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TECHNICAL REPORT ECOM-02482-4

CHARGE-CONTROLLED STORAGE DISPLAY PANEL

FOURTH QUARTERLY REPORT

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By

P. FOOTE, B. KAZAN, AND J. WINSLOW

OCTOBER 1967

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ELECTRO-OPTICAL SYSTEMS, INC., A Xerox Company
Pasadena, California

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J. 07703

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Technical Report ECOM-02482-4 October 1967

CHARGE-CONTROLLED STORAGE DISPLAY PANELS

Fourth Quarterly Report

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Report No. 4

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ABSTRACT

During the fourth quarter the performance and characteristics of current image storage panels were evaluated. Also, work was initiated on development of techniques for fabrication of large-area panels on single substrates.

The loss of stored images due to both frontal excitation of the panel by room light and optical feedback from the electroluminescent layer to the photoconductive layer was investigated and, to a great extent, eliminated. The voltage dependence of the panel's transfer characteristic was measured. Resolution measurements were made on a 12-inch, 50-line/inch image panel. Factors influencing the uniformity and speed of panel erasure were also studied.

In the area of technique development for large-area, single-substrate panels, several approaches were investigated. One approach involved formation of the panel electrode structures on acrylic plastic coated with a transparent conducting film of tin oxide. The usefulness of cadmium oxide as a transparent conductor on plastic and glass substrates was also investigated. A dual-conductor arrangement for electrode lines was devised and preliminary tests made. A new panel structure employing continuous electrodes instead of interdigitated electrodes was also studied.

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ILLUSTRATIONS

PUBLICATIONS, LECTURES, REPORTS, AND CONFERENCES

Dr. B. Kazan visited ECOM on 4 and 5 May 1967 to deliver four image storage panels and to discuss the future course of the program.

Philip Krzyzkowski, the technical monitor, visited EOS on 18 July 1967 to discuss the program.

SECTION 1

INTRODUCTION

During the fourth quarter the performance and characteristics of current image storage panels were evaluated. Also, analytical and experimental work was begun to develop techniques for fabrication of large-area panels on single substrates of plastic or glass.

The loss of stored images due to frontal excitation of the panel by room light was studied, and an effective method of minimizing this problem was developed. Another cause of image deterioration, optical feedback from the electroluminescent layer to the photoconductive layer, was investigated and, to a great extent, eliminated. The voltage dependence of the panel's transfer characteristic was measured in the range of 500 to 900 volts. Resolution measurements were made on a 12-inch, 50-line/inch image panel. Problems associated with uniform and rapid erasure of panels were also studied.

In the area of technique development for large-area, single-substrate panels, several approaches were investigated. One approach involved formation of the panel electrode structures on acrylic plastic coated with a transparent conducting film of tin oxide. The usefulness of cadmium oxide as a transparent conductor on plastic and glass substrates was also investigated. A dual-conductor approach for producing electrode lines was devised and preliminary tests made. This structure has the advantage of avoiding the requirement of high conductivity of the transparent conducting electrodes. A new panel structure developed on an internally funded program was also studied. Instead of using interdigitated electrodes this structure employs continuous electrodes, and this concept may have potential advantages for large-area panel construction.

SECTION 2

EVALUATION OF IMAGE PANEL PERFORMANCE

2.1 FRONTAL EXCITATION OF PANEL BY ROOM LIGHT

The highlight brightness of present image panels using blue-green EL phosphor (10 to 20 ft-L) is sufficient to permit viewing in moderate room illumination. However, the ZnO photoconductive control layer is sensitive to the shorter wavelengths of white room light. Therefore, the image on the panel is lost in a short time as the entire panel comes up to highlight brightness. This problem is particularly severe where white flourescent lighting is used, since this lighting is rich in the shorter wavelengths.

It is anticipated that the image panel, when used in a display system, will have the back side shielded from ambient illumination. Therefore, the main concern is to prevent rapid loss of the image due to frontal excitation by room light. (Throughout these discussions the glass side of the panel is called the front, and the side coated with the layers is called the back.)

Two general methods are available for prevention of excitation by room light. One method involves use of an external optical filter in front of the panel; the other is to interpose an opaque layer or optical filter between the electroluminescent and photoconductive layers. The latter method would complicate panel fabrication and, in the case of an opaque layer, would prevent viewing of stored images from the back side. It was decided, therefore, to investigate the external filter method.

The two characteristics required in the external optical filter are: (1) strong absorption of the ultraviolet and shorter visible wavelengths, and (2) high transmission in the spectral region emitted by the electroluminescent phosphor used in the panel. A survey of the various glass, gelatin, and plastic filters available revealed that Kodagraph yellow sheeting is an excellent match to the spectral requirements discussed above. This material has the additional advantage of low cost--about $0.30/ft^2, compared with approximately $20.00/ft^2 for Wratten gelatin filters.

Comparison of frontal excitation with and without the Kodagraph filter was made on a 6-inch image panel made with RCA yellow-green EL phosphor. In each case the panel (operated at 600V at 1 kHz) was erased, exposed and placed flat on a lab bench in the dark. The lab is provided with two sets of two 8-foot fluorescent lamps behind plastic diffusers. The panel was positioned directly under one set at a distance of 56 inches. When using the filter, a 1-square-yard piece of Kodagraph sheet was placed over the panel and taped to the bench top. The panel was then illuminated with the lab lights for various periods of time, and the panel images were photographed.

Figure 1 shows the results of these tests. Figures 1a and 1b show the images after 20 seconds and 10 minutes exposure, respectively, in the dark lab. Some decay in highlight brightness is observed, but no increase in background brightness can be detected. Exposure of the panel to 20 seconds of room light produced the image shown in Fig. 1c. Here the background has increased to such an extent that the image is partially obliterated. Figure 1d shows the panel after 10 minutes exposure to room light with the filter in place. Here, some increase in background is observed, but the image contrast is largely retained.

