Dec. 6, 1966 J. J. LAMBE ETAL 3,290,549

ELECTROLUMINESCENT DISPLAY DEVICE WITH PIEZOELECTRICAL SCANNING AND GATING MEANS

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FIG. 1.

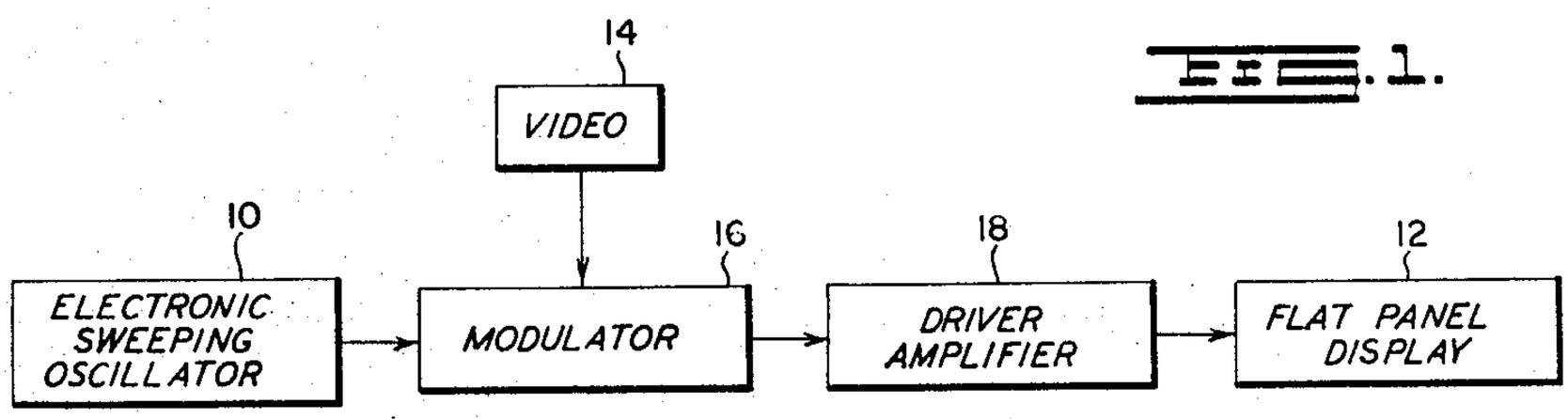


FIG. 2.

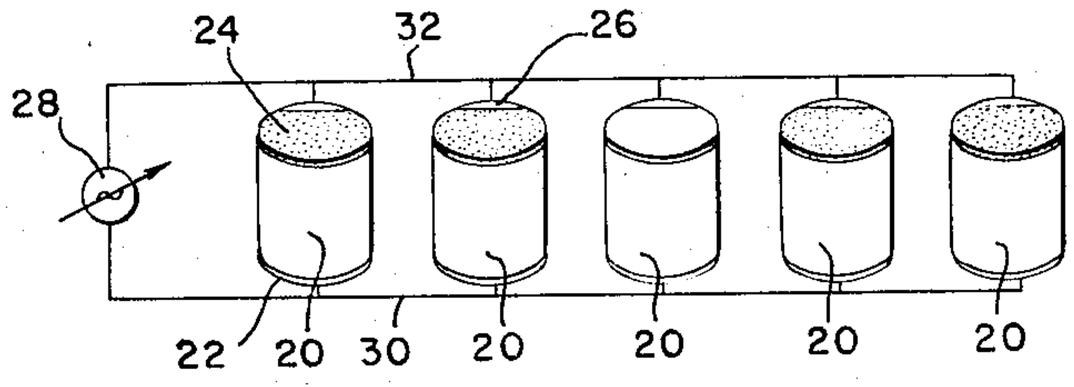


FIG. 3.

