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Report of Project MICHIGAN

ELECTROLUMINESCENT-PIEZOELECTRIC FLAT-PANEL DISPLAYS

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PREFACE

Project MICHIGAN is a continuing research and development program for advancing the Army's long-range combat-surveillance and target-acquisition capabilities. The program is carried out by a full-time Willow Run Laboratories staff of specialists in the fields of physics, engineering, mathematics, and psychology, by members of the teaching faculty, by graduate students, and by other research groups and laboratories of The University of Michigan.

The emphasis of the Project is upon basic and applied research in radar, infrared, acoustics, seismics, information processing and display, navigation and guidance for aerial platforms, and systems concepts. Particular attention is given to all-weather, long-range, high-resolution sensory and location techniques, and to evaluations of systems and equipments both through simulation and by means of laboratory and field tests.

Project MICHIGAN was established at The University of Michigan in 1953. It is sponsored by the U. S. Army Combat Surveillance Agency of the U. S. Army Signal Corps. The Project constitutes a major portion of the diversified program of research conducted by Willow Run Laboratories in order to make available to government and industry the resources of The University of Michigan and to broaden the educational opportunities for students in the scientific and engineering disciplines.

Progress and results described in reports are continually reassessed by Project MICHIGAN. Comments and suggestions from readers are invited.

Robert L. Hess
Technical Director
Project MICHIGAN

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ELECTROLUMINESCENT - PIEZOELECTRIC FLAT - PANEL DISPLAYS

ABSTRACT

A display panel consisting of electroluminescent phosphors deposited on piezoelectric crystals has been fabricated for the purpose of providing a controlled luminescent light spot. The scheme of operation provides for light-spot generation by using the electric fields generated at the piezoelectric-crystal surface, when the crystal is driven by voltages applied at the resonant frequency. The panel is made up of crystals connected electrically in parallel, but resonating at different frequencies. Light-spot sweep movement over the face of the panel and intensity variation are derived by frequency and amplitude modulation of the voltages applied to the piezoelectric crystal array. The device can be used immediately in the development of computer switches, character displays, luminescent dials, delay lines, and any displays requiring limited electric-field bandwidths. After additional phosphor research, it may have uses in the development of TV-like displays.

1
INTRODUCTION

A display panel consisting of electroluminescent phosphors deposited on piezoelectric crystals has been fabricated at Willow Run Laboratories. The scheme of operation provides for sweep movement of a light spot over the face of the panel and intensity variation of the light spot by the frequency and amplitude modulation of a voltage applied to the piezoelectric crystals. The device is feasible for immediate use in developing switches for computers, character displays, luminescent dials, and any displays requiring a limited bandwidth of electric fields. TV-like display development, however, will first require extensive research on electroluminescent phosphors. Materials that operate efficiently with electric fields in the megacycle region are needed. To date, little is known about phosphor characteristics at such high frequencies.

Flat-panel raster-type electroluminescent displays using a crossed-grid technique have been fabricated in the past. In such displays, the phosphor is part of a sandwich with a fine grid of transparent conducting parallel lines across the front surface, and a similar array of conducting lines on the back surface perpendicular to those on the front. By placing a potential difference across a pair of vertical and horizontal lines, a localized electric field is developed through the phosphor with a resultant luminescent light spot. Through the use of computer circuitry, the spot can be made to move in a raster-like manner, and by field-strength modulation, image reproduction can be obtained. This system has been demonstrated by Sylvania Electric Products, Inc. (Reference 1). It has, however, severe limitations in that, in order for a display to provide good resolution, the parallel lines must be placed close together. Consequently, more lines are necessary, which makes the switching problem for light-spot movement more difficult because more pairs of crossed lines must be handled and at higher rates of speed. The scheme of operation for the electroluminescent-piezoelectric display, on the other hand, minimizes the switching problem. Furthermore, color displays, which in the crossed-grid arrangement are virtually impossible unless efficient transparent phosphor layers can be developed, can be readily achieved with the approach described in this report, since any color component can be independently controlled.

2
PRINCIPLES INVOLVED in the IMAGE DISPLAY

The success or any electroluminescent image display using a raster-type writing program depends on the development of an electric-field sweep and the ability to modulate the sweep with video information. The display panel proposed here will use the electric field that is generated at the surface of piezoelectric materials when they are operated in their resonant condition to excite electroluminescent phosphors. An electric-field sweep is generated by sweeping the frequency applied to the piezoelectric materials.