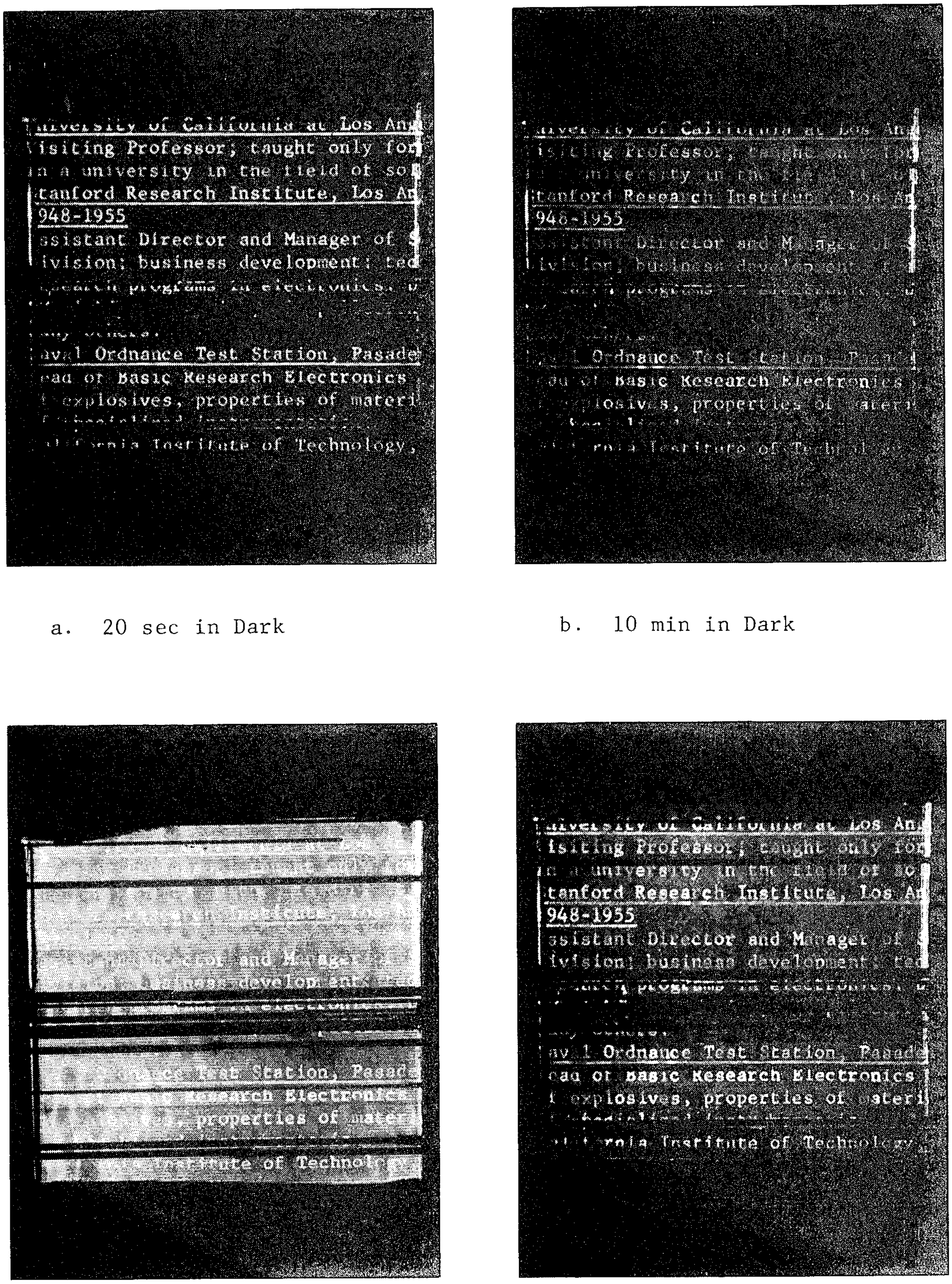
Photometric measurements were also made to determine the brightness reduction caused by the filter. It was found that the brightness was reduced by only 7 percent when the filter was placed on the panel.

There is an additional advantage in having this filter on the front of the panel. Much of the ambient nonyellow light is absorbed before it can fall on and be reflected from the glass surface. This improves the apparent contrast of the panel image when viewed in room light.

2.2 OPTICAL FEEDBACK STUDIES

In the Third Quarterly Report, observations were reported which indicated the presence of optical feedback from the EL layer to the photoconductive layer during panel operation. These observations were definitely confirmed by two experiments discussed below.

Both experiments made use of two different EL phosphors with two distinct light output spectra. One was U.S. Radium Corporation bluish-green EL (USRC green) and the other was RCA greenish-yellow EL (RCA yellow). The spectral outputs of both phosphors are rather broadband, but the USRC green is much richer in the shorter wavelength region to which the ZnO photoconductor responds. Therefore, one would expect any optical feedback effects to be more pronounced with the USRC green.



a. 20 sec in Dark

b. 10 min in Dark

c. 20 sec in Room Light, no Filter

d. 10 min in Room Light, with Filter

Figure 1. Photographs of Stored Images After Various Types of Frontal Excitation (see text)

A 12-in. image panel was made using one type of EL material on one portion and using the second type of EL phosphor on another portion. It was determined, using a Pritchard photometer, that a highlight brightness of 8.7 ft-L was obtained at 600V in the RCA yellow section; the same brightness was obtained at 480V in the USRC green section, the frequency being 1 kHz in both cases. In two separate runs each section was operated at the appropriate voltage to produce 8.7 ft-L highlight brightness, erased, and then exposed up to 1.0 ft-L. Then changes in brightness as a function of time were measured. Results are plotted in Fig. 2. In the USRC green run brightness increased during the entire 20-minute period; in the RCA yellow run a small initial increase was followed by a continual decrease in brightness. The initial increase in both cases is associated with light exposure preceding erasure. The subsequent decrease in the RCA yellow case is probably due to the slow return of the ZnO control layer to its equilibrium value of conductivity. Although this process also occurs in the panel section employing the USRC green phosphor, the effects of optical feedback are predominant.

To eliminate any variables due to operation of the two panel sections at different voltages, another experiment was performed. Two EL light sources, operated at 5.0 ft-L, one USRC green and one RCA yellow, were used in sequence to expose the same region of an erased 6-in. image panel (made with USRC green EL) for various lengths of time. The panel brightness was measured after each exposure. Maximum highlight brightness for this panel was 10.0 ft-L. Results of this test are given in Table I.

TABLE I

OPTICAL FEEDBACK EXPERIMENT

Exposure Time (minutes)	Image Panel Brightness (ft-L)	
	USRC Green Source	RCA Yellow Source
0 (erased)	0.1	0.1
2	2.0	0.1
10	7.5	1.0

These results conclusively demonstrate that the ZnO layer is significantly excited by the shorter wavelength output of the USRC green EL.

2.3 PANEL BRIGHTNESS AS A FUNCTION OF TIME

In view of the reduced feedback obtained with the RCA yellow EL discussed above it was of interest to investigate the time-dependent brightness changes in an

