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AN ELECTROLUMINESCENT-PIEZOELECTRIC FLAT-PANEL DISPLAY DEVICE*

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Abstract—A flat-panel, line display consisting of electroluminescent ZnS–Cu phosphors (EL) adjacent to piezoelectric voltage transformer elements (PE) has been fabricated to provide a controlled-movement luminescent light spot. Electroluminescence is excited by the electric fields generated at the surface of a piezoelectric element driven at its resonant frequency. The display is made up of thirty PE–EL units connected electrically in parallel, each unit resonating at a different frequency. Movement of the light spot over the face of the display is produced by frequency modulation of the voltages applied to the piezoelectric array, in the manner of a sweep frequency. Synchronized amplitude modulation permits the light spot to be localized and its movement to be controlled. The display has a sweep frequency range extending from 30 to 60 kc/s. PE–EL units under continuous operation generate 40 ft lamberts at 8·8 V_{rms}, and can generate over 100 ft lamberts by overdriving at 40V_{rms}. In sweep operation at 100 c/s, the light output is 40 ft lamberts at 35 V_{rms}. Power consumption in this mode is less than 10 mW. EL fatigue is analyzed and minimized in this display sweep technique.

Résumé—Une ligne d'étalage de panneaux plats comprenant des phosphores (EL) electroluminescents de ZnS–Cu adjacent à des éléments de transformateurs de voltage (PE) piézo-electriques ont été fabriqués pour fournir une source lumineuse à mouvement contrôlé. L'électroluminescence est excitée par les champs électriques générés à la surface d'un élément piézo-électrique commandé à sa fréquence résonante. L'étalage comprend 30 unités PE–EL jointes électriquement en parallèle, chaque unité résonant à une fréquence différente. Le mouvement de la source lumineuse sur la surface de l'étalage est produit par la modulation de fréquence des voltages appliqués a l'ensemble piézo-electrique en forme de fréquence de balayage. La modulation d'amplitude synchronisée permet de localiser la source lumineuse et de contrôler ses mouvements. L'étalage à une gamme de fréquence de balayage allant de 30 à 60 Kc/s. Les unités PE–EL en opération continue produisent 40 pieds lamberts (12,2 mètres lamberts) à 8,8 V de valeur efficace et peuvent produire au-dessus de 100 pieds lamberts (30,5 metres lamberts) en surcommande à 40 V. Dans l'opération de balayage à 100 c/s la sortie lumineuse est de 40 pieds lamberts (12,6 mètres lamberts) à 35 v. La puissance utilisée dans ce mode est moins de 10mV. La fatigue EL est analysée et minimisée dans cette méthode d'étalage à balai.

Zusammenfassung—Auf einer flachen Unterlage wurde eine Reihe von elektrolumineszenten ZnS–Cu–Phosphoren (EL) neben piezoelektrischen Elementen zur Spannungstransformation (PE) angebracht, um einen leuchtenden Lichtfleck mit Bewegungssteuerung zu erzeugen. Die Elektrolumineszenz wird durch die auf der Oberfläche eines bei der Resonanzfrequenz arbeitenden piezoelektrischen Elementes erzeugten elektrischen Felder angeregt. Die Anordnung besteht aus 30 PE–EL-Einheiten, die parallel geschaltet sind, und jede Einheit spricht bei einer anderen Frequenz an. Die Wanderung des Lichtflecks über die Oberfläche des Geräts entsteht durch Frequenzmodulation der an den piezoelektrischen Elementen wirkenden Spannungen, in Art einer Ablenkung schwingungs frequenz. Eine synchronisierte Amplitudenmodulation ermöglicht die Lokalisierung des Lichtflecks und die Steuerung seiner Bewegung. Die Ablenkungs frequenz des Geräts hat einen Bereich von 30 bis 60 kHz. Die PE–EL-Einheiten erzeugen bei kontinuierlichem Betrieb 40

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Fuss-Lambert bei 8·8 V_{eff} und können bei 40 V_{eff} bis zu 100 Fuss-Lambert erzeugen. Beim Arbeiten mit 100 Hz ist die Lichtausbeute 40 Fuss-Lambert bei 35 V_{eff}. Der Energieverbrauch beträgt dann weniger als 100 mW. Die EL-Ermüdung wurde analysiert und bei dem vorliegenden Verfahren auf ein Minimum reduziert.

