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AN ELECTROLUMINESCENT LIGHT-AMPLIFYING PICTURE PANEL

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This bulletin describes an experimental amplifier for light which uses a photoconductive layer electrically in series with an electroluminescent phosphor layer. With the series combination excited by an alternating voltage of audio frequency, e.g., 400 cps, a low light level impinging on the photoconductor decreases its resistance sufficiently to cause a much larger light output from the phosphor. Large-area light-amplifying panels, 12 inches square, using a newly developed photoconductive CdS powder have been built. These panels are capable of producing intensified half-tone images with high resolution. The response time of these panels, determined basically by the photoconductive material, varies from 0.1 second to several seconds. New photoconductive materials offer promise of greatly increased speed. Since the photoconductors can be made sensitive to x-rays and infra-red, the principles of the device may be useful for image conversion and intensification with these radiation sources.

Introduction

The possibility of a panel type of light amplifier was initially demonstrated by the operation of an electroluminescent panel[1] in series with a small photoconductive crystal of CdS as shown in Fig. 1. In the dark the high impedance of the CdS crystal permitted only a negligible fraction of the alternating supply voltage to be applied across the electroluminescent layer. As the incident light on the crystal was increased, its impedance decreased and greater voltage appeared across the phosphor layer. It was further demonstrated that, with equal areas, the lumens emitted by the phosphor could be many times greater (e.g., 50 times) than the lumens incident on the crystal.

The experiment described used small single crystals of CdS. Subsequently, however, a powder was developed which could be used for making large-area photoconductive cells.[2] This material enabled the practical construction of a thin large-area light-intensifying panel capable of picture reproduction.

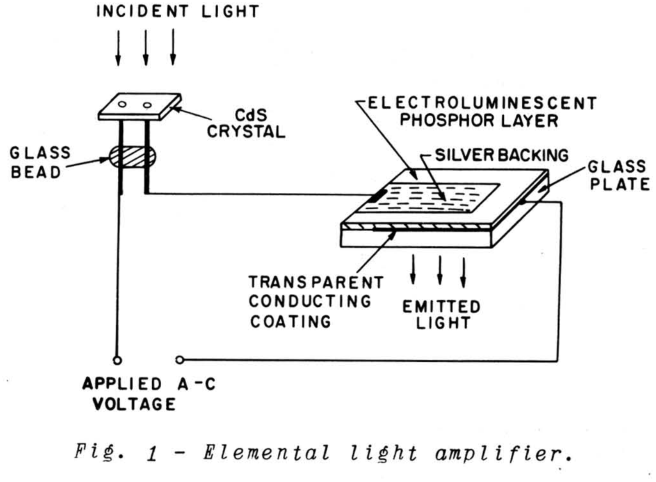

Fig. 1 - Elemental light amplifier.

[1] Payne, E. C., Mager, E. L., and Jerome, C. W., "Electroluminescence, A New Method of Producing Light", *Ill. Eng.*, Vol. 45, pp. 688-693; November, 1950.

[2] *LB-967, Large-Area High-Current Photoconductive Cells Using CdS Powder.*

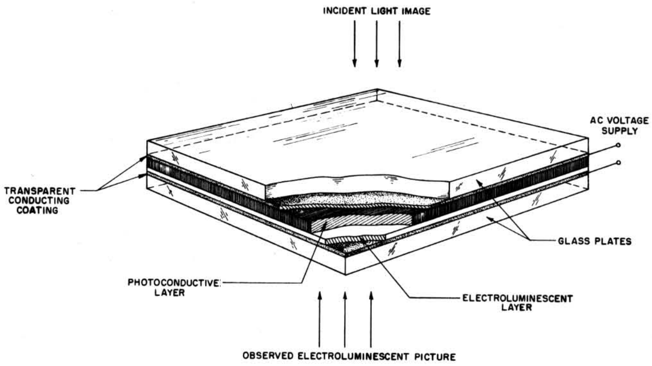

Fig. 2 - Sandwich type light amplifier.

The structure initially selected was sandwich-like, using a thin photoconductive layer and a layer of electroluminescent material held between two pieces of glass as shown in Fig. 2. A similar sandwich-like structure was also suggested by another laboratory.[3] Extensive experiments with such structures showed numerous shortcomings, in particular the severe limitation in gain caused by the opacity of the thick photoconductive layer required to control the electroluminescent layer. The development of new structures was thus required.