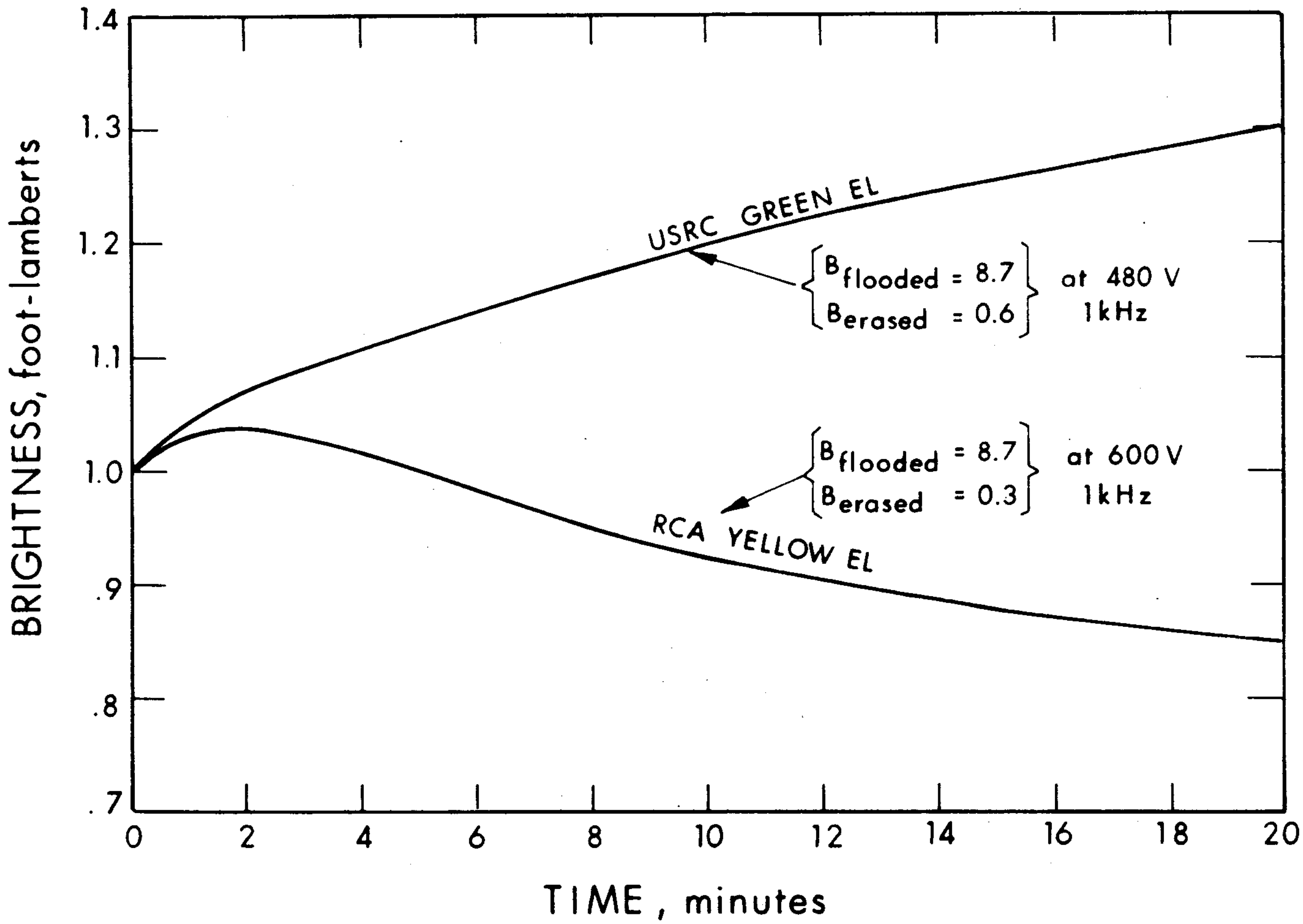


Figure 2. Image Panel Brightness as a Function of Time for Two Types of EL Phosphors on a Single 12-in. Panel

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image panel made with this phosphor after being excited to various brightness levels. This information gives a quantitative measure of the useful storage time of the panel, especially for halftone information.

The 6-in. image panel (made with RCA yellow EL) used for these measurements has a maximum highlight brightness of 10 ft-L and an erased brightness of 0.13 ft-L. Since there is evidence that previous light exposure influences the panel's brightness versus time characteristic, two series of measurements were made. In the first series the panel had been maintained in the dark for 24 hours prior to the measurements. With no exposure to light, the panel was erased, and its brightness was monitored for 1 hour. The panel was then erased again and was exposed enough to give a brightness of 0.4 ft-L, and again monitored for 1 hour. This procedure was repeated for five brightness levels, done in order of increasing brightness, with the levels spaced at approximately equal increments of log brightness. In the second series of measurements the same procedure was followed, except that the panel was exposed up to a brightness of 10 ft-L immediately before it was erased and reexposed to the desired brightness level. In all cases the panel was operated at 600V at 1 kHz. Changes in brightness were monitored continuously on a strip chart recording of the output of a Pritchard photometer.

Results of these measurements are shown in Figs. 3 and 4 for the dark-adapted and the light-adapted conditions, respectively. It is seen that there are relatively small differences in the two series of measurements, with these differences being most noticeable in the mid-range from 0.4 to 4.0 ft-L. More notable are the small changes in brightness after the first 10 minutes and the high contrast ratios retained after 1 hour. The asymptotic behavior of these curves implies that halftone image storage for at least several hours is feasible, although light output drops to ≈ 50 percent after about 1 hour. Small differences in the brightness versus time behavior shown in Fig. 2 and Fig. 4 are attributable to differences in the ZnO control layers on the two panels discussed, rather than to variations in the RCA yellow EL phosphor characteristics. At the present time techniques for complete reproducibility of the control layers have not been developed.

2.4 VOLTAGE DEPENDENCE OF TRANSFER CHARACTERISTIC

The transfer characteristics of the image panel discussed in Subsection 2.3 were measured as a function of operating voltage. The method used is described in the Third Quarterly Report, page 31.

The characteristics are shown in Fig. 5 for the range of 500 to 900V rms in 100V steps. Aside from the substantial increase in maximum brightness, the steep (sensitive) portions of the curves are displaced toward smaller exposures