1. INTRODUCTION

A FLAT panel providing a luminescent line display has been fabricated from electroluminescent ZnS:Cu phosphors (EL), adjacent to lead-zirconate-titanate piezoelectric elements (PE).*(1) This display utilizes both the resonance characteristic of the piezoelectric elements and a sweep frequency technique to produce controlled movement of a luminescent light spot. High levels of light output can be achieved with a low-voltage source, by shaping and electroding the piezoelectric elements so that they operate as voltage transformers. Piezoelectric devices have been used as tunable elements, as have traditional inductive and capacitive units, to localize electric field regions.(2–6) A sweep frequency technique for scanning a multielement display has been described by WALD.(6) In certain applications, piezoelectric devices have also been used to excite electroluminescent phosphors directly.(7,8) The PE–EL display described herein was developed by using a combination of these applications.

2. FACTORS INVOLVED IN THE PE–EL DISPLAY

There are basically two areas to consider in the fabrication of a PE–EL display: i.e., (1) the design of the electric-field sweep, (2) the electrical and the light output properties of a piezoelectric-electroluminescent (PE–EL) unit.

2.1 *Electric field sweep design*

The success of electroluminescent displays which use a technique of scanning and modulation simultaneously, depends on the development of an electric-field sweep and the ability to modulate the electric field with video information. The display described herein uses the tunable characteristic of piezoelectric units to provide the electric-field sweep. In addition, the display uses the important property that a piezoelectric unit operated at resonance generates an electric field. By proper design of a unit and its electrodes, intense electric fields can be generated, which are more than adequate for the excitation of the usual zinc sulfide EL phosphors.

The operation of the device can be understood by reference to Fig. 1. Piezoelectric parallelpiped units are placed electrically in parallel across a variable-frequency generator. Each unit has a fundamental resonant frequency (inversely proportional to its length). When the generator is tuned to the resonant frequency of a particular unit, that unit will respond and a strong polarization field will be generated across its end surface. The EL phosphor adjacent to this surface is then excited to electroluminescence. By sweeping the electric field frequency at a rate sufficient to avoid flicker, and by synchronous amplitude modulation of the electric field, a controlled light output pattern can be obtained.

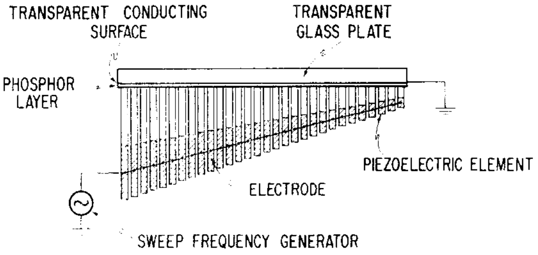

FIG. 1. PE–EL Display (schematic).

2.2 *The PE-EL Unit*

The heart of the electric-field sweep technique employed lies in the PE–EL unit. The performance of this unit depends upon the following factors:

(a). The ability of the piezoelectric element to generate an intense electric field for electroluminescence excitation.

(b). The ability of an element to generate this electric field with a narrow bandwidth of operation, as compared to the center frequency of resonance.

(c). The manner in which light output varies with the frequency and voltage of the sweep excitation driving the piezoelectric element.

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* The electroluminescent phosphor used was supplied by U.S. Radium and designated 3663; the piezoelectric material was supplied by Clevite and designated PZT–4.

(d). The power required and the phase relationship between driver voltage and current, for both resonant and non-resonant operation.

(e). The extent to which harmonics can generate undesirable light output.

(f). The ease with which the individual elements can be mechanically clamped in position, and the effects of different electrode arrangements.

(g). The extent to which phosphor fatigue is reduced through use of the sweep-frequency technique.

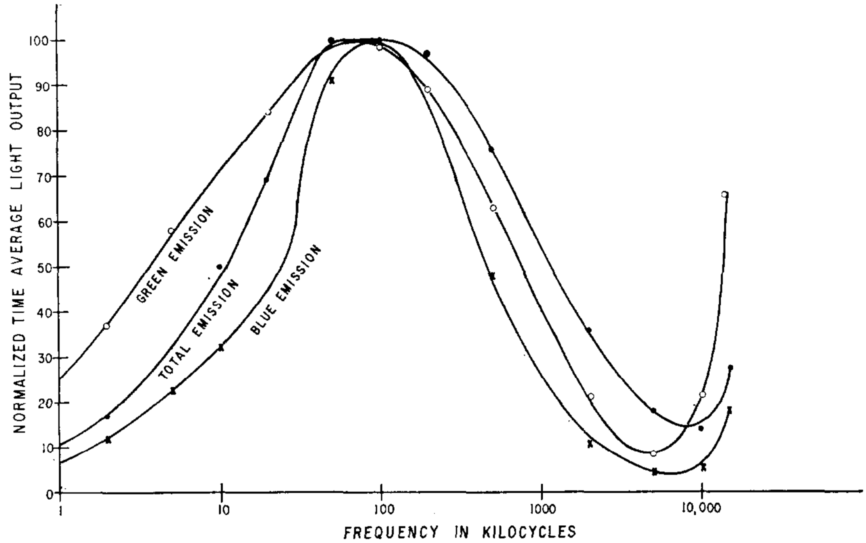

FIG. 2. Time Average Light Output vs. Frequency.