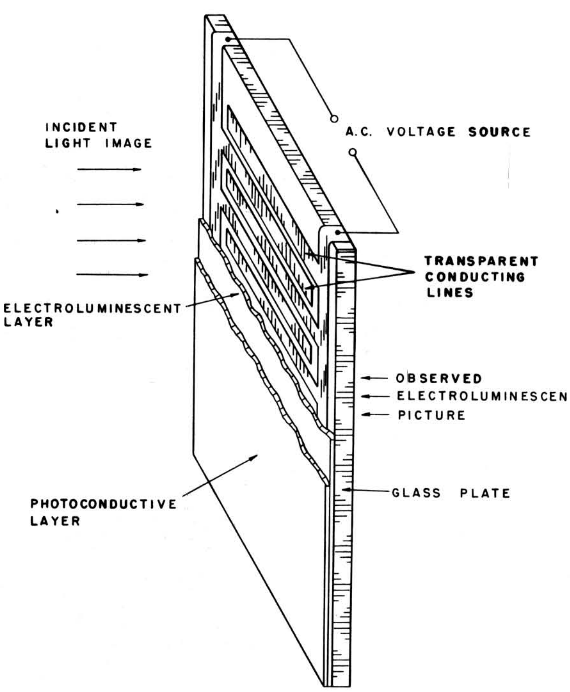

Fig. 3 - Interdigital type light amplifier.

[3] R. K. Orthuber and L. R. Ullery, "A Solid-State Image Intensifier", *J.O.S.A.*, Vol. 44, pp. 297-299; April, 1954.

Interdigital Electrode Type Amplifier

To illuminate the photoconductor more efficiently, the structure of Fig. 3 was devised. A set of fine interdigital transparent conducting electrodes on a glass plate was covered with a thin continuous layer of electroluminescent phosphor. Above the phosphor, another thin layer of photoconductive powder was deposited. With a-c voltage applied between the two sets of electrodes in the dark, there is relatively little a-c current flow between them due to the high impedance of the materials between the conducting lines. When portions of the photoconductive layer are illuminated, however, relatively low impedance paths are provided at these areas between the electrodes. Since the resulting increase in a-c currents must flow through the phosphor layer, which is between the photoconductor and the electrodes, electroluminescent light is emitted adjacent to the corresponding illuminated areas of the photoconductor.

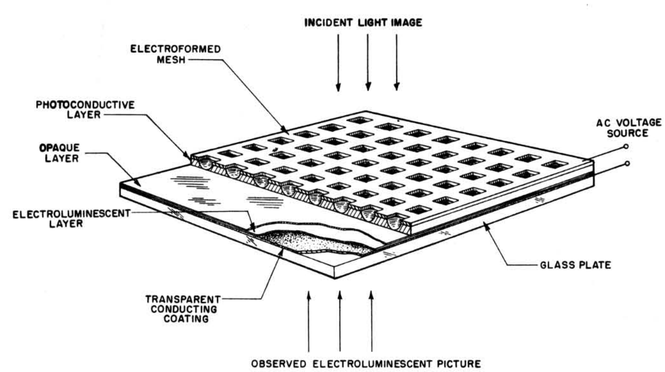

Fig. 4 - Mesh-supported-photoconductor type light amplifier.

In operation, it was found that most of the photocurrents flowed only through the regions of the phosphor layer adjacent to the edges of the electrodes. This reduced the sensitivity and made it difficult to make the impedance of the phosphor elements low enough with respect to the illuminated photoconductive elements. Although the principles were sound, it appeared possible to obtain greater light gains by other structures.

Mesh-Supported Photoconductor Type Amplifier

One such structure is shown in Fig. 4. A transparent conducting coating on glass was sprayed with a thin phosphor layer. To prevent light feedback, a thin insulating opaque layer of lampblack in binder was then sprayed on the phosphor layer. A fine metallic mesh[4] was then stretched approximately 15 mils above the surface of the opaque layer. The photoconductive powder in a binder was then spread over the mesh forming a curved surface within each mesh hole to improve light penetration. The above device was relatively efficient, but was difficult to make uniform.

Ridged Photoconductor Type Amplifier

Another arrangement is shown in Fig. 5. A grooved lucite plate, with many fine parallel "V" grooves, has a fine conducting line of silver paint at the bottom of each groove.

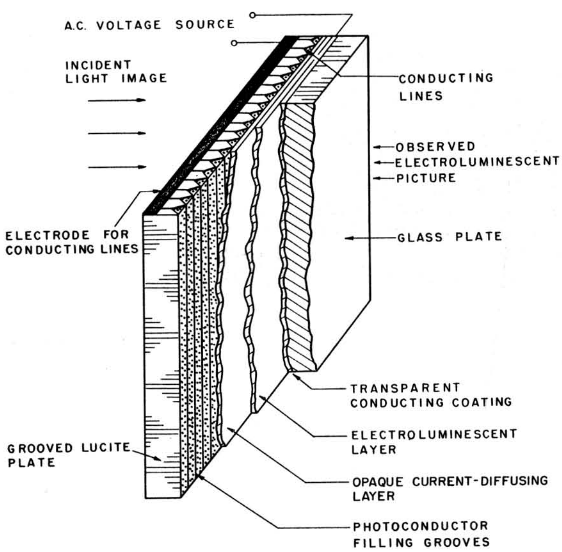

Fig. 5 - Ridged photoconductor type light amplifier.