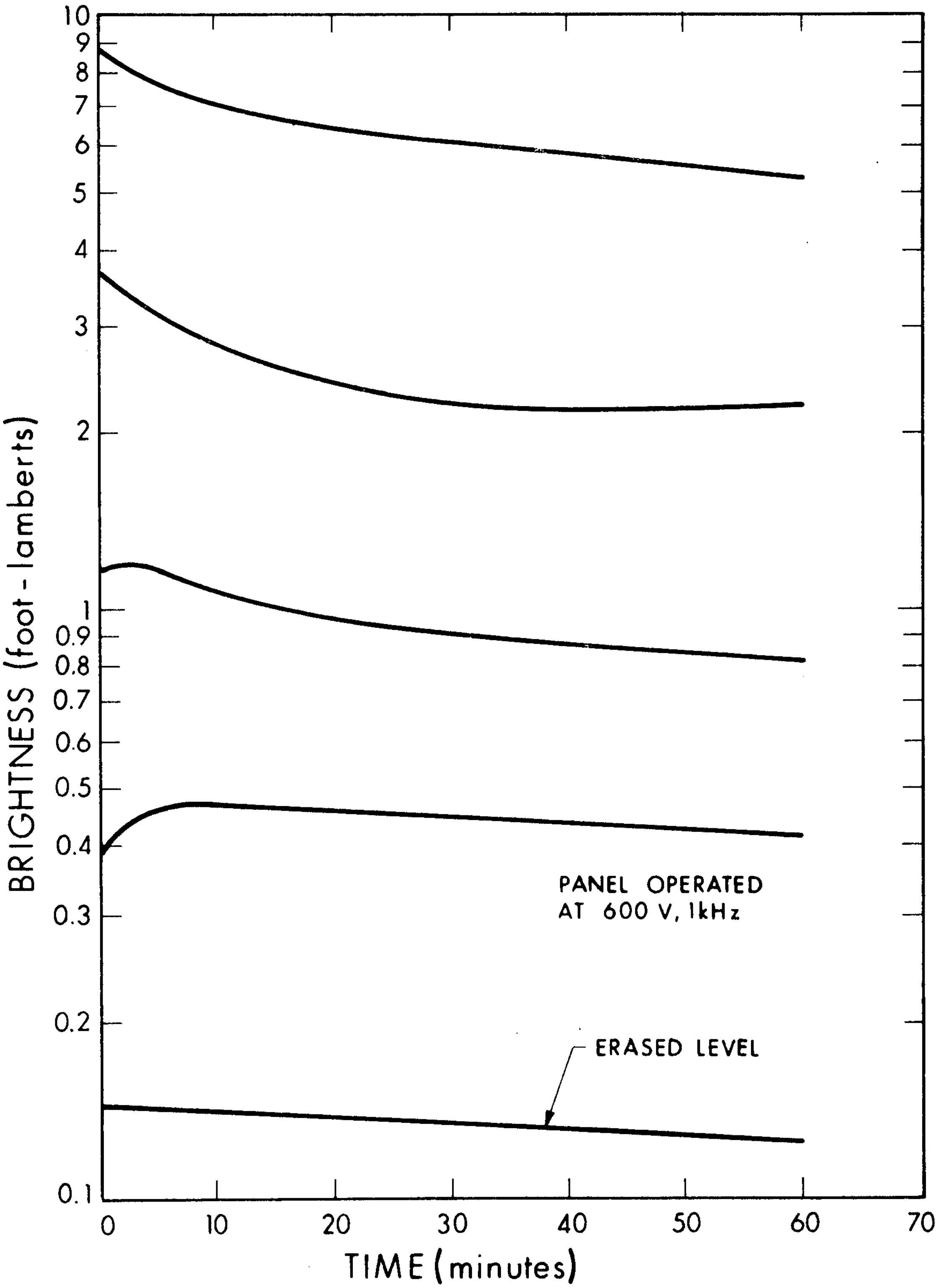

Figure 3. Brightness as a Function of Time for Dark-Adapted Image Panel (6-in. RCA Yellow EL Panel)

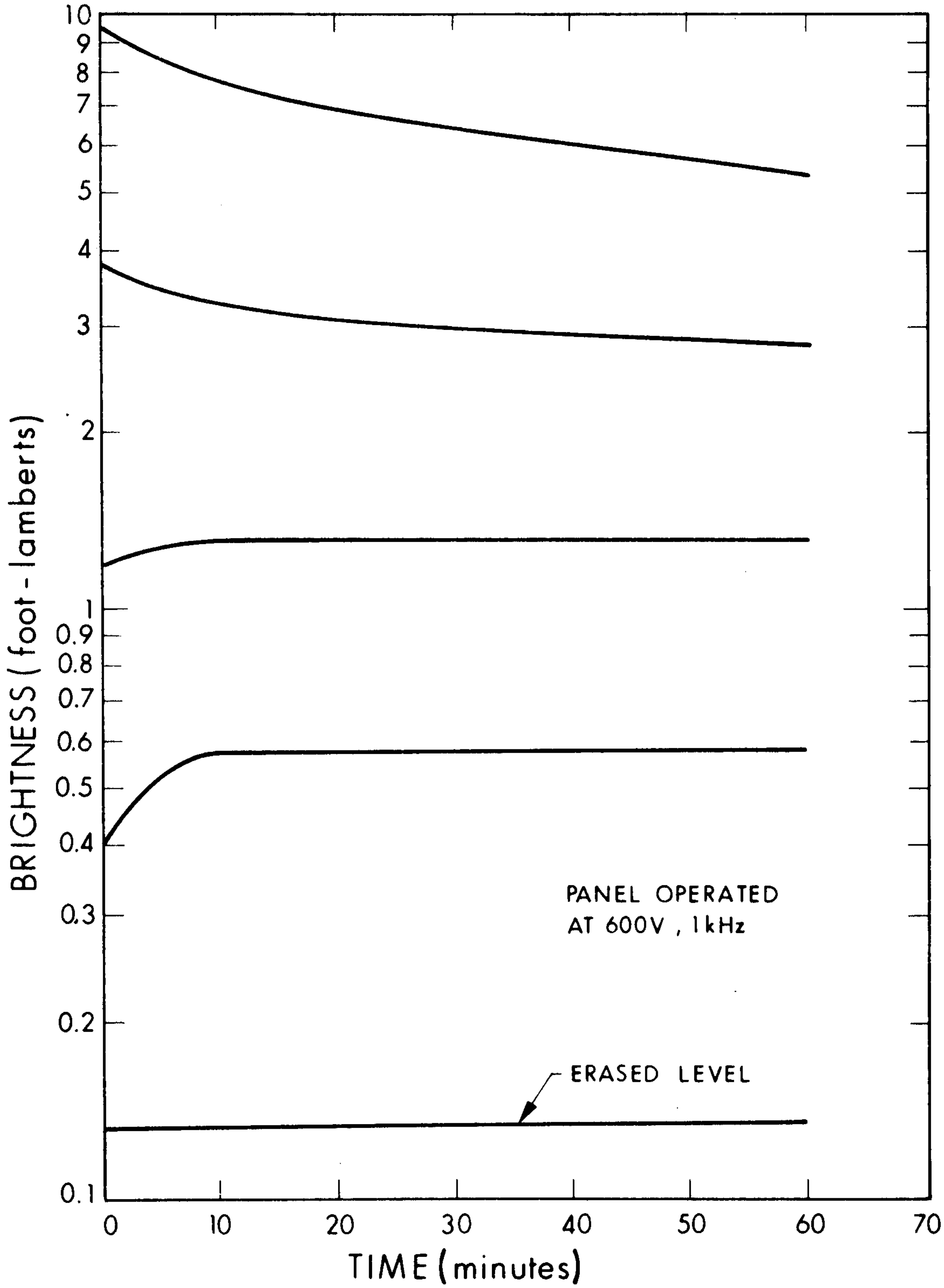

Figure 4. Brightness as a Function of Time for Light-Adapted Image Panel (6-in. RCA Yellow EL Panel)

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as the voltage is increased. The slopes of these curves in the steep region, i.e., the "gamma," all have values near three. This is in agreement with the high contrast appearance of images stored on these panels.

2.5 RESOLUTION

During the past quarter a 12-in. image panel with 50 lines/inch was completed. Resolution measurements were made on this panel by projecting and storing the image of a standard television test pattern (35 mm slide No. TM-102, Telemeasurements, Inc., Clifton, N. J.). Figure 6 is a photograph of the stored image.

The numbers beside the four sets of lines converging toward the center indicate the number of TV lines per frame at that point. It is seen that the limiting vertical resolution, i.e., perpendicular to the electrode lines, is in excess of 400 lines/field, while the horizontal resolution is about 750 lines/field. The limited resolution in the vertical direction is attributable to the electrode structure (about 600 electrode strips across the panel). In the horizontal direction the limit on resolution is due, not only to the thickness of the ZnO and EL layers, but is also due to the spreading of currents as they flow parallel to the ZnO surface.