A PE–EL unit consists of two components, namely, a phosphor layer and an adjacent piezoelectric element. It is convenient to discuss the factors noted above by first examining the characteristics of each of the components, and then by describing their combined performance.

2.2a *The Electroluminescent Phosphor*. The phosphor light output is a function of voltage, frequency, and time of operation. The zinc sulfide phosphors used require an applied field strength of the order of 10^4 V per cm for light emission. Over a limited voltage range, their brightness varies as a power of the applied voltage:(9)

$$B = KV^s \tag{1}$$

where B is brightness

V is the voltage drop across the phosphor layer

K is a constant

s is a constant, which may range from 3 to 8 for different phosphors.

The voltage requirements of zinc sulfide EL phosphors are easily met by the output from the piezoelectric units.

The frequency dependence of electroluminescent ZnS:Cu and ZnS:Se phosphors over a frequency range extending to 14 mc/s has been recently investigated.(10,11) The results of this investigation are shown in Fig. 2; the blue and green emission bands of the phosphors are shown separately. These results might well be compared with those of HARMAN, who measured the threshold voltage for electroluminescence also over a wide frequency range.(12) His data show a peaking in electroluminescence for a sintered ZnS sample, in the same frequency range in which the peak occurs in Fig. 2. Our phosphors were operated, however, at high voltages without a binder, in vacuum, and at high brightness levels. A power function rise of light output with voltage was observed; the exponent in equation (1) was approximately equal to 5 at 50 kc/s and shifted to 6·5 at 3 mc/s.

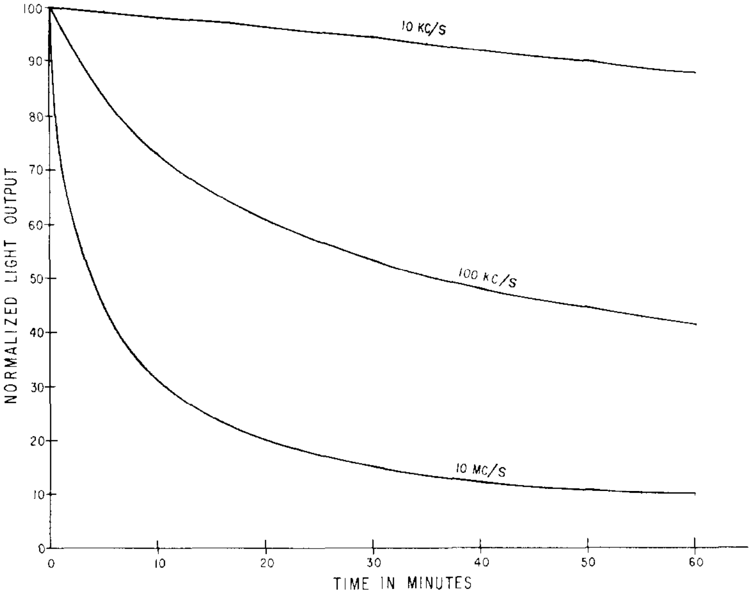

FIG. 3. Electroluminescence Fatigue for Three Frequencies of Operation.

The peaking of the blue and green emission curves in the vicinity of 100 kc/s is particularly significant for an electroluminescent display program. Brightness levels of 10 to 20 times greater than those available below 1 kc/s are clearly attainable. The upswing of electroluminescence beyond 1 mc/s is surprising, and, as yet, unexplained. Unfortunately, it is accompanied by an increasing loss factor, to the extent that equipment overloading becomes a severe problem.

Time-average-light output from zinc sulfide phosphors decreases with operating time for constant operating conditions. This property is usually referred to as "fatigue", and is shown, in Fig. 3, to increase markedly with operating frequency.(10,11,13) Operation in the megacycle region showed a decrease in electroluminescence of as much as 70 per cent within a 10 to 30 min time interval. In the lower "audio" frequency range, such drastic fatigue would not occur for days and even months.