2.1. ELECTRIC-FIELD SWEEP DESIGN

The operation of the device can be understood by referring to Figure 1(a). A group of five barium titanate piezoelectric cylinders are placed electrically in parallel across a variable-frequency generator. Each of the cylinders has its own resonant frequency, different from the others. When the generator is tuned to one of the resonant frequencies, a cylinder will respond in its vibrational mode, and a strong polarization field is generated across its end surfaces. The intensity of the field is dependent on the voltage output of the generator, and an electroluminescent phosphor deposited on an end surface lights up with proportional intensity. This device also takes advantage of the voltage amplification possible from piezoelectric materials. The potential difference across the phosphor layer can be three to four times the voltage driving the piezoelectric cylinder for resonance operation. Sweeping the generator frequency causes the different cylinders to respond one at a time, with the light output following the tuned cylinder and the light-intensity modulation being achieved by modulation of the generator voltage. With minaturization of components, a fine-resolution panel display composed of a matrix of cylinders is readily conceivable.

It is also possible to provide continuous light movement by using shaped bodies such as the quartz wedge shown in Figure 1(b). Localized resonance is obtained in a wedge, since the resonant frequency is a sharp function of geometry. A light spot can then be made to move along the wedge simply by varying the generator frequency.

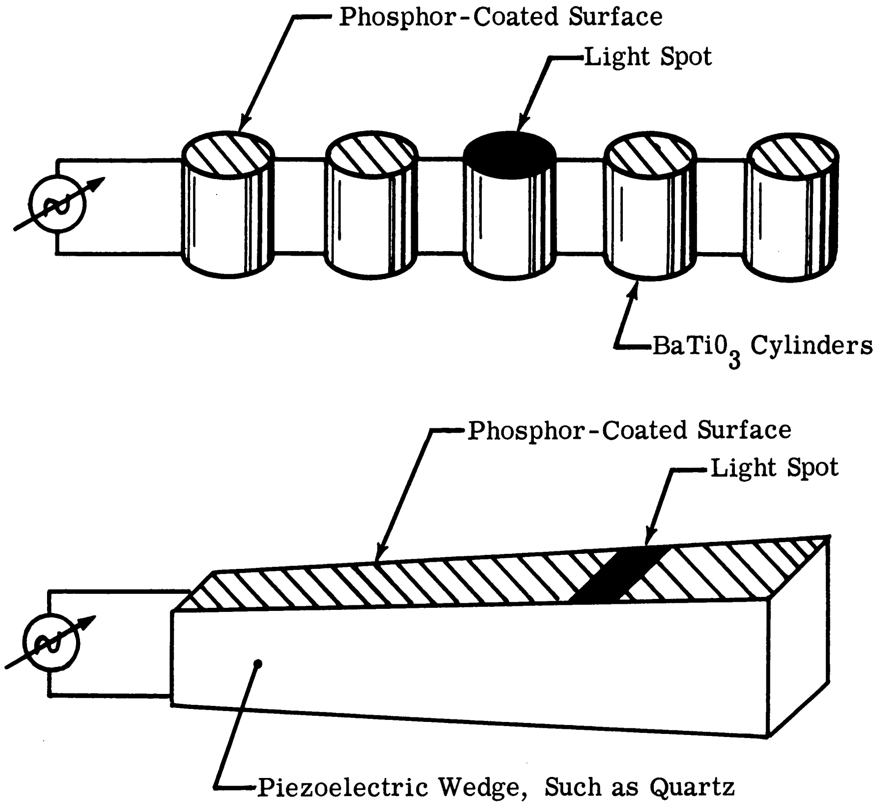

FIGURE 1. LIGHT-SPOT SWEEP USING PIEZOELECTRIC CYLINDERS AND WEDGES

An important advantage in device applications that derive from the electric-field type of sweep is that a localized-field spot is generated without the need for electrodes to be placed in proximity to it. The field is generated by polarization charges appearing at the crystal surface. These changes can be made to appear at surfaces to which no electrical connections are made. If the piezoelectric crystal is shaped properly, the vibrational polarization field can be induced with electrodes placed along the crystal a significant distance away from the surface of interest. This arrangement is illustrated in Figure 2. The transparent grounded electrode placed across the phosphor layer provides the minimum path length for the field and therefore the maximum field intensity. An additional advantage derived from this arrangement is that the voltage applied directly at the electrodes also adds to the total field across the phosphor. This extra contribution is not large enough to make an electroluminescent phosphor glow,