These grooves are filled with a bonded photoconductive powder. An opaque current-diffusing layer (consisting of a conducting form of CdS powder) is interposed between the grooved plate and the electroluminescent phosphor which is bonded to the transparent conducting coating of a glass plate. The ridges of the photoconductor provide continuous conducting paths for the photo-currents from the electrode at the apex of the photoconductor to the bottom of the photoconductor grooves. By means of the auxiliary current-diffusing layer, photocurrents which otherwise would enter the electroluminescent layer at restricted regions near the groove bottoms are caused to spread or diffuse slightly before entering the phosphor layer. Since the amount of diffusion is limited to about the width of a single photoconductive groove, essentially all of the phosphor layer can be excited by the photoconductive layer and at the same time the resolution of the device, basically determined by the distance between grooves, is not significantly affected. The current-diffusing layer, being opaque, serves the additional function of preventing feedback.

This arrangement enables efficient illumination of the photoconductor, and efficient excitation of the phosphor. Devices up to 12 inches x 12 inches in area operated with high gain and good resolution but conductivity variations in the dry CdS powder used for the diffusing layer were sometimes evident.

Grooved Photoconductor Type Amplifier

The structure of Fig. 6 had the advantageous features of the previous structure, but did not require a grooved lucite plate and used a current-diffusing powder in bonded form. A transparent conducting coating on a glass plate is sprayed with a thin (about 1 mil thick) phosphor layer. After covering the phosphor layer with an opaque layer (lampblack

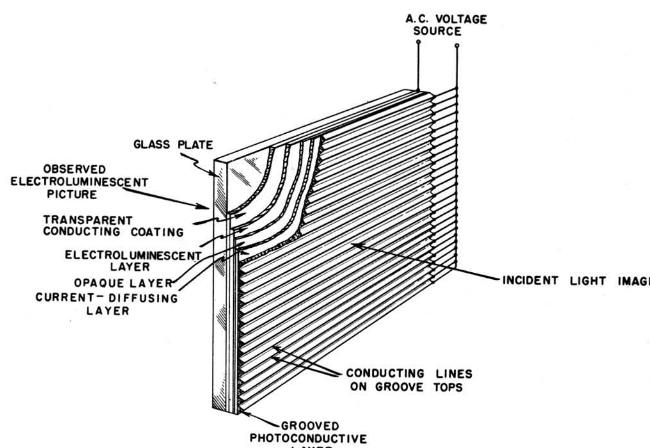

Fig. 6 - Grooved photoconductor type light amplifier.

[4] "Lektromesh", 25 square holes to the linear inch, made of nickel, with about 50 per cent transmission.

Fig. 7 - Photograph of grooved type light amplifier showing amplified picture resulting from a projected image.

in Araldite a fraction of a mil thick), a heavier current-diffusing layer of conducting CdS powder (bonded with Araldite and initially about 20 mils thick) is spread on the opaque layer and machined flat (to about 10 mils in thickness). A heavy layer of bonded photoconductive CdS powder (bonded in Araldite approximately 20 mils thick) is spread on the conducting CdS and again machined flat (to about 14 mils). After spraying the photoconductor surface with air-drying silver paint, fine "V" grooves (of about 60 degrees included angle) are cut into the photoconductor (15 mils deep, and 25 mils between centers). The bottom of the "V" grooves cuts slightly into the conducting CdS layer and the tops of the grooves are left with narrow conducting silver lines, several mils wide, which, connected to a common terminal, act as one electrode for the device.[5]

Structures such as described in Fig. 6 were made up to 12 inches x 12 inches in area. The gain and resolution equalled those of the grooved lucite plate structure of Fig. 5. In terms of resolution the output pictures were comparable in quality with commercial television pictures and had very good uniformity.

[5]The structure of Fig. 6 required machinable plastic-bonded layers of photoconductive powder which retained full photosensitivity. This was accomplished by using CN-502 Araldite suitably diluted with diacetone alcohol. It was noted that the plastic binder had marked effects on the response time of certain batches of CdS photoconductive powder. Such changes in response time were progressively acquired as the samples cured over a period of several days, with the photosensitivity also changing. These phenomena are not yet completely understood.

In Fig. 7 is shown a photograph of an early 12-inch grooved photoconductor type amplifier with an amplified output picture produced by projecting a low level image on the photoconductor side. The small dark spots are attributed to imperfect bonding of the photoconductive and current-diffusing layers. The few narrow dark lines visible in the picture are caused by disconnected conducting lines.

Component Characteristics

The three major components of the ridged and grooved photoconductor type amplifiers are the electroluminescent layer, the photoconductive layer and the current diffusing layer.

The electroluminescent layer is a capacitor with negligible losses at the audio frequencies. For layers 1 mil thick as used, the capacitance is about 200 μμf per cm². When excited with a-c voltage, the phosphor used emits light whose average value is given approximately by:

$$L_o = k_1 \, V^{(3.3)} \, \omega^{(.7)} \qquad (1)$$

where

k_1 is approximately 3×10^{-10}

V is the r.m.s. voltage applied

$\frac{\omega}{2\pi}$ is the frequency

L_o is the luminance in ft. lamberts

In Fig. 8 is shown a curve of measured values of electroluminescent light output as a function of applied a-c voltage at a fixed frequency of 400 cycles/sec. The decay time of the phosphor upon removal of the exciting voltage is relatively short (approximately 1 millisecond). The phosphor response time, however, upon sudden application of voltage depends on its previous excitation and on the audio frequency used, being in the range of one to 30 milliseconds.