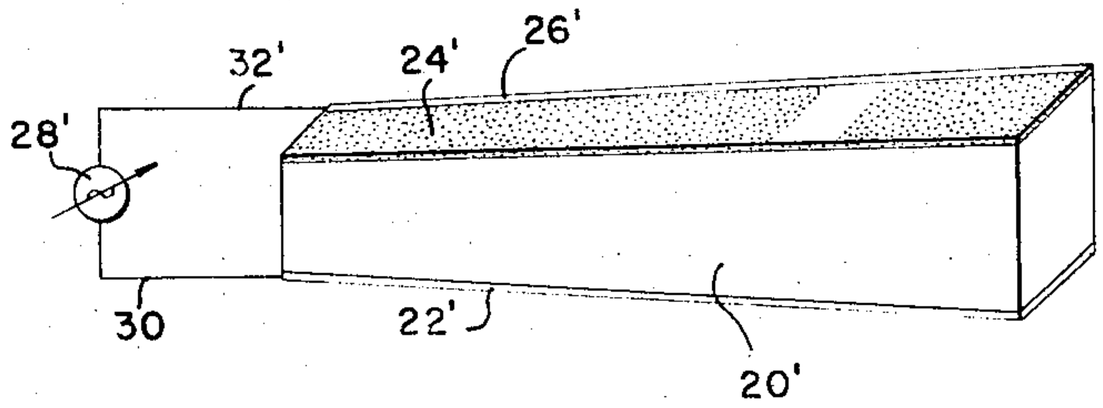
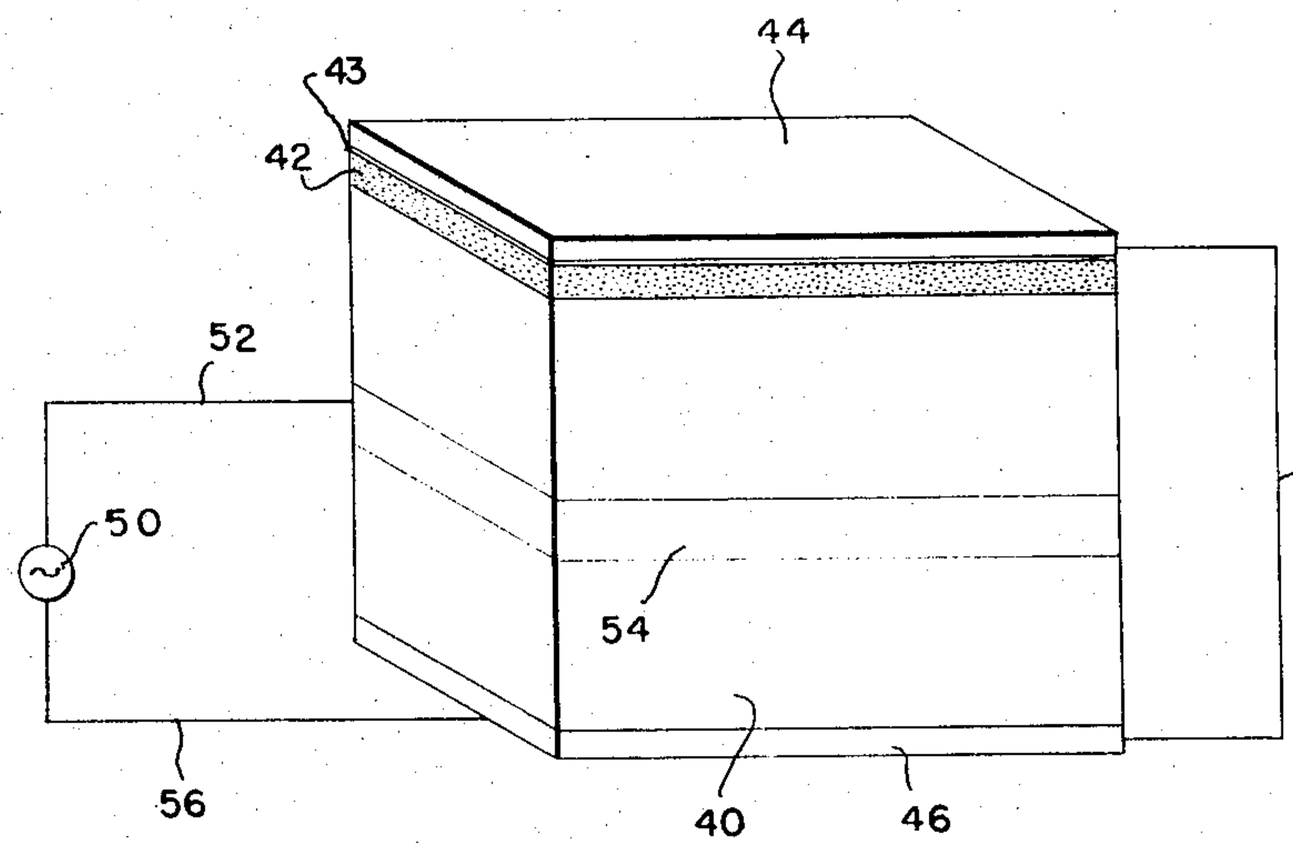


FIG. 4.



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Fig. 5.