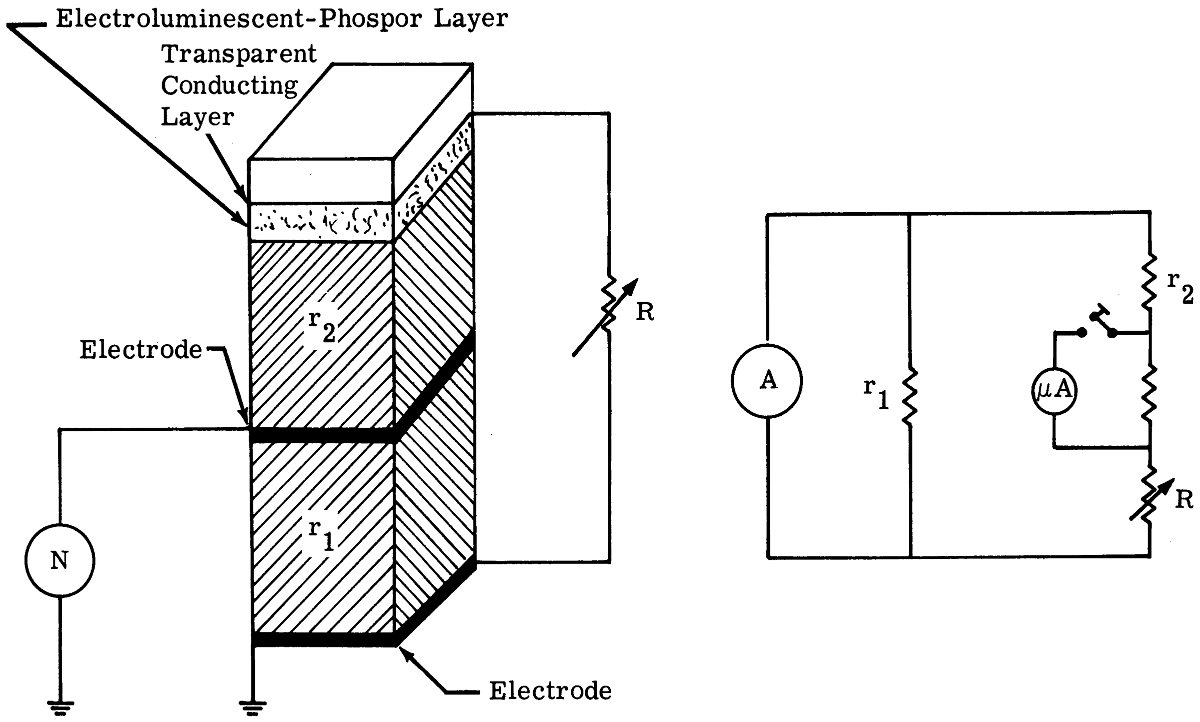

FIGURE 2. ELECTRODE ARRANGEMENT AND EQUIVALENT CIRCUIT. [hatched symbol] = piezoelectric material. [stippled symbol] = electroluminescent-phosphor layer. r_2 = electrical resistance of upper half of piezoelectric slug. r_1 = electrical resistance of lower half of piezoelectric slug. A = signal generator. μA = amplified signal voltage at phosphor layer during resonance.

but is large enough to reduce the requirement on the polarization field. It can be independently adjusted by placing a variable resistor between ground and the transparent conducting surface.

2.2. FLAT-PANEL DISPLAY

When the electric-field spot sweep is coupled with an electroluminescent phosphor for a flat-panel display, essentially performing as a TV-type display, the construction of the panel may look either like Figure 3 or Figure 4. In Figure 3, a mosaic of spots appears at the panel surface sufficient for good resolution and spaced to conform with some scan pattern. Each spot represents the surface of a piezoelectric cylinder. The length of the cylinder and the material of which it is made determine the resonant frequency of the cyliner. All cylinders may be placed electrically in parallel and are tuned to oscillate independently of one another so that only one spot lights up at a time. By frequency modulation of the generator, the light spot then can be moved in any desired scan pattern. Video information is displayed by amplitude modulation. If the state of the art of electroluminescent phosphors or piezoelectric materials places restrictions on the electrical bandwidth of operation, the mosaic of spots can be