The photoconductive powder with a given d-c field across it has approximately linear conductivity with incident light intensity. On the other hand, for a given light intensity, the conductivity of a cell varies as a relatively high power of the field. The measured d-c current may be approximately written:

$$I_{dc} = k_2 L_i \, V^n + I_d \qquad (2)$$

where

k_2 is a constant

L_i is the input illuminance in ft. candles

V is the d-c voltage applied

n is approximately 4 or greater

I_d is the dark current

The dark current, I_d, varies as a high power of the applied voltage, but is usually small compared with the first term.

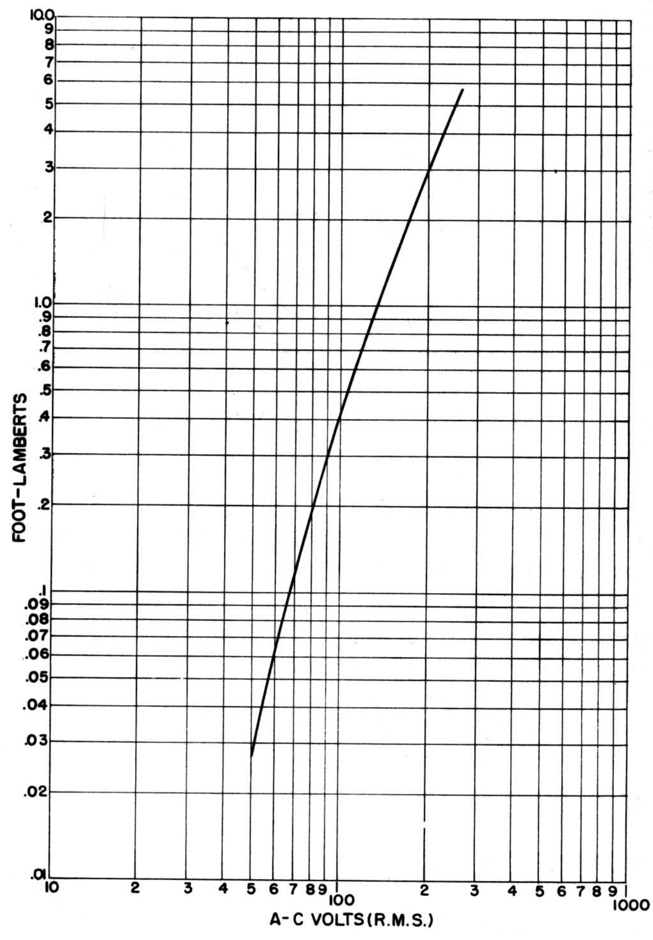

Fig. 8 - Curve of electroluminescent light vs applied a-c voltage.

If an a-c voltage is applied to the photoconductor, the instantaneous photocurrent may be represented by the expression:

$$I_{ac} = \frac{k_2}{10} L_i \, (V_p \sin n\omega t)^n - j\omega C V_p \sin n\omega t + I_d' \qquad (3)$$

where

$V_p \sin\omega t$ is the applied a-c voltage

C is the capacitance of the layer

$\frac{\omega}{2\pi}$ is the frequency

In general, the dark current, I_d', under a-c conditions is very much smaller than the capacitive current, $\omega CV_p \sin\omega t$, and can be neglected. The constant k_2 for the d-c Eq. (2) has been changed to $k_2/10$ for the a-c Eq. (3). This factor of 10, experimentally determined, is unchanged in the range of 300-4000 cycles/sec.

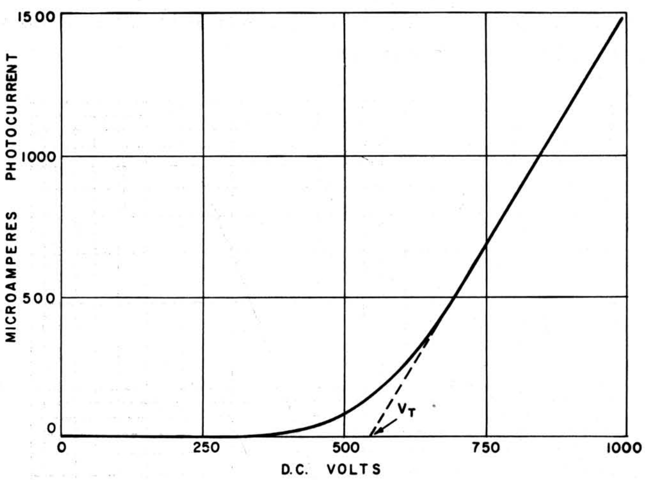

Fig. 9 - Curve of photocurrent vs applied d-c voltage.