It should be noted that the exposure used for producing the stored test pattern was adjusted to optimize the resolution. Because of the density of the halftone steps of the slide's gray scale, insufficient exposure was available on the panel to properly show its halftone response.

2.6 PANEL ERASURE STUDIES

During the past quarter, studies aimed at understanding and improving the erasure process were carried out. Panels are erased using two interdigitated sets of fine wires, with a high negative voltage being connected alternately to each set. The corona discharge appears as small, discrete beads at fixed points along each wire. The beads are of sufficient luminosity to be observed in a darkened room. The negative ions from these luminous beads apparently fall on the panel in a focused manner; i.e., portions of the panel under the beads are rapidly erased, while the portions between beads are erased only after considerable exposure to corona. The cause of this focusing effect is not understood at present.

Previously it was believed that the corona beads were due to dust or imperfections on the wires. Further study of corona discharge from uniform, polished wires has convinced us that the bead formation is a fundamental phenomenon.

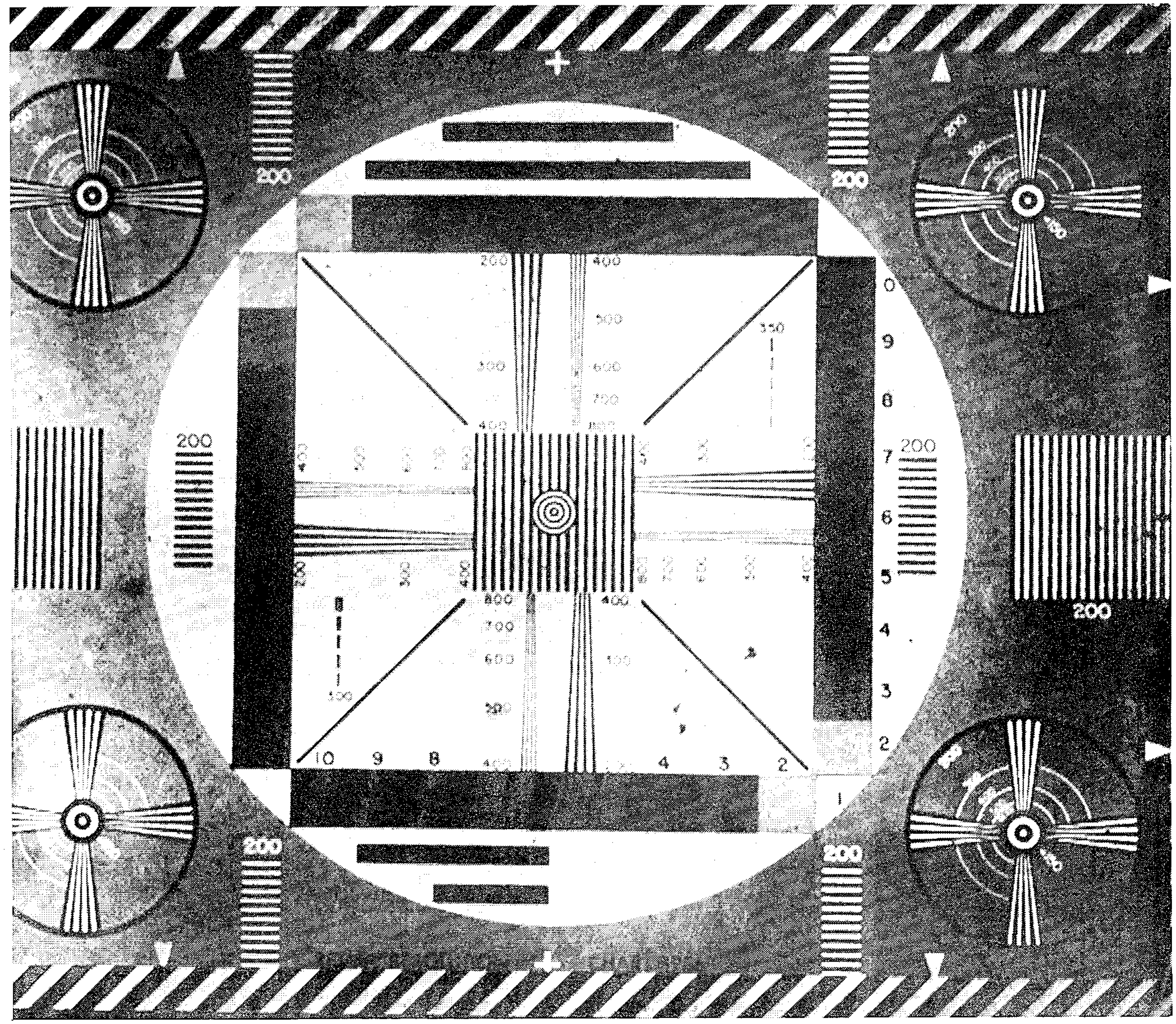

Figure 6. Photograph of Resolution Chart Stored on a 12-Inch Square Image Panel with 50-Line/Inch Electrode Structure

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This is confirmed by Cobine (Ref. 1) who states that negative corona invariably occurs as discrete beads, while positive corona occurs as a continuous sheath around a wire. There is some advantage, however, in using uniform, polished wire since the corona beads are spaced uniformly along the wire. On wire with a rough surface the beads are irregularly spaced, which makes erasure more difficult.

As a result of the corona beading and focusing effects, after complete wire erasure most of the panel is in an "over-erased" condition, i.e., many more oxygen ions are driven to the surface than are required to minimize conductivity in the ZnO. This leads to a low level threshold in the panel's response to light. Typically, 0.5 to 1.0 μ/cm^2 exposure is required before any brightness increase can be observed.

Several experiments were performed to determine the amount of corona charge (in terms of $\mu C/cm^2$) required for panel erasure. In the case of wire erasure it was found that about 1 mA of corona current at -7 kV is required for 10 seconds to erase a 6-inch square panel. In terms of charge per unit area this is about 40 $\mu C/cm^2$. Since the corona falls nonuniformly on the panel as described above, much of the erasing time is spent in eliminating bright spots on the panel.

To determine how much corona charge is needed for erasure under more uniform conditions, a point source of corona was used. A steel dissecting needle was placed 1.0 inch from a panel. Operating at -7 kV, a current of 5 μA for 15 seconds completely erased a 2-inch-diameter circle on the panel. This is equivalent to 3.7 $\mu C/cm^2$, more than an order of magnitude lower than that required with the wires.

Experiments with point source erasure were also done at various distances from the panel to determine the relationship between distance and amount of corona charge required. In this experiment -10 kV was applied to the point to generate sufficient corona at the greater distances. Results are given in Table II and are plotted in Fig. 7.

From the last column of Table II, and as shown in Fig. 7, it appears that the amount of corona charge required for erasure is essentially independent of distance in the range of 1.0 to 2.5 inches. It is also seen that relatively large areas can be erased with a single point, although a long exposure is required. If a higher potential were used, this time might be reduced significantly.