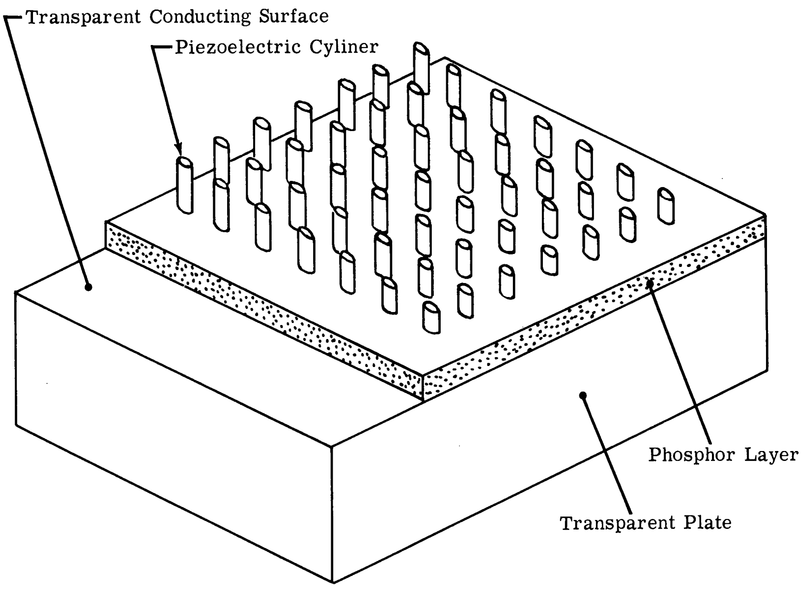

FIGURE 3. ELECTROLUMINESCENT PANEL USING PIEZOELECTRIC CYLINDERS

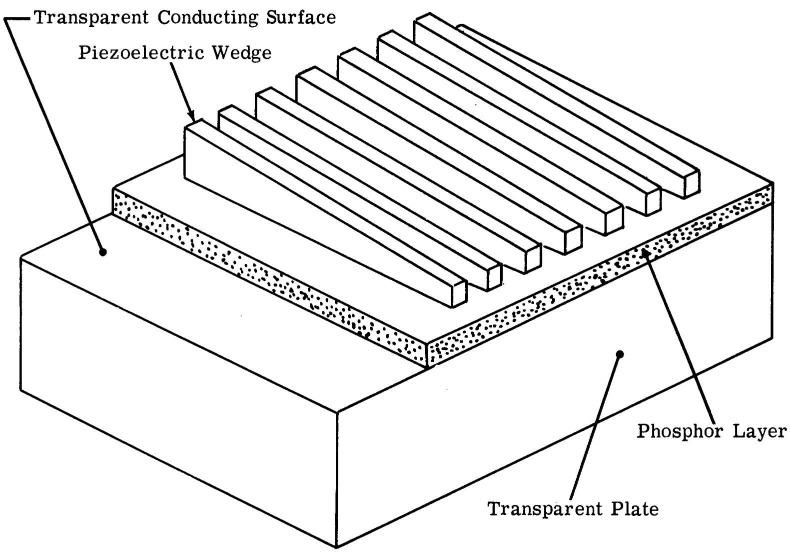

FIGURE 4. ELECTROLUMINESCENT PANEL USING PIEZOELECTRIC WEDGES

arranged in lines, so that one line at a time may be scanned by frequency modulation. Then, by simple one-dimensional switching techniques, all lines can be scanned in any desired sequence.

The scheme of Figure 4 is based upon the use of wedges of piezoelectric materials, rather than cylinders. Each line viewed at the panel surface represents the surface of a wedge or a series of adjacent wedges placed end to end, depending on the materials used and the panel size. The resolution available with a wedge is determined mainly by the piezoelectric material and the slope of the wedge. Device operation is the same as for the mosaic of cylinders.

At one particular frequency, only one spot on one wedge will light up. Changing the frequency causes the light to move. If bandwidth requirements permit, all wedges can be placed electrically in parallel, and by one traversal through the frequency range, the light spot can be made to move over the whole panel. If bandwidth requirements are too severe, then identical lines of wedges can be placed side by side and swept one at a time in any sequence by switching devices. Thus, the light-spot movement can be made to cover the entire panel with video information displayed by amplitude modulation of the electric-field generator.