If the measured d-c photocurrents are plotted on a linear scale, a curve as shown in Fig. 9 is produced. Over the range of d-c voltage used, the photocurrent per cm², neglecting the dark current, can be approximately expressed as follows instead of by Eq. (2):

$$I_{dc} = (1/R_{dc})\,(V - V_T) \quad \text{when } |V| > V_T \qquad (4)$$

$$\text{and} \quad I_{dc} = 0 \quad \text{when } |V| < V_T$$

In the above equation V_T represents the threshold voltage, i.e., the point of intersection of the straight-line sloping portion of the curve with the voltage axis and R_{dc} the incremental resistance of the photoconductor along the sloping portion. Since $1/R_{dc}$ of the photoconductor varies linearly with the input light intensity, L_i, the above equation can be rewritten:

$$I_{dc} = k_3 L_i\,(V - V_T) \quad \text{when } |V| > V_T \qquad (4a)$$

$$\text{and} \quad I_{dc} = 0 \quad \text{when } |V| < V_T$$

For the case of a-c applied voltage, we obtain:

$$I_{ac} = (k_3/10)\,L_i\,(V_p \sin\omega t - V\ ) - j\omega CV_p \sin\omega t \quad \text{when } |V_p \sin\omega t| > V_T \qquad (5)$$

$$\text{and} \quad I_{ac} = 0 \quad \text{when } |V_p \sin\omega t| < V_T$$

A calculated value of $k_3 = 1.25 \times 10^{-4}$ is obtained using the d-c curve of Fig. 9. The photoconductive cell used had electrodes of 20-mil spacing, an effective area of photoconductor of 0.75 cm², and was illuminated with 0.035 ft. candles (2870°K Tungsten source).

In the dark, the capacitance per cm² of a photoconductive layer in the grooved lucite structure of Fig. 5 is about 8 μμf measured at 1000 cycles/sec. This capacitance is measured between the set of conducting lines at the bottom of the grooves and an electrode covering the top surface of the photoconductor, thus including the capacitance of the lucite.

The photoconductor used has a response time between 0.1 and 1 second with the shortest response time at the high light levels. Since the photoconductor is much slower in response than the electroluminescent material, it controls the amplifier operation.

The current-diffusing layer, consisting of specially prepared CdS powder, is a non-photoconductive resistive material. Unlike the photoconductor, its conductivity is not lowered by a-c voltage. In Fig. 10 is shown a typical curve of d-c current vs d-c voltage for a 1 cm² bonded sample of this material 10 mils thick, with electrodes on opposite surfaces. Since the operation of the light amplifier requires currents below one milliampere/cm², the voltage drop going through the layer is relatively small (<30 volts).

As shown by the curve, the powder has a rapidly increasing impedance with a lowering

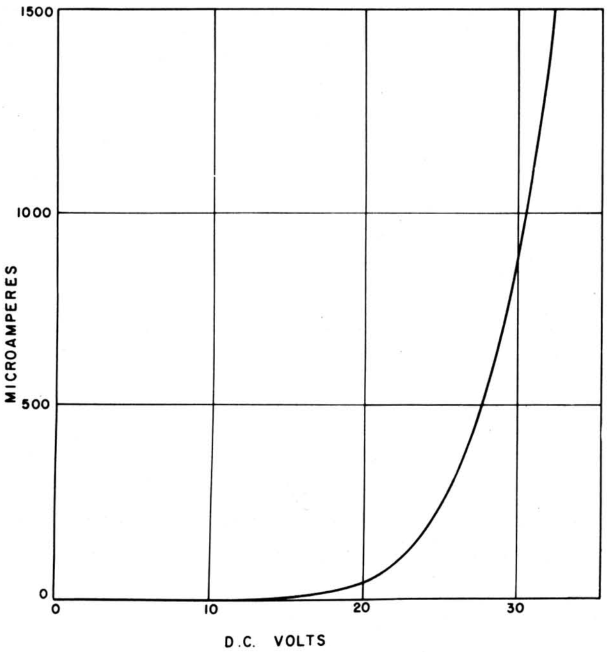

Fig. 10 - Curve of current vs applied voltage for current-diffusing layer.

of the voltage below 30 volts, which is useful for maintaining picture resolution and small-area contrast.

Analysis of the Complete Amplifier

The dark current and the capacitive current through the photoconductor layer are small and can be neglected. The effects of the current-diffusing layer can also be neglected since, as previously indicated, a relatively small voltage builds up across this layer at any time. With these assumptions, the problem simplifies to a series combination of a non-linear resistor (controlled by the incident light) and a capacitor with a-c voltage applied across the two. Using Eq. (3) for the photoconductor, the following differential equation applies:

$$dq/dt = \frac{k_2}{10} L_i \, [V_p \sin\omega t - q/C]^n \qquad (6)$$

where

C = capacity per cm^2 of phosphor layer

q = instantaneous charge on phosphor layer

V_p = peak value of applied a-c voltage

Because Eq. (6) is awkward to solve, it is more convenient to use the approximation, Eq. (4). This leads to:

$$\frac{dq}{dt} = \frac{V_p \sin\omega t - V_T - q/C}{R} \qquad |V_p \sin\omega t - q/C| > V_T$$

$$(7)$$

$$\frac{dq}{dt} = 0 \qquad |V_p \sin\omega t - q/C| < V_T$$

where V_T = threshold voltage

R = ac resistance of photoconductor ($=10R_{dc}$)