1. J. D. Cobine, Gaseous Conductors, (McGraw-Hill Book Co., New York, 1941), pp. 252-253.

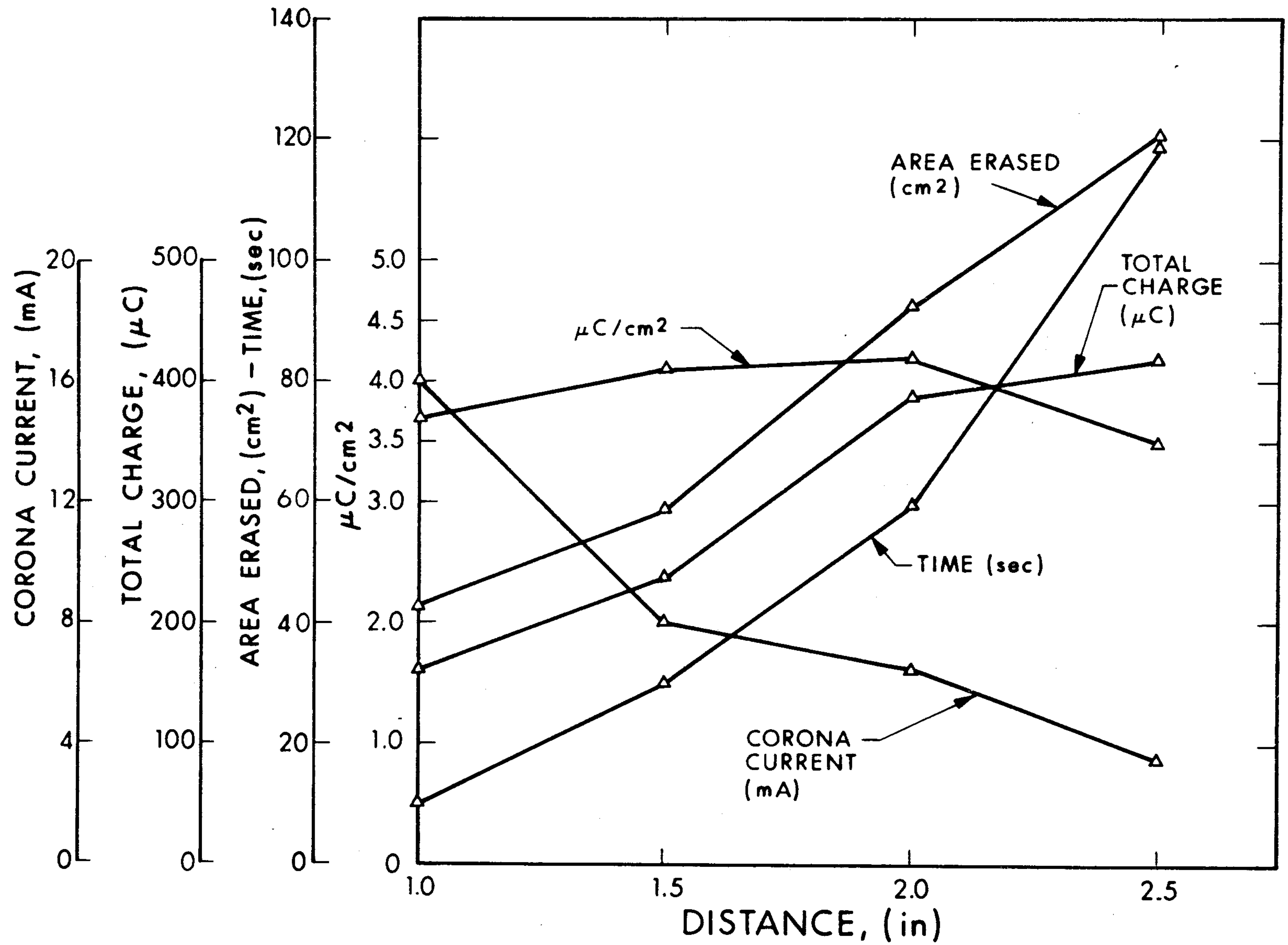

Figure 7. Point Erasure versus Distance

TABLE II

POINT ERASURE VERSUS DISTANCE

Distance (in.)	Corona Current (mA)	Time (sec)	Total Charge (μC)	Area Erased (cm^2)	$\mu C/cm^2$
2.5	3.5	120	420	121	3.5
2.0	6.5	60	390	93	4.2
1.5	8.0	30	240	59	4.1
1.0	16.0	10	160	43	3.7

As part of these erasure studies a wide variety of wires was tested for suitability for negative corona generation. It was concluded that one type of tungsten wire (General Electric Type 218CS) is best for the corona application. In addition to high strength, this wire has a clean, polished surface which yields uniform corona discharge; i.e., the corona beads are equally spaced along the wire. Both 1.5 mil and 2.0 mil wires have been used; the former gives better erasing, while the latter is less likely to break during use.

SECTION 3

IMAGE PANEL FABRICATION

3.1 INTRODUCTION

Midway through the last quarter it was decided, with approval from the Contracting Officer's Technical Representative, to emphasize development of techniques which would permit fabrication of large-area image panels, in the range of 2 x 2 feet or larger. The contract effort before this was based on the assumption that large-area panels would be built by assembling a mosaic of smaller panels. In the work discussed here some alternative methods which would potentially permit use of a single large substrate of plastic or glass were investigated. Based on this work and continuing effort during the contract period it is hoped that a more realistic comparison can be made between the multiple plate approach and the single large display panel approach.

The most obvious approach to single-substrate large-area panel fabrication would seem to be application of the present processes to larger sheets of glass coated with transparent, electrically conductive tin oxide. Although large sheets (up to 2 ft x 4 ft) of this material are available from Corning Glass Works, there are two reasons for not considering this approach to be feasible. The first is the problem of scratches and other defects in the coating. This problem is quite serious even with the 6 inch and 12 inch panels presently fabricated; with much larger panels the defects would make panel fabrication impractical. Another problem arises when the length of electrode lines on panels becomes much greater than one foot; the voltage drop along the line due to its limited conductivity leads to a large variation in brightness from the center to the edge of the panel. This problem is discussed quantitatively in Subsection 3.3.

3.2 TIN OXIDE COATED PLASTIC PANEL

Several sheets (6 in. x 6 in. and 12 in. x 12 in.) of acrylic plastic coated with a tin oxide transparent conductive layer (200 ohms/square) were obtained from Zep-Aero Co., El Segundo, California. Larger sheets are also available.

In the first attempt to fabricate an image panel with this material the standard photoresist process was used to produce the electrode pattern. Although this pattern was successfully produced, the electrode lines were observed to contain many cracks causing electrical discontinuities. Apparently the coating is sufficiently porous to permit the organic solvents used in the photoresist process to attack the plastic and cause crazing of the tin oxide layer.