2.3. FEASIBILITY DEMONSTRATOR

A device has been assembled consisting of a row of 23 electroluminescent-piezoelectric elements, all placed in contact with a rectangular sheet of transparent, conducting glass. Each element resonates at a different frequency, each is operated with the electrode arrangement of Figure 2, and all are placed electrically in parallel. The unit provides a luminescent light spot which can be made to move and change intensity in a controlled manner. It demonstrates readily the feasibility of a electroluminescent-piezoelectric display. This device is shown in Figure 5. A block diagram of the associated electronic system used is shown in Figure 6. The electronic sweeping oscillator operates automatically to provide the necessary range of frequencies to drive all piezoelectric elements. It can be adjusted to sweep at differ-

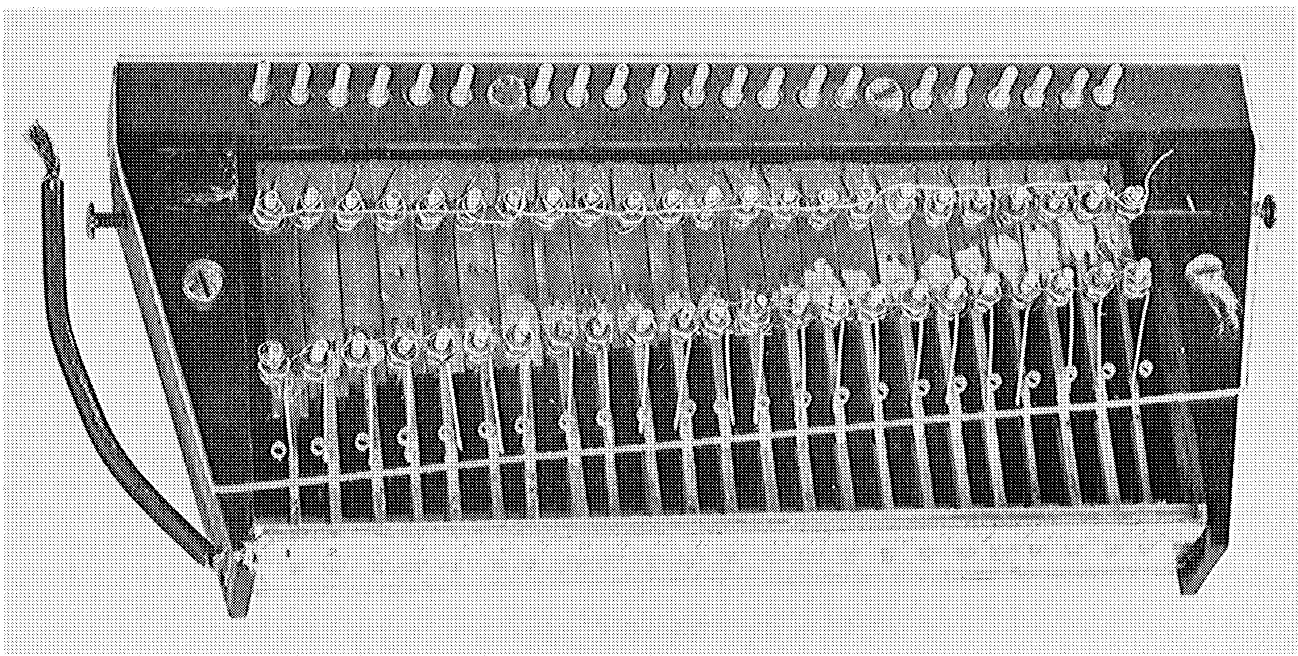

FIGURE 5. SINGLE-LINE-SCAN FEASIBILITY MODEL

ent rates. By feeding video pulses into the modulator, synchronized properly with the sweep rate, one can generate a corresponding localized light-pulse pattern on the display. This is identical in nature to Z-axis modulation of a single-line sweep in a cathode-ray oscilloscope. A luminescent thermometer-type meter can be readily derived by having the video gate modulate the field sweep. Thus, for example, a controlled luminescent line can be generated through the use of a thermocouple signal to determine a gate width for the sweep-frequency oscillator, starting from the frequency necessary to light up the first element.