Solution of this equation[8] gives for the charge, q, on the condenser:

$$q = -V_T C + \frac{V_p C\,(\sin\omega t - RC\omega\cos\omega t)}{1 + R^2C^2\omega^2}$$

$$+ \left\{V_T C + q_1 - \frac{V_p C}{1 - R^2C^2\omega^2}\left[\frac{V_T}{V_p} + \frac{q_1}{CV_p} - RC\omega\sqrt{1 - \left(\frac{V_T}{V_p} + \frac{q_1}{CV_p}\right)^2}\,\right]\right\} \cdot$$

$$\left\{ e^{-\frac{1}{RC}\left[t - \frac{1}{\omega}\arcsin\left(\frac{V_T}{V_p} + \frac{q_1}{CV_p}\right)\right]} \right\} \qquad (8)$$

where

q_1 = charge on condenser at the start of a conduction cycle.

Of interest is the maximum value of q which determines the peak voltage on the capacitor (phosphor). Based on tests at this laboratory and also information reported elsewhere[7], the light output of an electroluminescent sample is determined primarily by the peak voltage applied, being essentially unaffected by the wave shape for a particular repetition rate. For non-sinusoidal voltages the light output of the phosphor is thus roughly equal to its output using sinusoidal voltages with the same peak value. Since q reaches a maximum at the end of each conduction period, a solution is desired for its value at this time under cyclic conditions. However, under cyclic conditions the charge at the end of a conduction cycle must be minus that at the beginning of

[8] Solution of the equation and formulation of Eq. (9) were provided by E. G. Ramberg.

[7] J. F. Waymouth and F. Bitter, (Paper presented at New York meeting of Electrochemical Society, April 1953, Abstract No. 27).

the cycle. Suppose q_1 is the charge at the end of the last conducting cycle so that at the end of the new conducting cycle $q = -q_1$. The time, t, corresponding to the end of the new cycle can be determined from the relation given with Eq. (7) for the conducting condition: $|V_p \sin\omega t - q/C| > V_T$. This relation gives, at the end of the conducting cycle,

$$V_p \sin \omega t + q_1/C = V_T \quad \text{or}$$

$$t = \frac{1}{\omega} \arcsin\left(\frac{V_T}{V_p} - \frac{q_1}{CV_p}\right)$$

Substituting this value of t into Eq. (8) and using $-q_1$ for q leads to the condition:

$$\frac{-x+b-a\sqrt{1-(b-x)^2}}{x+b+a\sqrt{1-(b-x)^2}} = e^{-a[\arcsin(b-x)-\arcsin(b+x)]} \qquad (9)$$

where $x = \dfrac{q_1}{V_p C}$

$a = \dfrac{1}{RC\omega}$

$b = \dfrac{V_T}{V_p}$

For very large a, $x \cong b - \dfrac{a}{\sqrt{a^2+1}}$

for very small a, $x \cong \dfrac{-a(1-b^2)}{\sqrt{1-b^2+ab}}$

In Eq. (9), x represents the fraction of the peak a-c supply voltage which appears on the capacitor when it has its maximum charge. Eq. (9) can be solved by trial and error giving a curve such as shown in Fig. 11 of x vs a. This particular curve was plotted with an assumed value of $b = V_T/V_p$ of 0.65. Assuming a given peak a-c voltage, V_p, the actual values of peak voltage on the capacitor can be determined from Fig. 11 as the factor, a, is varied.

Converting the values of x in Fig. 11 to light output using the curve of Fig. 8 produces the calculated curve of Fig. 12, assuming a

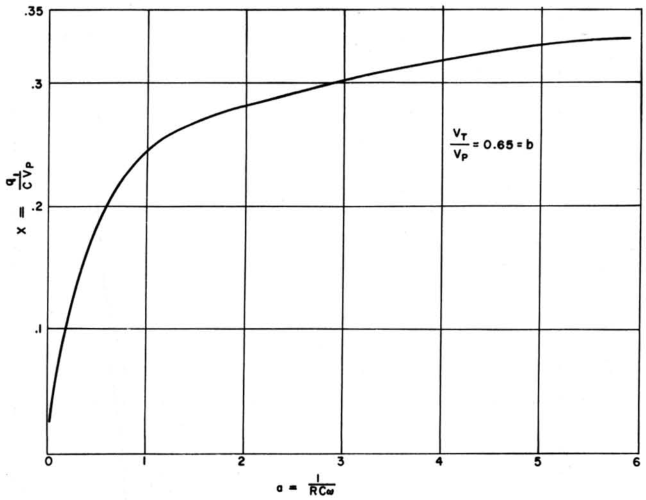

Fig. 11 - Curve of peak voltage across electroluminescent layer vs a ($=1/R\omega C$).

1000-volt peak a-c supply. The values of a are indicated at the top of Fig. 12.