Comparison of fatigue curves obtained over the wide frequency range used here reveals one strikingly similar characteristic: The per cent decay from peak luminescence is strictly a function of the number of cycles of operation, as shown in Fig. 4, where four horizontal lines obtained over different ranges are shown. In the lower frequency regions, measurements were made with a fewer number of total cycles because of the longer time required to obtain appreciable fatigue. Therefore, there are higher light levels at the lower frequency end than at the high. However, all lines overlap frequency-wise and show that for a fixed number of cycles of operation, the per cent fatigue from initial light output is the same for all frequencies.

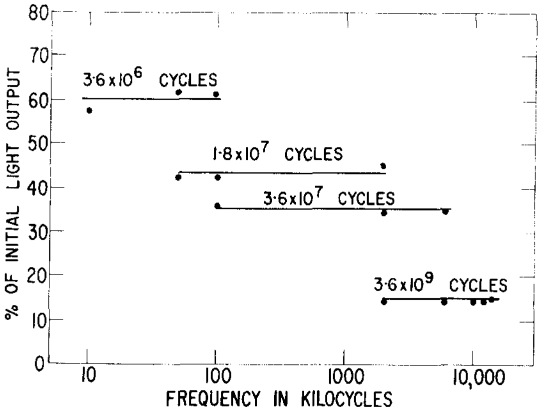

FIG. 4. Per cent Electroluminescence Fatigue vs. Frequency for a Constant Number of Cycles of Operation.

Thus it is possible to describe the dependence of the light output on the number of cycles of operation by the relationship

$$I_N = \frac{I_0}{1+aN^p} \tag{2}$$

where I_N is the time average light output
I_0 is the intial light output
N is the number of cycles of operation
a and p are constants.

For the ZnS:Se phosphor:
$a = 1{\cdot}8\times10^{-7} \quad p = 0{\cdot}82$

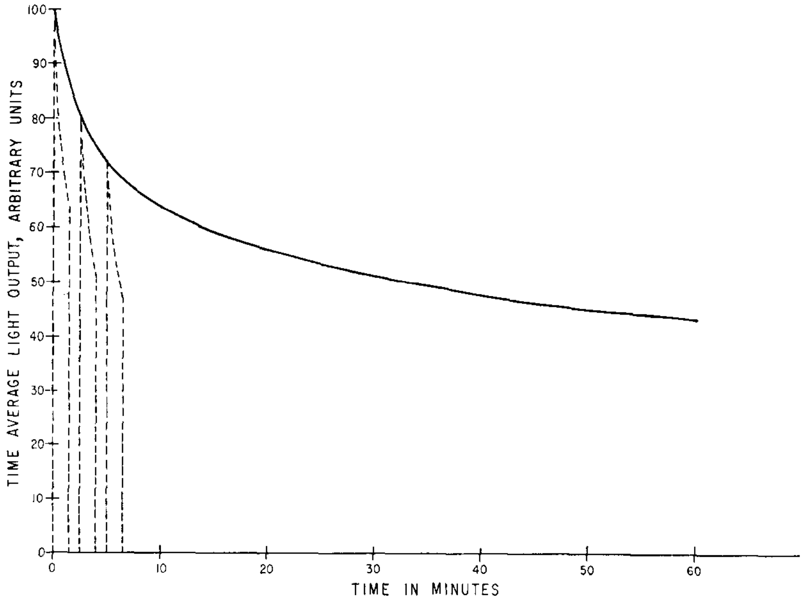

FIG. 5. Shake Effect.

This relationship is independent of the frequency of the applied electric field over the frequency range measured (1 kc–10 mc/s).

An unusual feature of this measurement is the "shake" effect shown in Fig. 5. If a phosphor powder is mechanically shaken (vibrated) after a fatigue run so as to cause a reshuffling of the phosphor powder particles, a new field application will result in a higher level of electroluminescence than the fatigued level attained before shaking. An apparent partial restimulation of electroluminescence therefore occurs which is then followed by the same process of fatigue originally noted. Figure 5 shows many "shake" cycles, with the successive peaks diminishing until the phosphor is in a completely fatigued state. This experiment indicates that by shaking, all "sites" of electroluminescence in the phosphor particles are exposed to high fields simply by geometric reorganization. If one wanted to perform an experiment designed to compare the crystal or impurity structure in fatigued phosphor with virgin phosphor, it would be advisable to fatigue a phosphor completely by use of this "shake" technique.