Another approach, which eliminated the photoresist process, was also tried. The conducting sheet was coated with EL phosphor in an epoxy binder. Then the line pattern was produced by scribing through the EL and tin oxide layers. After application of the ZnO control layer the panel was tested in operation. This revealed that about 20 percent of the lines were open-circuited, apparently due to scratches or thin spots in the as-received material. With respect to storage and erasure the panel performed in the normal manner.

Since the manufacturer indicated that the material used in these experiments was the best his process could produce, it was decided to discontinue this approach.

3.3 CADMIUM OXIDE COATED PANEL

Cadmium oxide is similar to tin oxide in that it is a transparent conductor. Its great advantage over tin oxide is that it can be deposited on glass and plastic substrates held at room temperature, by either vacuum deposition of the compound or by reactive sputtering of cadmium metal in the presence of oxygen gas at low pressure. By contrast, tin oxide films are generally produced only on glass, which must be heated to near its softening point during the process. An exception to this is the Zep-Aero material (Subsection 3.2) which is made by a proprietary process, and which is unsatisfactory for this application. Cadmium oxide is somewhat less transparent than tin oxide in films of comparable conductance; however, it has high transmission in the yellow, which makes it a good match to the yellow EL discussed in Section 2.

To evaluate the usefulness of CdO for the panel electrode structure, such a structure was prepared by vacuum deposition of CdO on a 4-inch glass square through a metal mask which defined the interdigitated pattern. The sheet resistance of the layer was 600 ohms/square. Optical transmission of the layer in the yellow range was 85 percent. This panel was completed by the usual processes and was tested. It exhibited normal operation, and there were no open or shorted lines.

Although a glass substrate was used in this case, other experiments demonstrated the feasibility of using a plastic substrate. Continuous, adherent films of CdO were produced on both acrylic and polycarbonate plastic by reactive sputtering.

Due to the small size of these samples (limited by the size of our present sputtering chamber) these samples were not processed into panels. Since CdO is readily soluble in acids, there should be no serious problem in photoresist production of the electrode pattern, given a substrate which is not attacked by the photoresist solvents.

Several problems are apparent with respect to fabricating large panels with CdO electrodes. Both available coating methods require use of a vacuum chamber, which for very large panels would be both inconvenient and expensive. One solution might be to coat a long roll of thin flexible plastic, e.g., 1 mil Mylar, in the manner used to produce long rolls of vacuum aluminized plastic films. Then sections of the CdO coated film could be bonded to a rigid, transparent substrate before further processing.

It is also not clear at this time that CdO films of both sufficient transparency and conductivity can be produced. The effect of conductivity along the electrode lines on panel performance was analyzed in the appendix to the First Quarterly Report (pages 29-33); these results are used in the following calculation. Assume a 4-foot-wide panel made with 0.010-in.-wide electrode lines on 0.020-in. centers in which the CdO has a sheet resistance of 100 ohms/square and the combined sheet resistance of the EL and ZnO layers is 10^9 ohms/square. In this case the αL factor is 1.08, and from Fig. A-2 of the referenced appendix it is seen that only 20 percent of the applied voltage appears across a line pair at the panel center, and increases to 32 percent at the panel edge. This would give an undesirable variation in brightness across the panel. It can also be seen from the definition of α given in Fig. A-2 that in order to reduce αL to the acceptable value of 0.25 the CdO sheet resistance would have to be 100/16 = 6.3 ohms/square. It is believed the film would have very low transparency at this resistance level.

3.4 DUAL-CONDUCTOR PANELS

In view of the problems discussed in the previous sections a new approach to large-area panel fabrication was developed. Figure 8 shows the dual-conductor panel design concept. Since all high conductivity materials are opaque and since some transparent or translucent materials of moderate conductivity are available, it appears possible to combine the two to form suitable panel electrode lines.

The opaque conductor occupies a small fraction of the line width, obscuring only a small fraction of the light from the EL. For example, a 0.001-in.-diameter copper wire along the center of a 0.010-in. line has 90 percent light transmission along with an effective sheet resistance of 8.5×10^{-3} ohm/square

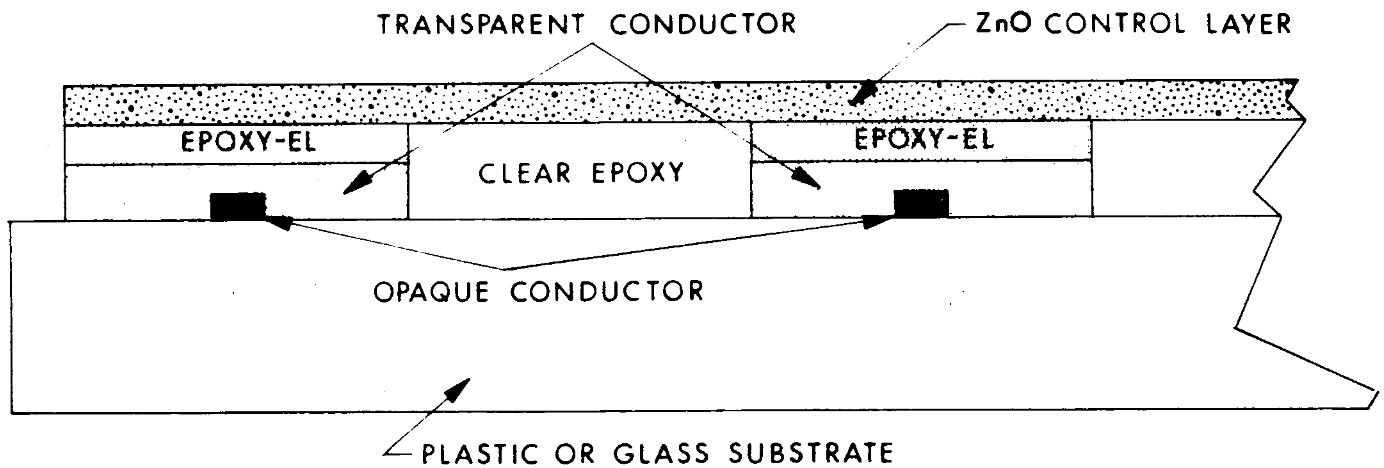

Figure 8. Cross Section View Illustrating Dual-Conductor Panel Design Concept

or 41 ohms across a 4-foot panel width. The conductivity requirements for the transparent conductor are thereby considerably relaxed. As a first approximation it would appear that a sheet resistance comparable to that of the ZnO control layer under full illumination would be appropriate, i.e., in the range of 10^6 to 10^7 ohms/square.

With respect to fabrication of large dual-conductor panels it would be desirable to avoid processes requiring a vacuum system. If the proper materials can be found, the fabrication process outline would be as follows:

a. Imbed fine metal wires in plastic substrate in interdigitated pattern and apply edge electrodes with silver-epoxy.

b. Apply transparent conductor by spraying or other appropriate method.

c. Apply EL-epoxy layer by spraying.

d. Produce line pattern in layers (b) and (c) by lapping, machining, or scribing.

e. Fill in between lines with clear epoxy.

f. Apply ZnO control layer by spraying.