Referring now to Eq. (5) for the photoconductor with $k_3 = 1.25 \times 10^{-4}$, the factor, a, can be written in terms of the input light on the photoconductor, (assuming C = 200 μμf per cm^2 and $\omega = 2\pi\ (400)$):

$$L_i = .04\ a$$

The corresponding input light levels in lumens per sq. ft. are shown at the bottom edge of Fig. 12. Also shown in Fig. 12 is a curve of measured values of output and input light using

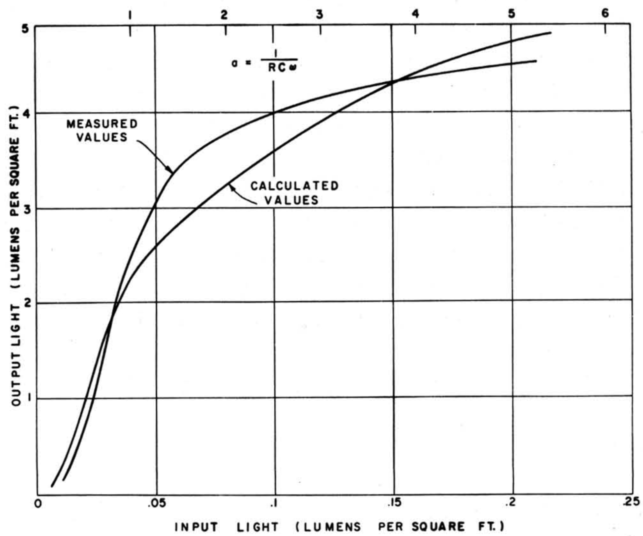

Fig. 12 - Curve of output lumens vs input lumens for light amplifier.

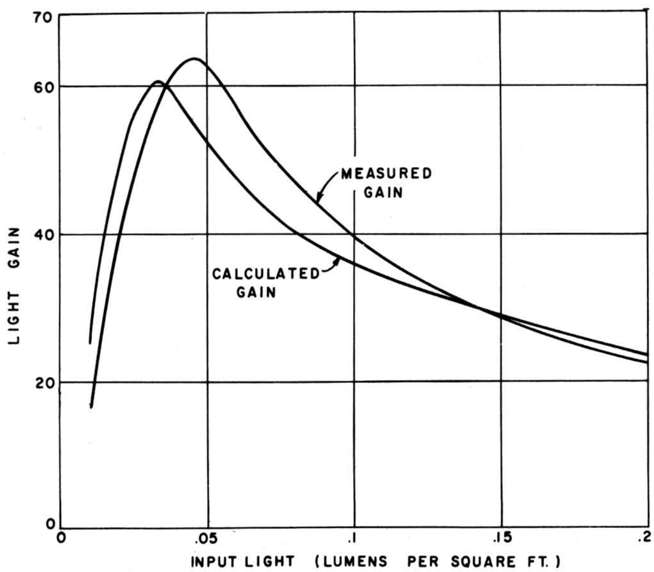

Fig. 13 - Curve of gain vs input light for light amplifier.

a grooved lucite plate amplifier, such as shown in Fig. 5, operated at 400 cycles with an applied a-c voltage of 1000 volts peak.

In Fig. 13 are shown the curves of light gain as a function of input light level, derived from the curves of Fig. 12. Although Figs. 12 and 13 indicate fairly good correlation between the measured and calculated values, such correlation was obtained by using a value of b = 0.65. This assumes a threshold voltage for the photoconductor of 650 volts as compared to the threshold voltage of about 550 volts shown in Fig. 9 for the photoconductor sample measured. The discrepancy is believed to be partially due to the voltage drop across the current-diffusing layer being somewhat greater than assumed, since the current flow into it from the photoconductor is concentrated along narrow lines rather than spread over the surface as is the case when solid electrodes are used in measurements. In addition, the correlation of photoconductor resistance with light is somewhat inaccurate due to the time constants and slow drift of the photoconductor at low light levels. Although the calculated operation of the light amplifier is approximate, the model assumed for the photoconductor is reasonably useful.

Both the measured and calculated curves of Figs. 12 and 13 are based on the use of a tungsten light source operating at 2870 degrees K. Such a light source emits a considerable amount of infra-red radiation to which the photoconductor is sensitive, but which is not measured by a ft. candle meter. To measure the "intensity gain" of the light amplifier, i.e., the gain using input light whose spectral distribution is identical to the output light, a test was made using an electroluminescent source panel to provide the input light. This source had a spectral distribution identical to that of the amplifier output, having been made with the same type of phosphor. Under these conditions, the maximum energy gain was about 14.

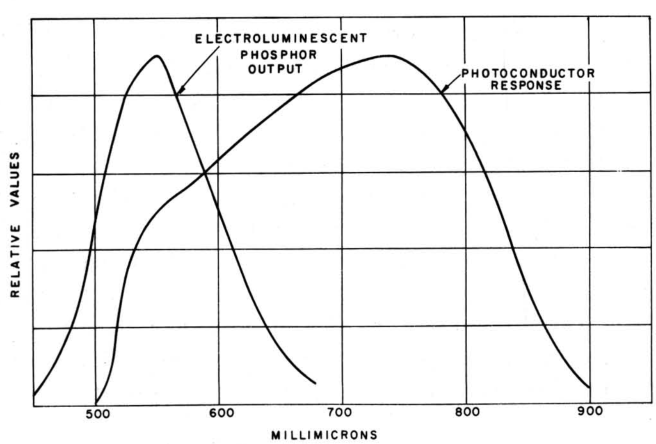

Fig. 14 - Spectral curves for photoconductor and electroluminescent phosphor.

