. Thus, plasma propagation in a backward direction is prevented. Upon commencement of a plasma discharge in the region adjacent the electrode **20***c* and termination of the discharge in the region adjacent the electrode **20***b*, the potential V_{20c} of the electrode **20***c* is raised to the level $-V_5$ as shown by the waveform portion **60** of FIG. 4(*d*), while the potential V_{20b} of the electrode **20***b* returns to the quiescent level $-V_1$ as shown by the waveform portion **62** of FIG. 4(*c*).

At a time t_4, which occurs one plasma discharge propagation time T after the time t_3, the gas in the region between the plate **24** and the first electrode **20***a* has recovered sufficiently so that a new plasma discharge may be sustained therein, and at this time another input pulse may be applied to the terminal **34** to read the next item of information into the delay line portion **31** of the display device. Thus, it may be seen that the repetition rate of the input pulses applied to the display device of the invention should be selected so that the pulse period is an integral multiple not less than three times the plasma discharge propagation time T.

Accordingly, as may be seen from FIG. 4(*a*), at time t_4 another input pulse **50'** is applied to the input terminal **34** to read another binary "1" into the display device. Of course, in accordance with the aforementioned exemplary code, no pulse would be applied to the terminal **34** at time t_4 in the event of a binary "0" were to be read in at this time. As a result of receipt of the input pulse **50'**, a new plasma discharge is initiated in the region between plate **24** and electrode **20***a* in the same manner as discussed above, causing the potential V_{20a} of the electrode **20***a* to initially drop to the level $-V_2$ and then rise to the level $-V_5$ as shown at **52'** and **54'**, respectively, in FIG. 4(*b*). Moreover, in accordance with the plasma discharge propagation discussed above, at time t_4 the plasma discharge in the region between plate **24** and electrode **20***c* terminates as shown by the drop in the potential V_{20c} of the electrode **20***c* along waveform portion **64** of FIG. 4(*d*), while a plasma discharge is commenced in the region between plate **24** and electrode **20***d* as shown by the rise in the potential V_{20d} of the electrode **20***d* along the waveform portion **66** of FIG. 4(*e*).

At a time t_5, which occurs one plasma discharge propagation time T following the time t_4, the plasma discharge in the region between plate **24** and electrode **20***a* terminates as illustrated by the drop in the potential V_{20a} of the electrode **20***a* along waveform portion **58'** of FIG. 4(*b*), while a plasma discharge in the region between plate **24** and electrode **20***b* commences as shown by the rise in the potential V_{20b} of the electrode **20***b* along waveform portion **56'** of FIG. 4(*c*). Also, at time t_5 the plasma discharge in the region between plate **24** and electrode **20***d* terminates as illustrated by the drop in the potential V_{20d} of the electrode **20***d* along waveform portion **68** of FIG. 4(*e*), while a plasma discharge in the region between plate **24** and electrode **20***e* is initiated as shown by the rise in the potential V_{20e} of the electrode **20***e* along waveform portion **70** of FIG. 4(*f*).

Plasma discharge propagation continues in the region **31** along the chain-like pattern of electrodes **20** in the same manner as described above, and eventually a plasma discharge resulting from information initially read into the device at time t_1 is commenced in the region between the plate **20** and the last electrode **20***n* in the chain, thereby completing the read-in operation. In order to provide a simultaneous plasma discharge display of the information now contained in the delay line region **31**, immediately after commencement of a plasma discharge in the region adjacent the electrode **20***n*, the contact arm **42** of the switch **40** is moved into contact with the terminal **46** to apply the potential $+V_4$ to the transparent conductive layer **30**. Plasma particles from those regions between plate **24** and electrodes **20** in which a plasma discharge presently exists pass through the respective adjacent apertures **26** into adjacent portions of the display region **32**. A plasma discharge is developed in each portion of the display region **32** between a display surface raised portion **28** and an aperture **26** which is aligned with a delay line region wherein a plasma discharge is present. Thus, a plurality of intense plasma discharges occur in the display region **32** at locations corresponding to delay line electrode locations where binary "1's" are presently stored, thereby providing the desired display of information.