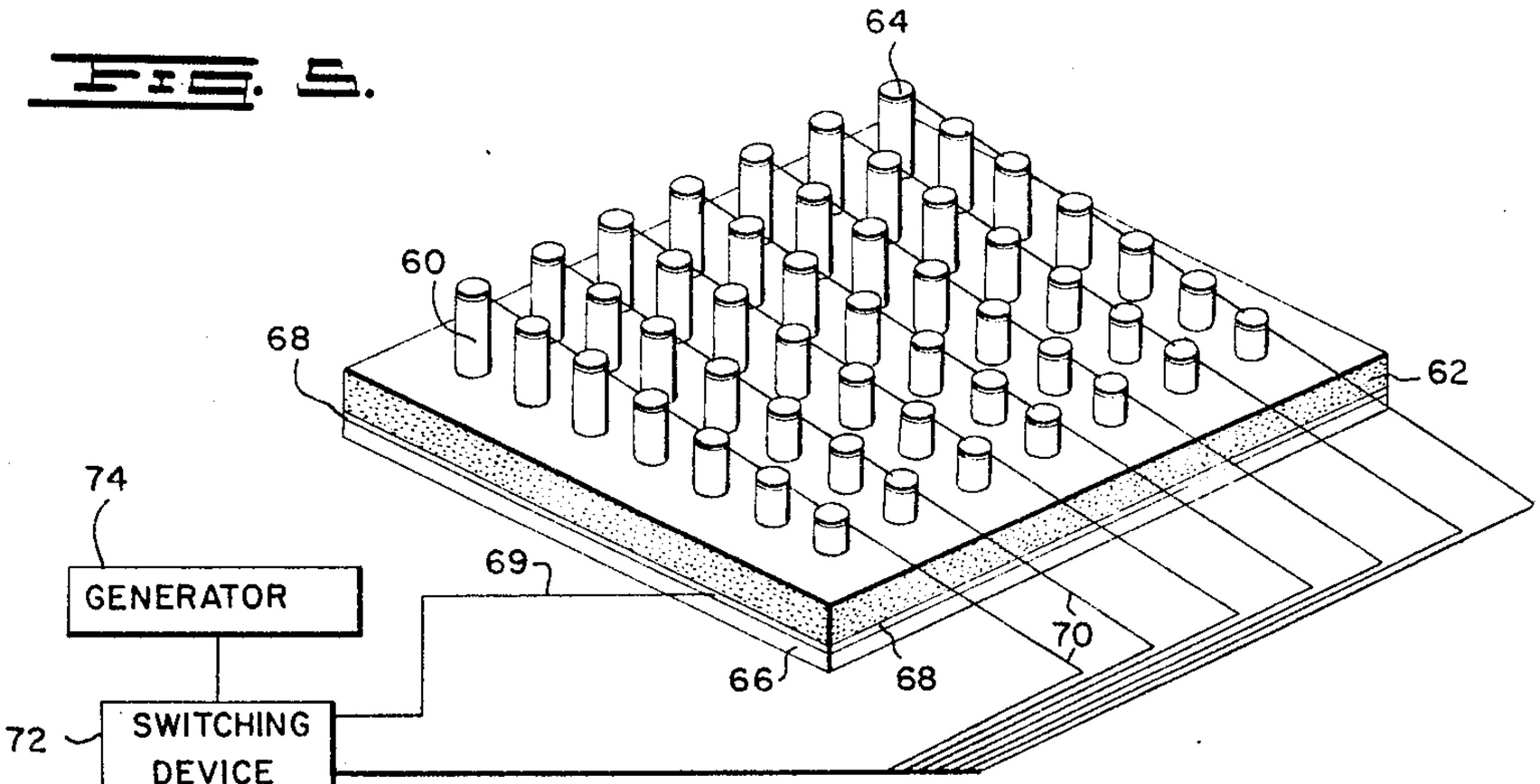


Fig. 6.