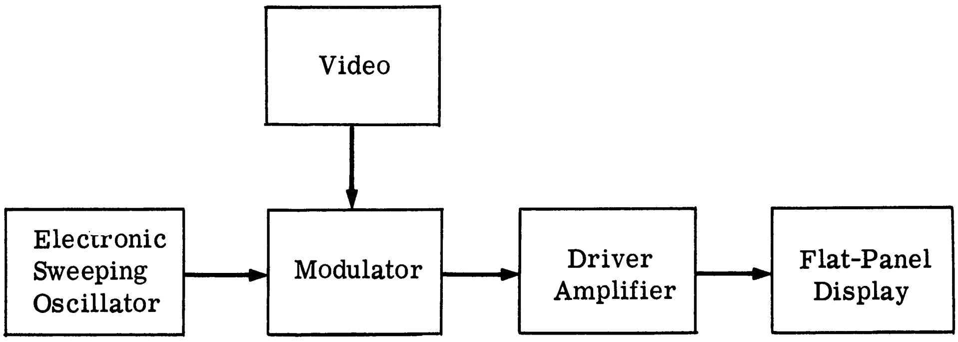

FIGURE 6. BLOCK DIAGRAM FOR ELECTRONIC SYSTEM ASSOCIATED WITH ELECTROLUMINESCENT-PIEZOELECTRIC FLAT-PANEL DISPLAY

3
FURTHER DEVICE DEVELOPMENT

The display panels described in this report make use of electroluminescent phosphors. They might equally well have made use of electric-field-sensitive fluorescent liquids, gels, or gases with suitable discharge characteristics. These materials could be contained in a thin panel, wherein one surface of the container might be the piezoelectric material itself. The container could be one thin unit complete in itself, or broken down into some form of an array of encapsulated cells. Three-dimensional displays are also possible when the gases or lumiescent materials are transparent, since piezoelectric materials such as quartz are also transparent.

Dials for instrument panels might be developed in a relatively simple manner. For example, if a luminescent circle designating some particular area were needed, a dial could be formed from a piezoelectric disc. The disc would be flat on one surface, have a conical hole bored in the other, and be coated on the flat surface with an electroluminescent phosphor. The application of a single driving frequency would cause a luminescent circle to appear. Changes in the driving frequency would cause the circle to get larger or smaller, and might thereby delinate a varying target area.

One- and two-dimensional delay lines can be obtained from simple display panels such as those described above. The important features here are that a spot of light can be made to move in any desired path and with a controlled velocity. The speed with which a light spot moves along the surface is determined by the speed with which the electrical generator frequency is changed. When a panel is coupled to an array of photodetectors, any desired sequence of events can be triggered, with complete and independent control of the timing of these events. Since the panel is a fabricated solid-state device requiring no internal electronics or gadgetry for its operation, and since photodetectors, such as CdS, meet the same description, panels and photodetectors can be fabricated in a unit package. These can be shaped and positioned to fit unusual compartment requirements. Furthermore, it is clear that multiple arrays and panels can be formulated so that any number of identical sequences can be triggered at the same time. It follows from these applications that computer circuitry may well be simplified and expanded.

Display panels such as we have described can also serve admirably as frequency-spectrum analyzers. Any signal fed into the display can have its frequency components examined by the luminescent pattern on the panel. Another useful device naturally evolves from this kind of application. One can readily conceive of a character display, where a signal consisting of a mixture of frequencies is fed to the panel so that a number, letter, or figure will appear and be sustained as long as the signal is applied. Therefore, keyed characters, or automated character sequences, are well within the possibilities for this technique.

REFERENCE

1. Aviation Week, "Thin-Panel Radar Possible with Electro-luminescence Technique," July 1957, Vol. 67, p. 32.

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Piezoelectric crystals
Light spot
Electric fields
Resonant frequency
Sweep movement
Frequency modulation
Amplitude modulation

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UNITERMS

Display panel
Electroluminescent phosphors
Piezoelectric crystals
Light spot
Electric fields
Resonant frequency
Sweep movement
Frequency modulation
Amplitude modulation

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Willow Run Laboratories, U. of Michigan, Ann Arbor
ELECTROLUMINESCENT-PIEZOELECTRIC FLAT-PANEL DISPLAYS by S. Nudelman, J. Lambe, J. Mudar, G. Trytten. Rept. of Proj. MICHIGAN. Oct 60. 8 p. incl. illus. 1 ref.
(Rept. no. 2900-202-T)
(Contract DA-36-039 SC-78801) Unclassified report

A display panel consisting of electroluminescent phosphors deposited on piezoelectric crystals has been fabricated for the purpose of providing a controlled luminescent light spot. The scheme of operation provides for light-spot generation by using the electric fields generated at the piezoelectric-crystal surface, when the crystal is driven by voltages applied at the resonant frequency. The panel is made up of crystals connected electrically in parallel, but resonating at different frequencies. Light-spot sweep movement over the face of the panel and intensity variation are derived by (over)

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1. Communication systems and components — Display systems
I. Title: Project MICHIGAN
II. Nudelman, S., Lambe, J., Mudar, J., Trytten, G.
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