It will be apparent that since the display device of the present invention employs a delay line to read information into the device, a complex logic address system is not required. At the same time, since the plasma discharge propagating delay line of the present invention does not attenuate the informational signals as they propagate along the line, distortion of the displayed image is avoided. Moreover, the resultant image provided by the display device of the present invention is extremely bright and well defined.

Although the invention has been shown and described with reference to a particular embodiment, nevertheless various changes and modifications obvious to a person skilled in the art to which the invention pertains are deemed to lie within the purview of the invention.

What is claimed is:

1. A display device comprising: a housing having an electrically conductive transparent wall along a portion thereof, said housing containing a gaseous medium capable of sustaining plasma discharge, a plurality of electrodes mounted in said housing in a plane spaced from said transparent wall, an electrically conductive element, means for providing electrical resistance between each of said electrodes and said electrically conductive element, electrically conductive means mounted within said housing between said electrodes and said transparent wall and defining a plurality of apertures aligned with respective ones of said electrodes, means for applying between said electrically conductive element and said electrically conductive means a first voltage of a magnitude less than the ionization potential of said gaseous medium, means for applying between one of said electrodes and said electrically conductive means a second voltage sufficient to initiate plasma discharge in a region of said gaseous medium between said one electrode and said electrically conductive means, whereby said plasma discharge propagates to regions of said gaseous medium between other ones of said electrodes and said electrically conductive means, and means for applying between said electrically conductive transparent wall and said electrically conductive means a third voltage sufficient to develop plasma discharge in a region of said gaseous medium between said electrically conductive means and said transparent wall which is coupled via one of said apertures to a region of said gaseous medium in which plasma discharge exists at the time of application of said third voltage.

2. A display device according to claim **1** wherein said gaseous medium includes a noble gas.

3. A display device according to claim **1** wherein said electrically conductive transparent wall defines a plurality of portions extending away from the plane of said wall in a direction toward said electrically conductive means, each said extending portion being aligned with a different one of said apertures in said electrically conductive means.

4. A display device comprising: a housing having an electrically conductive transparent wall along one side

thereof, said housing containing a gaseous medium capable of sustaining plasma discharge, an element of electrically resistive material mounted in said housing in a plane parallel to the plane of said transparent wall, a plurality of electrodes disposed in a predetermined pattern on the broad surface of said resistive element facing said transparent wall, an electrically conductive plate mounted within said housing between said electrodes and said transparent wall in a plane parallel to said broad surface of said resistive element, said plate defining a plurality of apertures aligned with respective ones of said electrodes, means for applying between the opposite broad surface of said resistive element and said plate a first voltage of a magnitude less than the ionization potential of said gaseous medium, means for applying between one of said electrodes and said plate a second voltage sufficient to initiate plasma discharge in a region of said gaseous medium between said one electrode and said plate, whereby said plasma discharge propagates to regions of said gaseous medium between other ones of said electrodes and said plate, and means for applying between said electrically conductive transparent wall and said plate a third voltage sufficient to develop plasma discharge in a region of said gaseous medium between said plate and said transparent wall which is coupled via one of said apertures to a region of said gaseous medium in which plasma discharge exists at the time of application of said third voltage.

5. A display device comprising: a housing having an electrically conductive transparent wall along a portion thereof, said housing containing a gaseous medium capable of sustaining plasma discharge, a plurality of electrodes mounted in said housing in a plane spaced from said transparent wall, said electrodes being arranged in a chain-like pattern in said plane, an electrically conductive element, means for providing electrical resistance between each of said electrodes and said electrically conductive element, electrically conductive means mounted within said housing between said electrodes and said transparent wall and defining a plurality of apertures aligned with respective ones of said electrodes, means for applying between said electrically conductive element and said electrically conductive means a first voltage of a magnitude less than the ionization potential of said gaseous medium, means for applying between the electrode at one end of said chain-like pattern and said electrically conductive means a second voltage sufficient to initiate plasma discharge in a region of said gaseous medium between the said electrode and said electrically conductive means, whereby said plasma discharge propagates sequentially along said chain-like pattern to regions of said gaseous medium between respective successive ones of said electrodes in said pattern and said electrically conductive means, and means for applying between said electrically conductive transparent wall and said electrically conductive means a third voltage sufficient to develop plasma discharge in a region of said gaseous medium between said electrically conductive means and said transparent wall which is coupled via one of said apertures to a region of said gaseous medium in which plasma discharge exists at the time of application of said third voltage.