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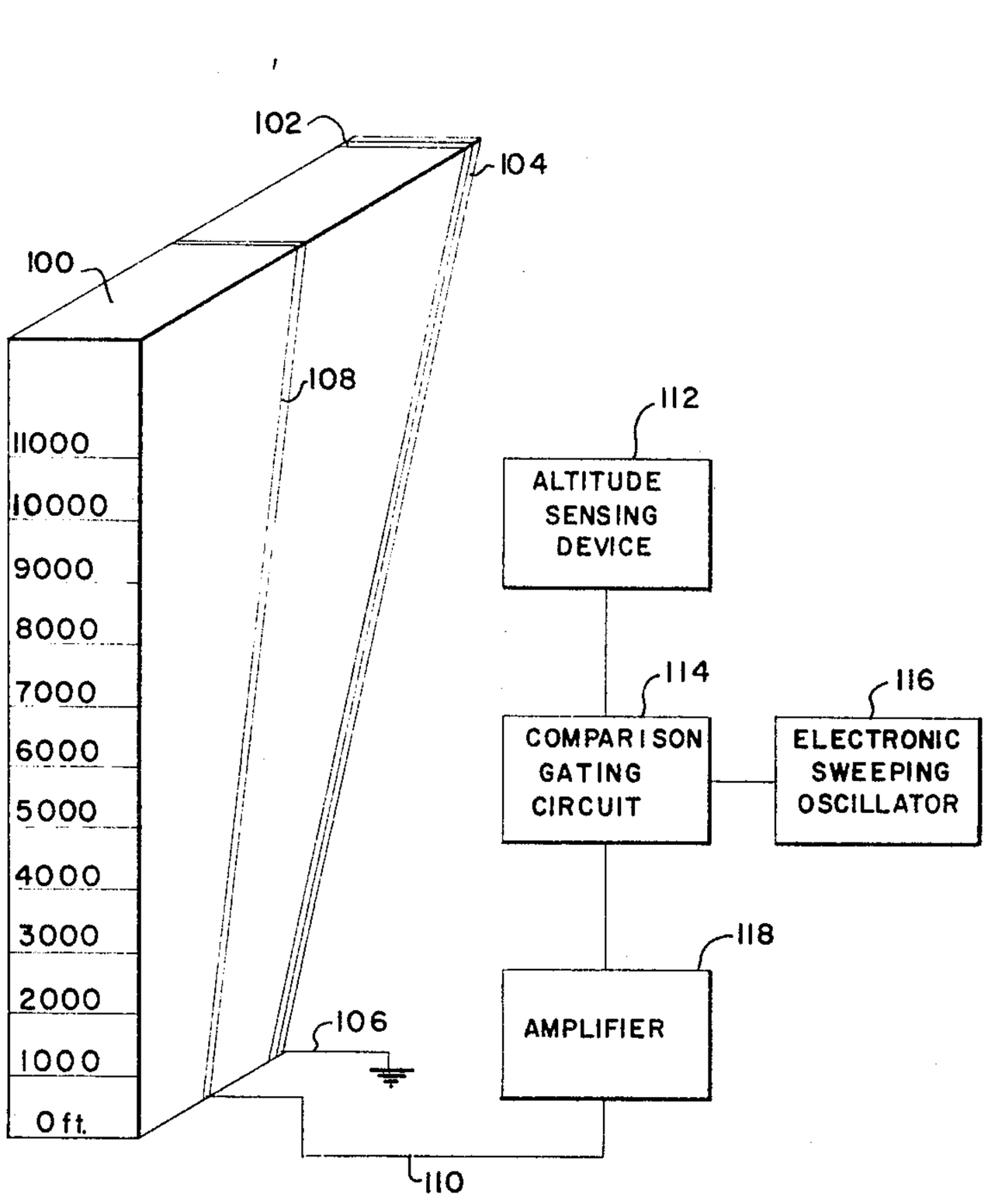


FIG. 7

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ELECTROLUMINESCENT DISPLAY DEVICE WITH PIEZOELECTRICAL SCANNING AND GATING MEANS

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2 Claims. (Cl. 315—55)

The present invention relates to display devices and, more particularly, to a display device employing an electroluminescent light emitting phosphor of which selective areas may be energized by an electric field established by one or more piezoelectric crystal elements.

The conventional electroluminescent display devices which are capable of effecting energization of selected areas of the light-emitting phosphor material typically comprise a first grid of spaced parallel conductors, a second grid of spaced parallel conductors spaced in electrically insulated relationship with the first grid, the conductors of the second grid running at substantially a right angle to the conductors of the first grid, and a phosphor layer positioned between the grids. The phosphor layer is composed of an electroluminescent phosphor emitting light phased with the applied voltage. In operation, a switching arrangement is employed to simultaneously energize selective ones of the conductors of the first and second grids to generate an intense electric field in localized regions of the device where the conductors cross one another. The electric field causes the phosphor to luminesce as a spot and by proper synchronization of the switching arrangement, a spot can be made to traverse the phosphor layer and thereby create a raster. By modulation of the applied voltage, it is possible to vary the intensity of the emitted light and thereby display information much in the same manner as in conventional television receiver systems.

A typical system employing such a device is illustrated and described in U.S. Patent 2,698,915 entitled "Phosphor Screen," William W. Piper.

The conventional crossed grid type of electroluminescent display devices have certain disadvantages which the present invention overcomes. Among these disadvantages is the necessity for the use of a high-speed precision switch with which it is difficult to obtain high resolution. Colored displays are impractical as it is necessary in order to obtain color displays to use a plurality of superposed layers of different color light emitting phosphors, each layer having its own crossed grid network. And, thirdly, control requirement on the phosphor circuitry, and voltages are severe in order to avoid electroluminescence by sufficiently high electric field being developed in areas other than the cross-over points of the conductors, causing a background problem.