It is noted that the EL is removed from between the lines in this process, which should give very low erased brightness.

Several experimental panels were fabricated to test the dual-conductor approach. The transparent conductor used in these experiments was reduced ZnO in an epoxy binder which was applied to panels by spraying. During early work on the image panel, prior to the start of this contract, it was discovered that ZnO in epoxy is much more conductive and much less photosensitive than the same material in a Pliolite binder. In gap cell tests the resistance of ZnO-epoxy layers was found to be in the range of 5×10^5 to 5×10^6 ohms/square. This fact, together with the observation that the ZnO control layer on standard image panels does not significantly attenuate the light from the EL layer, suggested use of ZnO in epoxy for the transparent conductor.

The first panels were constructed by milling 0.006-in. slots on 0.050-in. centers in polycarbonate plastic. Copper wires 0.007-in. in diameter were pressed into the slots in the interdigitated pattern. Approximately 0.003 in. of the surface was then abraded away, thus creating a flat surface on the plastic and wires. The ZnO-epoxy and EL layers were then sprayed on and the lines were separated by scribing 0.025-in.-wide lines through the layers; following this, clear epoxy was used to fill in between the conducting stripes. After application of the ZnO in Pliolite control layer, the panels were tested. In most areas of the panels the transparent conductor did not function as desired; i.e., the entire stripe width did not light up under illumination. In a few regions, however, the entire width did light up and was erasable with corona. It is believed that poor contact between the copper surface and the ZnO-epoxy layer caused the poor panel performance. The unmodified Araldite 502 epoxy resin used here is known to shrink during the curing cycle and may make a weaker bond to the copper than to the plastic. In this case poor electrical contact between the wire and epoxy layer would result.

Further tests of this approach were made by vacuum depositing opaque aluminum lines on glass and acrylic substrates through a metal mask which produced 0.010-in. wide lines of 5 ohms/square sheet resistance on 0.080-in. centers. These substrates were then made into panels by the process used for the wire panels. Results of testing were quite similar to the wire panels, with only small areas functioning properly. Many of the lines became open circuited after the epoxy cured. This is further evidence that this epoxy may not be suitable for this work.

The tests described above indicate some degree of feasibility for the dual-conductor approach. It is believed to be worthwhile to continue this effort in the next quarter, with emphasis on development of improved transparent conducting materials and binders.

3.5 CONTINUOUS ELECTRODE PANEL

The work described in this section was performed on an internally funded program at Electro-Optical Systems, Inc., concerned with a proprietary application of image storage panels. This is reported because the panel structure employs a continuous transparent conducting electrode instead of the interdigital structure presently used. With the interdigital structure, both the conducting sheet from which it is made and the technique used to etch the pattern must be nearly perfect or else discontinuous electrode lines will result. In addition, the resistive voltage drop along these lines limits the size of the panel. With a continuous electrode panel small imperfections do not interfere with panel operation, and the problem of voltage drops along long, thin lines is eliminated. Panel designs of this type are thus potentially useful where large-area displays are to be fabricated in a single unit.

The panel was tested by connecting it to a 200V rms, 1 kHz supply and erasing and exposing it in the usual manner. The panel, at this stage of development, has limited brightness and contrast. With 200V applied at 1 kHz (the maximum safe operating voltage) the maximum highlight brightness is about 1.0 ft-L and the maximum contrast ratio is about 7:1.

In their existing form, such panels have a limited brightness and contrast. Because of the special techniques required to improve these characteristics as well as the problem of fabricating such structures in large areas, it is not believed presently advisable to concentrate effort in this approach.

SECTION 4

CONCLUSIONS

The frontal excitation of image panels by room light and resultant loss of the stored images can be minimized by use of an inexpensive external optical filter. Optical feedback from the electroluminescent layer to the photoconductive layer which degrades image quality during long storage was greatly reduced by using an EL phosphor with spectral output peaked at a longer wavelength, to which the ZnO is insensitive. Such panels can store images for 1 hour or more with only a 50 percent drop in maximum contrast ratio.

Measurement of the panel's transfer characteristic as a function of applied voltage revealed a shift of the steep portion of the curve toward smaller exposure as the voltage is increased. On a 600-line panel (12 inches square with 50 lines/inch) resolution was shown to be about 750 TV lines/field horizontally and about 400 lines/field vertically. Preliminary studies of panel erasure characteristics showed that 3 to 4 $\mu C/cm^2$ of negative corona from a point source is required for complete erasure; however, about 10 times this amount is used when wires are used for erasure due to nonuniformity of the corona discharge.

Effort was directed along several lines in connection with developing a panel design suitable for panel fabrication in large areas. Acrylic plastic coated with a transparent conductive film of tin oxide was found to be unsatisfactory for panels due to imperfections in the coating. Cadmium oxide, formed by vacuum deposition or reactive sputtering, was found to be a suitable transparent electrode material for small glass or plastic panels, but the problem of achieving sufficient conductivity along with good transparency remains to be solved. A dual-conductor approach to panel electrode fabrication was devised in which a fine opaque line of high conductivity material, such as a metal wire, is used instead of the transparent conductive strips presently used. Such a design has the potential advantage of allowing large area panels to be fabricated much easier than those of present design. In addition, the operation of a new panel structure employing continuous electrodes was studied also because of its potential advantage for large-area fabrication.

SECTION 5

PROGRAM FOR NEXT QUARTER

The following is the proposed work program for the fifth quarter:

a. Continuation of experimental investigation of new panel structures and fabrication techniques potentially useful for large area display panels.

b. Improvements in techniques for producing 50-line/inch glass image panels and initiation of work on four 12-inch square panels for delivery to ECOM at the end of this contract.

c. Further studies aimed at improving the uniformity and speed of panel erasure, and attempts to develop selective erasure methods.

SECTION 6

IDENTIFICATION OF PERSONNEL

The key technical personnel assigned to this contract and the manhours of work performed by each are shown below.

Name and Title	Manhours Worked This Quarter
Paul Foote, Research Engineer	442
Dr. B. Kazan, Chief Scientist	184
John Winslow, Senior Research Engineer	88

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13. ABSTRACT

During the fourth quarter the performance and characteristics of current image storage panels were evaluated. Also, work was initiated on development of techniques for fabrication of large-area panels on single substrates. The loss of stored images due to both frontal excitation of the panel by room light and optical feedback from the electroluminescent layer to the photoconductive layer was investigated and, to a great extent, eliminated. The voltage dependence of the panel's transfer characteristic was measured. Resolution measurements were made on a 12-inch, 50-line/inch image panel. Factors influencing the uniformity and speed of panel erasure were also studied. In the area of technique development for large-area, single-substrate panels, several approaches were investigated. One approach involved formation of the panel electrode structures on acrylic plastic coated with a transparent conducting film of tin oxide. The usefulness of cadmium oxide as a transparent conductor on plastic and glass substrates was also investigated. A dual-conductor arrangement for electrode lines was devised and preliminary tests made. A new panel structure employing continuous electrodes instead of interdigitated electrodes was also studied.

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