Fatigue could be associated with a uniform filling of deep traps, or a uniform degradation in electroluminescence centers. Tests for deep traps using high voltage–low frequency fields simultaneously with photostimulation were negative. Our measurements of phosphors in air and in various dielectrics indicate, in agreement with ROBERTS, that fatigue is a characteristic of a fundamental permanent change of the phosphor.(14)

The information presented regarding the frequency and fatigue properties of zinc sulfide EL phosphors poses a dilemma. On the one hand, it appears that for maximum light output, the phosphor should be operated in the vicinity of 100 kc/s.

However, for maximum operating time, fatigue data indicate the desirability of a lower operating frequency. This difficulty, partially resolved in the display technique used here, will be discussed in Section 2.2c.

2.2b *The Piezoelectric Element.* Voltage and power transformers can readily be fabricated from ceramic piezoelectric materials. A considerable voltage gain can be obtained by properly shaping a unit and by properly applying the driving and generating electrodes. This subject is treated in detail by KATZ in Chapter 5 of his book,(15) and will be dealt with only briefly here.

The PE–EL units which we constructed were shaped in the form of a parallelpiped, as shown in Fig. 6a. Notice that the driver electrodes are below and that the direction of piezoelectric polarization between the electrodes is perpendicular to the length of the unit. The generator electrodes are above, and the direction of polarization is parallel to the length of the unit. As noted by KATZ:(15)

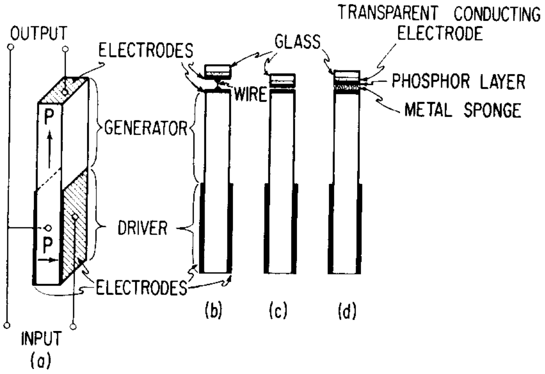

FIG. 6. Transverse Type Piezoelectric Transformer and Several PE–EL Arrangements.

> "The application of a periodic electric field to the lower half of each bar causes mechanical vibration of the whole bar by the converse piezoelectric effect. At specific frequencies which are integrally related for 'long thin bars', resonant modes of vibration occur along the length, and result in standing-wave distributions of large amplitude of elastic stress and strain. The resonantly amplified strain in the upper half of each bar produces an electric field distribution by the direct piezoelectric effect, which results in a potential difference appearing across the output terminals. A voltage step-up of considerable magnitude may be obtained by these means."

The unit is operated in the fundamental longitudinal mode as a half-wave resonator (total length equals one-half wavelength). The entire bar is mechanically supported at a vibration node which occurs at the junction of the driver generator segments. The ends are essentially mechanically free. According to KATZ,(15) the voltage gain for this device, in the electrically open circuit case, is given by:

$$A_{x_0} = \frac{4Q_m}{\pi^2} \cdot \frac{Y_3^E g_{33} d_{31}}{(1-k_{33}^2)} \cdot \frac{L}{T} \tag{3}$$

where Y_3^E is Young's modulus
k_{33} is the coupling coefficient
Q_m is the mechanical Q of the unit
g is the field force
d_{31} is the strain field
L is the length of the unit
T is the thickness of the unit.

The PE elements were made of PZT–4 material, obtained from Clevite with the following specifications:

$$Q_m = 600, \quad Y_3^E = 6{\cdot}7 \times 10^{10} \text{ newtons/m}^2$$
$$g_{33} = 24 \times 10^{-3} \text{ volt m/newton}$$
$$d_{31} = -110 \times 10^{-12} \text{ C/newton}$$
$$k_{33} = 0{\cdot}64$$

Substituting in Equation (3) yields

$$A_{v_0} = 7{\cdot}3 \frac{L}{T}$$

The longest of the PE–EL units was $2L = 5{\cdot}1$ cm, and was 0·63 mm thick. Therefore

$$A_{v_0} = 292$$

Thus large voltage gains are readily possible. The measured gain of the above unit driving a phosphor element was 300.

PE materials are able to generate and withstand high electric fields without electrical breakdown or depolarization. The fields used to polarize our units were about $1{\cdot}6 \times 10^4$ V/cm. The procedure for polarization consisted of applying the high electric field to a PE unit submerged in an oil bath at 150°C, and then lowering the temperature as rapidly as possible by surrounding the oil bath with an ice water bath. The electrodes were applied by painting the PZT–4 surfaces with DuPont Silver Paint No. 6320 (see Fig. 6a). The paint was dried in an oven at 150°C and then fired at 750°C.