It is an object of the present invention to produce an electroluminescent display device wherein discrete areas thereof may be selectively energized by varying the frequency of the energizing potential.

A further object of the invention is to produce an electroluminescent display device capable of exceedingly good resolution, definition, and brightness characteristics.

The invention typically may be defined as an electroluminescent display device comprising a piezoelectric crystal structure shaped to provide zones of differential response to oscillating potentials, electroluminescent means responsive to an electric field positioned as a coating on the surface of the crystal structure, and means for applying an oscillating potential to the structure to create an electric field at a surface zone of the structure; which

zone is determined by the frequency of the applied potential.

Other objects and advantages of the invention will be manifested from reading the following detailed description of several embodiments of the invention when considered in light of the accompanying drawings in which:

FIG. 1 is a diagrammatic illustration of a system capable of employing and energizing the invention;

FIG. 2 is a diagrammatic illustration of a basic principle of the invention wherein a plurality of discrete crystalline elements are adapted to energize the associated phosphor coatings;

FIG. 3 is a diagrammatic illustration of another embodiment of the invention wherein a single wedge-shaped crystalline element is employed to energize selected areas of an associated phosphor coating;

FIG. 4 is a diagrammatic illustration of an alternative arrangement for energizing an electroluminescent display device in accordance with the present invention;

FIG. 5 is a perspective view of a modification of the invention which is capable of displaying conventional video television signals wherein each scanning line of the device is similar to the arrangement shown in FIG. 2 being comprised of a plurality of individual crystalline cylinders, each provided with a coating of electroluminescent phosphor material on one surface thereof;

FIG. 6 is a perspective view of another modification of the invention which is capable of displaying conventional video television signals wherein each scanning line of the device is similar to the arrangement shown in FIG. 3 being comprised of a single wedge-shaped crystalline element being provided with a coating of electroluminescent phosphor material on one surface thereof; and

FIG. 7 is a diagrammatic illustration of an embodiment of the invention for use as an aircraft altitude meter.

The underlying principle of the present invention is that a luminescent light spot can be created and caused to move about on a panel surface of electroluminescent material by varying the frequency of the driving voltage applied to the means for establishing the electric field applied to the phosphor material. The intensity of the light output will depend upon the magnitude of the driving voltage, since this voltage, in turn, is responsible for the electric field strength applied to the phosphor. As shown in the schematic diagram of FIG. 1, an electronic sweep frequency oscillator **10** is actually all that is necessary to achieve a light spot movement on the display panel **12**, while a video input **14** is fed to a modulator **16** to provide for amplitude modulation of the driving voltage and thereby effect an intensity modulation of the resultant luminescent spot. The output of the modulator may be fed through a driver amplifier network **18**.

FIG. 2 illustrates one simple embodiment of a display device incorporating the principles of the invention. There is shown a plurality of piezoelectric cylinders **20**, each being provided with an electrically conductive coating **22** disposed on the bottom thereof. The top of each of the cylinders **20** is provided with an electroluminescent phosphor coating **24** and an electrically conductive coating **26**. It may be desirable in certain applications of the invention to insulatingly separate the coatings **24** and **26** by slight spacing therebetween or alternatively by disposing a dielectric material therebetween. It will be noted that the phosphor coating **24** consumes the majority of the area of the top of the cylinders **20**, while the electrically conductive coating **26** consumes only a small portion of the area of the top. The plurality of cylinders **20** is connected in electrically parallel relationship across a variable frequency generator **28** by electrically conductive leads **30** and **32**. The lead **30** is connected to the electrically conductive coating **22** on the bottom of the

cylinders **20**, while the lead **32** is connected to the electrically conductive coating **26** on the top of the cylinders **20**. Each of the cylinders **20** is formed of a crystalline material such as barium titanate and has its own resonating frequency, each differing from the other.

The phosphor layers **24** give off light through a phenomenon of electroluminescence which is a process by which certain semiconducting materials known as phosphors, emit radiant energy at room temperature under the primary stimulus of a varying electrical potential, which generates a varying electric field. Such phosphors include, for example, gallium phosphide and zinc sulfide activated with copper. While there are several scientific theories presently advanced to explain the mechanism by which electroluminescence occurs, a discussion of these theories is not essential in this description.