In Fig. 14 are shown in relative values the spectral response curve of the photoconductor and the spectral distribution curve for the electroluminescent phosphor used in the light amplifier. These curves indicate that the operation of the light amplifier with the yellow electroluminescent input light reduces the gain to about 50 per cent of the gain expected with an input light source having its peak coinciding with that of the photoconductor. With such matching conditions, the maximum energy gain is about 30.

Gain and Light Output as Affected by Supply Frequency

Both the measured and calculated gains are based on the use of an a-c voltage of 400 cycles. The effects of varying the frequency can be seen by reference to Fig. 12. Increasing ω and decreasing R by a factor, K, causes no change in a $(=1/R\omega C)$ and in the peak voltage applied to the phosphor layer. Such an increase in the values of 1/R for the photoconductor, however, requires that the input light levels be multiplied by this same factor. Since the voltage on the phosphor layer is changed in frequency by a factor, K, the light output is increased by the factor $K^{(.7)}$ as indicated by Eq. (1). If an audio frequency, f, other than 400 cycles is used, the amplifier will have new gain curves of the same shape as in Fig. 14, but changed in level by the factor given below:

$$Y = \left(\frac{400}{f}\right)^{.3} \qquad (10)$$

Also, the input light levels will be multiplied by the factor f/400 for corresponding points on the curves.

As an example of the effects of a frequency change, assume that the operating frequency is 10,000 cycles instead of 400. From Eq. (10) the gain at all points of the curve, including the maximum gain will be reduced to 38 per cent of the gain at 400 cycles. At the point of maximum gain, the input light will be 1.1 ft. candles and the output light 27.5 ft. lamberts. Similar considerations show that operation below 400 cycles/sec will increase the gain and lower the levels of input and output light at the point of maximum gain. At the high audio frequencies, considerable heat is generated in the photoconductor. For example, at 10,000 cycles/sec the power dissipation is about 1 watt per cm^2.

The Use of Feedback

The ridged photoconductor panel (Fig. 5) and the grooved photoconductor panel (Fig. 6) amplifiers have been designed to operate without feedback. However, a fraction of the output light may be permitted to excite the photoconductor, for example, by eliminating the opaque layer and making the current-diffusing layer thin. In determining the gain with feedback, the fact that the feedback light from the phosphor is of a different spectral distribution than the input light must be considered (factor k) and also the fact that the photoconductive layer may not be illuminated from phosphor side with the same efficiency as from the input side when, for example, the photoconductive layer is grooved (factor B). With these considerations, the gain with feedback, G_f, is given by:

$$G_f = \frac{G}{1 - kBG} \qquad (11)$$

where

G is the gain without feedback

k is the ratio of photoconductor responses to output and input light respectively due to spectral differences

B is the effective fraction of the output light capable of exciting the photoconductor

Since the gain, G, of the amplifier varies with the total input (or output) light Eq. (11) is valid only if the output is maintained constant.

The effect of limited amounts of feedback is thus to increase the gain as well as to make the gain curve more peaked. If the factor kBG is made greater than unity, a picture element, once excited by an input signal, will remain on regeneratively. Two of the primary problems with such storage devices are: (1) providing efficient feedback illumination of the photoconductor, and (2) preventing adjacent elements from exciting each other.

Operation with Infra-red and X-ray Input Pictures

Although much of the work on the light amplifier as described above has been concerned with its operation using input pictures of visible light, some tests have been made using both infra-red and x-ray input images. Inspection of the spectral sensitivity curve (Fig. 14) for the photoconductor shows that in the near infra-red (700-900 millimicrons) the powder has sensitivities comparable with those for wavelengths in the visible region. For wavelengths further in the infra-red the amplifier requires new photoconductive materials.

Tests with x-rays indicate that some amplification can be achieved with direct x-ray excitation. It is also possible to operate the amplifier with a fluoroscope screen close to the input side so that the visible image formed on the fluoroscope screen will be intensified by the amplifier.

Future Improvements

Further development of electroluminescent phosphors will directly benefit the light amplifier. The sensitivity of the photoconductive powder is considerably lower when operated with a-c voltages as compared to d.c.

Since this effect is not inherent in photoconductors but a property of the particular powder, substantial increases in light gain can be expected with improved photoconductors. In addition, the non-linearity of the photoconductive powder further limits the effectiveness of the present amplifier. Increase of the photoconductor breakdown voltage should serve to produce substantial increases in gain because of the rapidly increasing light output of the phosphor with voltage. The response time of the amplifier is also subject to improvement with new photoconductive materials.

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