2.2c *Combined characteristics*. The PE–EL unit is shown in Fig. 6b, c, d. Various schemes were used to place the phosphor layer in electrical contact with the end of the parallelpiped. The general procedure in all cases is to evaporate a metallic electrode on the back of the phosphor surface. Several techniques can then be used to establish electrical contact between the electrodes at the end of the PE unit and the phosphor surface. The simplest technique entails the soldering of a fine flexible wire to the two electrodes, as shown in Fig. 6b. This avoids any appreciable mechanical damping of the PE unit, and provides the best arrangement for obtaining reliable data. The development of a simple panel, however, requires some means of direct contact between the phosphor surface and the PE generating electrode to avoid soldering many wires in a large multielement display. Excitation of sufficient electroluminescence is easily accomplished by bringing the PE electrode up to within 0·003 in. of the phosphor electrode as shown in Fig. 6c. However, the precision required in separation leads to a difficult and expensive method of fabrication. An approach which has some merit is to attach wired PE electrodes to an insulating panel which has a proper distribution of metallic electrodes to which the phosphor electrodes can make physical contact. This procedure has the advantage that the box containing the piezoelectric units can be separated from the phosphor panel, so that a phosphor panel can be readily replaced when it becomes unusable. Finally, the simplest approach is to use some form of a metallic sponge between the phosphor and PE electrodes as shown in Fig. 6d.

The PE–EL units used in the panel which we constructed operated in the frequency range of 30–60 kc/s. There were thirty elements making up the line display, each of which had its resonant frequency approximately 1 kc/s from its neighbors. The frequency–length constant of PZT–4 is 1650 cycle/m, so that the length of the PE–EL elements varied from five to five halves cm. The shorter lengths at the higher frequency causes the voltage gain to diminish. This is compensated for, however, to an appreciable extent by the increase in electroluminescence with increasing frequency. No effort was made to maintain a constant length-to-width ratio for this simple display. The sweep rate was 30 c/s.

Fatigue in ZnS electroluminescent phosphors is a function of the number of cycles of operation (as shown in Section 2.2a). Thus at the higher frequencies, higher rates of fatigue are expected. The sweep technique used in a PE–EL panel, however, partially compensates for this effect. In practice, any one phosphor element is excited only a small fraction of a sweep period. Thus for a thirty-element display, each element is driven only one one-thirtieth of the sweep period. The operating lifetime is then expected to be thirty times longer than that obtained from a continuously driven phosphor.

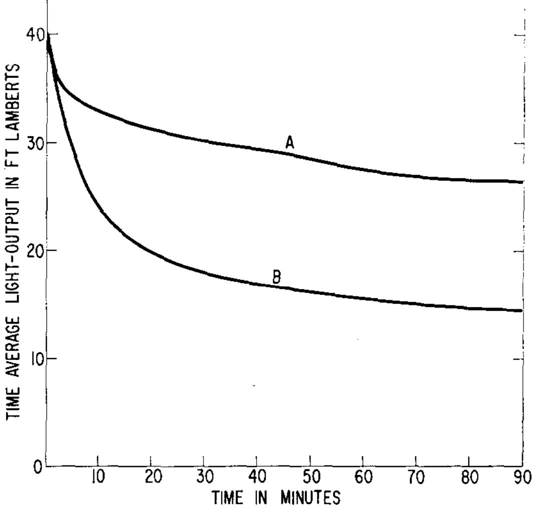

FIG. 7. Electroluminescence Fatigue for Swept Field Compared to Continuous Operation.

An example of the actual performance of a unit is shown in Fig. 7. The phosphor was excited by a PE unit operating at 60 kc/s and a sweep-frequency generator operating from 30 to 60 kc/s. A sweep rate of 100 c/s was used as the driving source. Considerable improvement in the operating lifetime is shown, although the improvement was not as great as expected. However, the initial light output was so much higher than that obtained in the usual operating frequencies below 1 kc/s, that even after some fatigue, the PE–EL units provide excellent performance after months of operation.

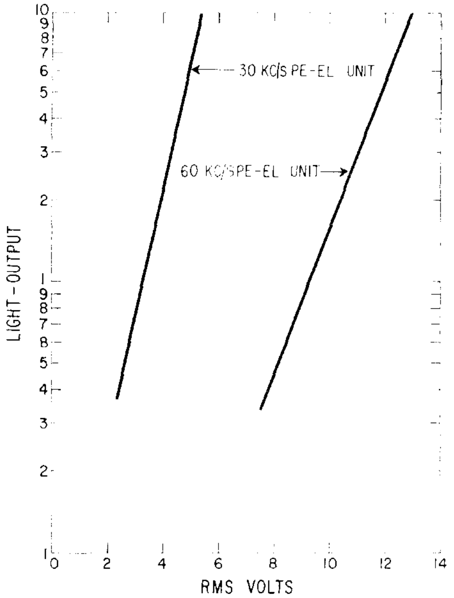

FIG. 8. Time Average Light Output vs. Voltage Applied to Two PE-EL Units.