The material which is used to fabricate the crystalline cylinders **20** is a piezoelectric material and may be defined as one which exhibits a phenomenon of expansion along one axis and contracts on another axis when subjected to an applied voltage and in response thereto a strong polarization (electric) field is generated across its end surfaces. The intensity of the generated field is dependent upon the applied voltage. Such piezoelectric materials may be either single crystals as quartz, Rochelle salt, or ammonium dihydrogen phosphate; or they may be polycrystalline material such as ferroelectric barium or lead titanate ceramics which have been polarized.

With the above background, it will be appreciated that when a generator **28** is energized to produce a voltage of a frequency equal to the resonant frequency of one of the cylinders **20**, that cylinder will respond in its vibrational mode and a strong polarization (electric) field will be generated across its end surfaces. For purposes of illustration, we will assume that the generator **28** is producing a voltage of a frequency equal to the resonant frequency of the centermost cylinder **20** of the plurality illustrated in FIG. 2. The intensity of the field produced or developed by the resonating cylinder is dependent upon the voltage output of the generator **28**. The electric field established across the end surface of the resonating cylinder is sufficient to energize the electroluminescent coating **24** and thereby cause light to be emitted therefrom. It will be appreciated that by changing the frequency of the generator **28**, the different cylinders **20** can be made to respond selectively, with the light output following the tuned cylinder **20** and the light modulation being achieved by modulating the amplitude of the voltage output of the generator **28**.

Similar results, that is, the ability to effect selective area energization of an electroluminescent coating, may likewise be achieved by the structures shown in FIG. 3. In the structure shown in FIG. 3, a crystalline wedge **20'** similar to the cylinders **20** of FIG. 2, made of quartz or the like material, and is provided with an electrically conductive coating **22'** on the bottom surface thereof. An electroluminescent phosphor layer **24'** is coated on the major portion of the top of the wedge **20'** and an electrically conductive coating **26'** on the remaining portion of the top thereof. The wedge is electrically connected to frequency generator **28'** through conductors **30'** and **32'**. Localized resonance of the wedge **20'** is obtained by varying the frequency of the generator **28'** which will accordingly energize selective areas of the electroluminescent phosphor coating **24'**. Since the resonant frequency of the crystalline material of the wedge **30'** is a sharp function of the geometry of the wedge, localized resonance may be readily attained.

It will be appreciated that of primary importance in the application of device of the type already explained is that the movement of the light spot or energized area of the phosphor coating may be generated without the need for electrodes other than the conductive coatings on the top and bottom of piezoelectric material to be placed in close proximity to the display device. The electric field which is effective to energize the phosphor material is generated by polarization charges appearing at the surface of the crystal. These charges can be made to appear at surfaces to which no electrical connections are made. If the crystalline elements are properly shaped, the vibrational polarization fields can be induced with the electrodes placed a significant distance along the crystal away from the surface thereof which is coated with the phosphor layer.

It has been found advantageous in certain applications where it is desirable to obtain a maximum field across the surface of the energizing crystal to employ a structure such as shown in FIG. 4. In the arrangement illustrated in FIG. 4, there is a crystalline element **40** provided with an electroluminescent phosphor coating **42** on the upper surface thereof. A transparent electrically conducting coating **43**, such as stannic chloride on a sheet of glass **44**, is disposed over the entire uppermost surface of the phosphor coating **42**. The base of the element **40** is provided with an electrically conductive coating **46** which may in certain applications be transparent to thereby allow the light emitted from the phosphor coating **42** to be viewed from both sides, the crystalline material of the element **40** must either be transparent or translucent. Both the electrically conductive coatings, **43** and **46** are coupled together through an electrically conducting wire **48**. A generator **50**, capable of producing a variable frequency voltage, has one of its output terminals connected to an electrically conductive strip **54** through an electrically conducting wire **52**. The strip **54** is adapted to be in intimate contact with the side walls of the crystalline element **40**. The other output terminal of the generator **50** is connected to the electrically conductive coating **46** through an electrically conducting wire **56**.

In operation, the generator **50** is effective, when operated at the resonant frequency of the crystalline element **40**, to create an electric field across the surface thereof. The conducting coatings **43** and **46** provide a minimum path length for the electric field and, therefore, achieves maximum therein. This action is similar and can be compared to moving the plates of a parallel plate condenser closer to one another, while maintaining the same potention difference across the plates. Since the field intensity is given by the following relation:

$$E = v/d$$

where d is the distance between the plates and v is the voltage across the plates. Therefore, by maintaining a given applied voltage, the field intensity E may be increased by making the distance d between the plates smaller. It is also to be understood that the arrangement illustrated in FIG. 4 has an advantage in that the voltage applied directly to the electrode strip **54** also contributes a field across the electroluminescent phosphor layer **42** in addition to the polarization field created by the piezoelectric material of the crystal **40**.