6. A display device comprising: a housing having an electrically conductive transparent wall along a portion thereof, said housing containing a gaseous medium capable of sustaining plasma discharge, a plurality of like equally spaced first electrodes mounted in said housing in a plane spaced from said transparent wall, said first electrodes being successively arranged in a chain-like pattern in said plane, at least one second electrode mounted in said housing in said plane between adjacent non-successive ones of said first electrodes in said chain-like pattern, an electrically conductive element, means for providing electrical resistance between each of said first and second electrodes and said electrically conductive element, electrically conductive means mounted within said housing between the plane of said first and second electrodes and said transparent wall and defining a plurality of apertures aligned with respective ones of said first electrodes, means for applying between said electrically conductive element and said electrically conductive means a first voltage of a magnitude less than the ionization potential of said gaseous medium, means for applying between the first electrode at one end of said chain-like pattern and said electrically conductive means a second voltage sufficient to initiate plasma discharge in a region of said gaseous medium between the said first electrode and said electrically conductive means, whereby said plasma discharge propagates sequentially along said chain-like pattern to regions of said gaseous medium between respective successive ones of said first electrodes in said pattern and said electrically conductive means, means for biasing said second electrode to a potential sufficient to prevent the propagation of said plasma discharge between non-successive ones of said first electrodes in said chain-like pattern, and means for applying between said electrically conductive transparent wall and said electrically conductive means a third voltage sufficient to develop plasma discharge in a region of said gaseous medium between said electrically conductive means and said transparent wall which is coupled via one of said apertures to a region of said gaseous medium in which plasma discharge exists at the time of application of said third voltage.

7. A device for providing a visual display of binary electrical information comprising: a housing having an electrically conductive transparent wall along a portion thereof, said housing containing a gaseous medium capable of sustaining plasma discharge, a plurality of electrodes mounted in said housing in a plane spaced from said transparent wall, said electrodes being arranged in a chain-like pattern in said plane, an electrically conductive element, means for providing electrical resistance between each of said electrodes and said electrically conductive element, electrically conductive means mounted within said housing between said electrodes and said transparent wall and defining a plurality of apertures aligned with respective ones of said electrodes, means for applying between said electrically conductive element and said electrically conductive means a DC voltage of a magnitude less than the ionization potential of said gaseous medium, means for applying between the electrode at one end of said chain-like pattern and said electrically conductive means a series of voltage pulses representative of binary electrical information to be displayed, each of said pulses being of such magnitude and polarity to initiate plasma discharge in a region of said gaseous medium between the said electrode and said electrically conductive means, whereby each plasma discharge generated in said region propagates sequentially along said chain-like pattern to regions of said gaseous medium between respective successive ones of said electrodes in said pattern and said electrically conductive means, and means for applying between said electrically conductive transparent wall and said electrically conductive means at a predetermined time after the application of the first of said series of voltage pulses to said electrode a display control voltage sufficient to develop plasma discharges in respective regions of said gaseous medium between said electrically conductive means and said transparent wall which are coupled via respective ones of said apertures to those regions of said gaseous medium in which a plasma discharge exists at the time of application of said display control voltage, whereby a plasma discharge display of the binary electrical information represented by said series of voltage pulses is provided.

8. A device according to claim 7 wherein said voltage pulses have a pulse repetition period equal to an integral multiple not less than three times the plasma discharge propagation time between successive ones of said regions between said electrodes in said pattern and said electrically conductive means.

9. A device according to claim 7 wherein said display control voltage is applied immediately after a plasma discharge is developed in the region of said gaseous medium between the electrode at the other end of said chain-like pattern and said electrically conductive means.

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