Exceedingly high levels of light output have been achieved for continuous operation (no sweep) with low voltages applied to the piezoelectric crystals. Light levels of 40 ft lamberts have been attained at a frequency of 30 kc/s and an applied voltage of 8·8 $V_{\rm rms}$. By overdriving the PE elements at 40 $V_{\rm rms}$, light levels above 100 ft lamberts are available. A plot of light output versus applied voltage is shown in Fig. 8. Power requirements are also low. A continuously operated PE-EL element driven at 58 kc/s and 6 $V_{\rm rms}$ consumed 0·13 W (Fig. 9). With the 30-c/s sweep operation, the light output was reduced. To maintain the 40 ft lambert output obtained with 8·8 $V_{\rm rms}$, it was necessary to increase the voltage to 34·5 $V_{\rm rms}$. Each element consumes about 10 mW, averaged over the time of operation for a 30-element device. These measurements were obtained with the phosphor surface area dimensions approximately equal to the cross sectional area dimensions of the piezoelectric parallelpipeds, and equal to 0·33 × 0.03 in^2. When the PE element is operated at resonance, the voltage and current are in phase, whereas off resonance they are 90° apart, as shown in Fig. 9.

A measure of the effective bandwidth of operation can be obtained by using a "Q" defined as:

$$Q = \frac{\text{Center Frequency of Resonance Operation}}{\text{Bandwidth for Light Output to Diminish 30 per cent}}$$

This number should be as large as possible, since the higher the value of Q, the more elements can be driven over the same sweep-frequency bandwidth of operation. The maximum experimental value of Q for a PE-EL unit obtained was 802,

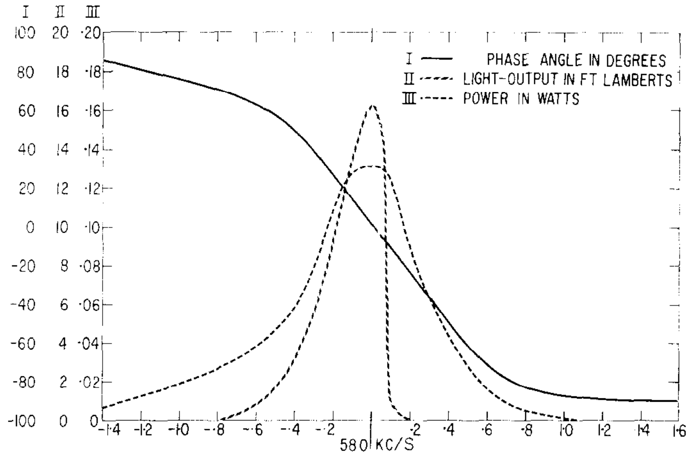

FIG. 9. Light Output and Electrical Properties of a PE-EL Unit Operating Near Resonance.

which exceeds the mechanical Q of 600 of the PZT–4 material. This apparent inconsistency is explained by the fact that the phosphor light output varies with voltage according to a power function (as discussed in Section 2.2a). The high Q value was obtained with a PE element operating at a resonance frequency of 57·2 kc/s.

Harmonics of the driving electrical frequency can generate undesirable light output. Our simple 30-element thermometer operating from 30 to 60 kc/s was not susceptible to this problem. However, a 160-element device, which we are now fabricating for Lear, Inc., requires some modification. It is necessary to extend the frequency range of operation, or to join a number of 30-element units so that the driver can be switched from one to another in successive sweep periods. Undesirable second harmonic output can also be avoided by placing the driving electrodes so that the PE element resonantes only in the second harmonic mode. The electrode arrangement shown in Fig. 6 drives both the fundamental and second harmonic. It is possible to select one or the other by impedance level requirements for matching driving source and electrical load. Although an electrode rearrangement permits simple operation from the second harmonic over an extended frequency range, the light output is somewhat reduced. The decision was made by Lear engineers to use the switching technique which involves the use of a simple solid-state switching device. Their present 30-element panel is operated by a small, lightweight transistorized package.*

3. FURTHER DEVICE DEVELOPMENT

Instead of being arranged to provide a thermometer-type display, the 30-element panel can be arranged with fewer elements for alpha-numeric displays. Triggering devices can be developed. 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 is determined by the rate at which the driving electrical frequency is varied. When a panel is coupled to an array of solid-state photodetectors, a sequence of events can be triggered, with complete and independent control of the timing of these events.