This device also provides significant voltage amplification. The potential difference across the phosphor has been found to be three to four times the voltage driving the piezoelectric element (at resonance operation). Using a driving voltage of about 100 $v._{RMS}$, light output comparable to the TV type displays has been obtained.

In an application where the device is employed as a TV type display, for example, arrangements such as illustrated in FIGS. 5 and 6 may be used. In FIG. 5 an arrangement of piezoelectric cylinders **60** are disposed in a predetermined pattern on a layer **62** of an electroluminescent phosphor which, in turn, is desposited on a transparent supporting panel **66** formed of glass or the like material. The supporting panel **66** is provided with the transparent conductive coating **68**. The opposite end of the cylinders **60** are coated with an electrically conductive material **64**.

The various groups of cylinders **60** are connected to-

gether in rows in parallel by wires **69** and **70** to a switching device **72** which, in turn, is connected to a generator **74** capable of producing variable frequency signals. It will be noted that the cylinders **60** of each row vary in length from one side to another in an arrangement similar to that illustrated in FIGURE 22, therefore, each cylinder will resonate and establish an energizing field for the phosphor layer at a different frequency. When the generator **74** is tuned to a frequency at which one of the cylinders **60** will resonate, that cylinder will create an electric field at the end thereof in contact with the electroluminescent layer **62** and cause a localized zone thereof to fluoresce. The intensity of the field created by the individual cylinders **60** is a function of the voltage output of the generator **74**; the higher the voltage, the higher the intensity of the field and the resultant emitted light.

By varying the generator frequency, the various cylinders **60** of a single row may be made to respond one at a time, with the light output following the tuned cylinder, and the light modulated in accordance with the modulation of the generator voltage. At the completion of the energization of an entire row of cylinders **60**, the switching circuit **72** may be caused to switch the voltage signal produced by the generator **74**, to selectively energize adjacent rows of cylinders. It will be appreciated by those skilled in the art that by proper synchronization the cylinders **60** can be energized in such a manner as to produce a raster much in the same way a raster is produced in the conventional cathode ray tubes used in television reception.

Another embodiment of the invention is illustrated in FIG. 6 wherein an arrangement of piezoelectric wedges **80**, each being of the type illustrated in FIG. 3, is disposed on a layer **82** of an electroluminescent phosphor which, in turn, is deposited on a transparent electrically conductive coating **84**, of a supporting panel **86**. The opposite side of the wedges **80** from that in contact with the phosphor is provided with an electrically conductive coating **88**. Each wedge **80** is connected to a variable frequency generator **90** through a switching circuit **92** by an electrically conducting wire **89**. The wires **89** may be cabled together as shown. The conductive coating **84** is likewise connected to the switching device **92** through an electrically conducting wire **91**. The generator **90** is capable of producing variable frequency signals to cause various zones of the wedges **80** to resonate and thereby create associated electric fields to excite the electroluminescent phosphor **82**. Thereby a light spot can be produced and caused to move along a wedge **80** by merely varying the frequency of the generator **90**. Then, as in the embodiment illustrated in FIG. 5, the adjacent wedges **80** may be selectively energized by the switching circuit **92**. The resolution available with a wedge is determined mainly by the piezoelectric material from which the wedges are made and geometry of the wedge. For all intents and purposes, the embodiment illustrated in FIG. 6 is operated in the same manner as the embodiment of FIG. 5. Accordingly, if the generator **90** is operating to produce a voltage signal of a given frequency, only one spot on the energized wedge will establish a field of the proper intensity to cause light to be emitted from a single zone of the phosphor layer **82**. A change in the frequency of the applied voltage causes the light spot to move.

If bandwidth requirements permit, all of the wedges **80** can be placed electrically in parallel and by a single traversal through the frequency range, the spot would move over the entire panel.

With limited bandwidth requirements, the wedges **80** are connected as shown in FIG. 6 and are, in operation, frequency scanned one at a time in any desired sequence by the switching device **92** and will display video information by amplitude modulation of the electric field generator **90**.

With reference to FIG. 7, there is shown a system embodying the principles of the invention in an aircraft attitude meter. The system employs a single wedge-shaped crystalline element **100** similar to that illustrated in FIG. 3. The wedge element **100** is formed of quartz or other suitable material which is substantially transparent to the light emitted from an associated electroluminescent phosphor material layer **102** coated on one side of the element. A conductive coating **104** is applied to the outer surface of the phosphor layer **102** and may be a light transparent material such as stannic chloride in which case the light emitted from the phosphor coating may be viewed from two sides of the wedge element **100**, or may be formed of an opaque conducting material which would obviously permit viewing of the light emitted from the phosphor layer **102** only through the material of the element **100**. The conductive layer **104** may cover the entire exposed surface of the phosphor layer **102** as illustrated in FIG. 4 or may be applied in the manner illustrated in FIGS. 2 and 3. The conductive layer **104** is shown as being connected to ground potential through a conductive wire **106**.