Areal, flat-panel types of display requiring low resolution and simple on or off light elements can readily be constructed. For example, a 10 by 10 x–y panel can be assembled, either by the use of extended sweep-frequency range by applying electrodes to the PE element to attenuate the second harmonics, or by the use of a solid-state switch as used by Lear, Inc. However, a device to produce images comparable in quality to TV images must await considerable research. Such a device, with its requirement for large information capacity, would have to operate over megacycles of frequency sweep. The high-Q elements used in the display which we constructed for Lear, Inc., provided an operating bandwidth of from 50 to 100 c/s (at the 70 per cent light output level) about the resonant frequency of the piezoelectric element. This bandwidth can serve for a simple on-off device, but hardly suffices for high-quality image displays. These displays would require electroluminescent phosphors which can be excited efficiently with frequencies in the range of 1–20 mc/s.

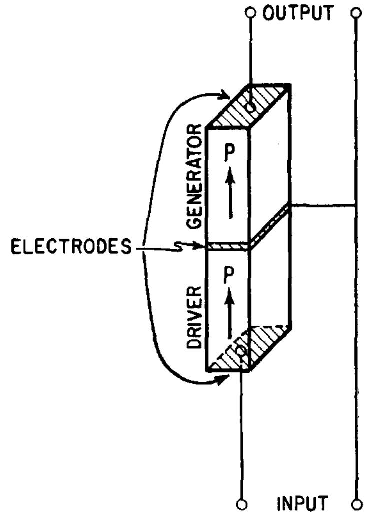

FIG. 10. Ring Type Piezoelectric Transformer.

If improved displays are to make use of the design shown in Fig. 6, new piezoelectric ceramic materials must be found which will operate in this high-frequency range and which will provide the necessary voltage amplification. Fortunately, quartz is already available and can be used as shown in

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* For details on the complete Lear panel and its electrical characteristics, consult H. Marcus, Instrument Division, Lear, Inc., Grand Rapids, Michigan.

Fig. 10. The open circuit voltage of this arrangement is independent of geometric considerations, since it is a function only of the mechanical Q_m and the electro-mechanical coupling coefficient. Quartz may be more than adequate, since it is known to have Q's from 10,000 to 10,000,000. It is interesting to note that a piezoelectic crystal wedge nonscanning analyzer has already been made of quartz.(16) This device was designed to provide a moving light spot from a gaseous discharge induced by the electric field from the wedge. Since a wedge is the shape which results from stacking many PE elements side by side (as in Fig. 1) in decreasing length to go from the high-frequency end of a panel to its low-frequency end, the extension of this technique to a PE–EL display is obvious.

The PE–EL scanning device with its demonstrated high light level provides some hope that a direct display can be formed without using a storage technique to compensate for low-level electroluminescence,(17,18) The PE–EL also compensated somewhat for the lack of persistence in the phosphors since the rate at which the electric field decayed is slower than the electroluminescent phosphor decay (see discussion of the high value of Q and the narrow bandwidth of operation in Section 2.2c). The shape of a plot of the light output versus frequency, as the frequency was swept through the resonance of a PE element regardless of the direction of sweep, was skewed. The onset of light output was sharp, while the diminution of light output occurred relatively slowly. This observation is compatible with the fact that the onset side is a function of the product of the natural characteristics of the PE element and the driving signal, whereas the decay side is characteristic of the PE element. An effective, practical bandwidth is usually from 1000 to 3000 c/s. The display constructed for Lear, Inc. was optimized for these operating conditions by using a repetition rate of 100 c/s. This is compatible with the relationship between bandwidth and a pulse period given by:(19,20)

$$\Delta F \cdot T = 1$$

For a bandwidth of 3000 c/s, $T = 0{\cdot}3 \times 10^{-3}$ sec. This value also equals that obtained for the excitation time per element for the 30-element display; i.e., the sweep period divided by 30.

Since new phosphors are required for operation in the megacycle region, an estimation of the problem that luminescence decay will present would be premature. Finally, one must consider the matter of driving a large capacitive load such as exists in the PE–EL display. For the 30-element display, the technique was to use the capacity in the tuned circuit to generate the frequency sweep.* This technique may also be applicable to large panels.

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* R. Racy of Lear, Inc. suggested and designed the circuitry for this application.