A strip **108** of electrically conductive material, similar to the strip **54** of FIGURE 4, is applied to the side walls of the element **100** and is, in turn, connected to the energizing circuit through a conductive wire **110**.

The surface of the element **100** which is opposed to the surface on which the phosphor layer **102** is applied is provided with indicia indicating various altitudes. If wedge **100** is formed of non-transparent piezoelectric material, the phosphor layer should be positioned between the wedge and an indicia bearing member.

The energizing circuit comprises an altitude sensing device **112** which is capable of producing a D.C. output signal proportional in strength to the sensed altitude. Conventional radar systems may be satisfactorily employed for this purpose. The output signal produced by the altitude sensing device **112** is fed to a comparison-gating circuit **114**. The comparison-gating circuit **114** is capable of producing a saw-tooth reference signal. The comparator portion of the circuit **114** compares the D.C. signal received from the sensing device **112** with the saw tooth reference signal. The slope of the saw tooth signal is set to correspond to the altitude range required for the sensing device **112**. The D.C. signal from the sensing device **112** will then exceed the saw tooth signal up to an altitude match. The saw tooth reference signal of the comparison-gating circuit is synchronized with a sweep frequency signal fed thereto by a sweep frequency generator **116**. Thereby, the saw tooth reference signal commences when the sweep frequency generator **116** starts its frequency scan. For all levels of the D.C. signal from the sensing device **112** which exceed the reference signal, a gate is opened and the output of the sweep frequency generator **116** is passed to an amplifier **118** and to the altitude display device through the conductor **110**.

In operation, therefore, when the altitude sensing device **112** senses a signal corresponding to 11,000 feet, for example, a D.C. signal is fed to the comparison-gating circuit **114** which is operative to open a gate and allow only that frequency signal of the generator **116** effective to energize the top portion of the wedge element **100** to pass to the amplifier **118** and thence to the conductive strip **108** of the wedge element **100** through the conductor **110**. Whereupon the electroluminescent phosphor material **102** adjacent the upper portion of the wedge element **100** is excited to give off visible light indicating an altitude of 11,000 feet.

As in the embodiment of FIGURE 4 the altitude meter piezoelectric crystal display element **100** provides significant voltage amplification. Thus, at any resonant frequency applied to the crystal wedge **100** through conductor **110**, the potential difference across the phosphor **102**

will be found to exceed the driving voltage applied between strip **108** and ground return wire **106**.

Other satisfactory systems employing the concepts of the invention include the use of a sweep frequency oscillator with a voltage tuneable bandwidth. Thus, as the voltage increases with altitude, so will the bandwidth of the sweep frequency oscillator and the display will light up accordingly.

Although the description of the devices has made reference to the electroluminescent material as being phosphor, it must be understood that satisfactory results could be obtained by employing other materials which are electroluminescent. These materials include electric field sensitive fluorescent liquids and jells, or gases with suitable discharge characteristics. In use, these materials are contained in a thin panel, one surface of which is in contact with the piezoelectric material.

Display devices such as those hereinabove described and illustrated in the drawings also may be employed as frequency spectrum analyzers. In such an application, the signal to be examined is fed into a variable, sharply tuned, resonant circuit synchronized to the sweeping oscillation. The tuned circuit employs a voltage dependent capacitor to vary the resonant frequency of the circuit. The output of the tuned circuit is rectified and filtered to eliminate the carrier. This video signal is then fed to the modulator **16** of FIG. 1 and thence to the display device **12** through an amplifier **18** and thereby cause the display panel **12** to exhibit visibly the frequency characteristics of the incoming signal.

In accordance with the provisions of the patent statutes, we have explained the principle and mode of operation of our invention and have illustrated and described what we now consider to represent its best embodiments. However, we desire to have it understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically illustrated and described.

We claim:

1. An electroluminescent display device comprising a wedge shaped piezoelectric crystal element, an electroluminescent material disposed on a tapering longitudinal surface of said crystal element, an electrode disposed on the same surface as said material, said electrode and said material extending along the entire length of said surface, the widthwise dimension of said electrode, with respect to the width of said tapering longitudinal surface, being less than the widthwise dimension of said electroluminescent material, and a base electrode extending over that surface of said crystal which is opposite to said tapering surface.

2. The display device of claim **1** wherein said electrode on said tapering surface is positioned along one longitudinal edge thereof.

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