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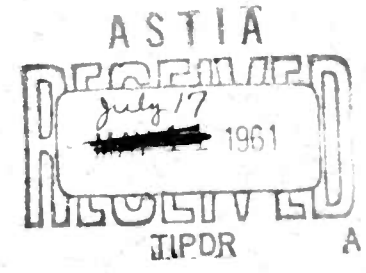
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ELECTROLUMINESCENCE IN OPTICAL AMPLIFIERS

F. H. Nicoll
A. Sussman
H. B. Devore

RCA Laboratories

DECEMBER 1959



WRIGHT AIR DEVELOPMENT DIVISION

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Aeronautical Research Laboratory

Contract AF 33(616)-5509

Project 7072

Task 70844

WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This report was prepared by RCA Laboratories, Radio Corporation of America, Princeton, New Jersey, on Air Force Contract No. AF33(616)-5509, under Task No. 70844 of Project 7072. "Research on the Quantum Nature of Light." The report covers the research program from 1 March 1958 to 30 November 1959. The work was administered under the direction of the Aeronautical Research Laboratory, Directorate of Laboratories, Wright Air Development Division, with Mr. George A. Klingler as the Task Scientist.

The authors of this report are F. H. Nicoll, A. Sussman, and H. B. DeVore. F. H. Nicoll and A. Sussman were active in the entire program of work and conceived and introduced ideas which led to the successful device described in this report. H. B. DeVore joined the program shortly before its completion and carried out part of the work on materials. H. Ogawa, as technician, constructed the panels and much of the associated equipment. F. H. Nicoll was the project engineer in charge of the basic research and development work.

Acknowledgement is made to Radames K.H. Gebel of the Aeronautical Research Laboratory for conceiving a design on an improved solid state optical amplifier for color using an electro-luminescent multi-color panel, and for initiating this contract thereon; and also to D.W. Epstein and H. Johnson for their initial enthusiasm and continued interest. Acknowledgement is also made to George A. Klingler for his efforts given to assure the success of the project.

ABSTRACT

This final report covers work done in two broad areas. The first is work directed specifically towards the fabrication of a prototype light amplifier having a two-color input and a two-color output; the second is work on materials which might eventually be of value in light amplifiers.

The work which leads directly to the two-color light amplifier is described along with that work which was rejected for the final prototype.

The final method, using two photoconductors on the input, is covered in more detail. A full description of the construction of a 6" x 6" panel is given and the exact formulation of the various layers appears in the Appendix.

Results are given for the two prototype panels to be delivered under the contract and the means of testing and demonstrating the panels is described. A section of the report is devoted to a description of the mounting and testing equipment for these panels.

The second area of work covered in the report is on materials. This includes measurements on cadmium sulfide and cadmium selenide photoconductive powders. Several specific properties are examined and some work on temperature dependence is reported.

The materials work also covers an investigation of some properties of both AC and DC electroluminescent phosphors. The desirable features of DC electroluminescence are examined and some experimental work on phosphor powders excited by DC fields is included in the report.

Some results on bistable behavior in cadmium selenide powder are given. These show both light triggering and voltage triggering.

The phenomenon of shortened decay produced by field reversal is examined briefly in cadmium selenide.

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INTRODUCTION

This final report covers the most important results of the previous six quarters. In addition, a more detailed description of some of the materials work of the seventh quarter is also given.

The construction and operation of prototype 6" x 6" panels (4 3/4" x 5 1/2" picture area) is given in detail, with a description of the equipment needed to demonstrate the panels. The results obtained with the two-color input, two-color output light amplifier are given, together with color photographs of the output images.

FACTUAL DATA

I. PRINCIPLES OF SOLID STATE LIGHT AMPLIFIERS

Solid-state light amplifiers have been described in several publications,^{1,2} and, in particular, the details of the photoconductor-electroluminescent type have been emphasized. In general, the amplifier consists of a layer of photoconductor on a layer of electroluminescent material with an opaque layer between the two to prevent optical feedback. AC voltage is applied between the electrodes on the outer surface of the photoconductor and the under surface of the electroluminescent layer, thus forming a series circuit of photoconductor and electroluminescent material in which current flow through the electroluminescent layer is controlled by the photoconductive layer resistance. This resistance is in turn controlled by light falling on it from the incident picture. Because of the intimate relation between the photoconductive and electroluminescent layers, these variations in resistance appear as variations in light from the output electroluminescent layer. If the sensitivity of the photoconductor is great enough, then the output picture is brighter than the input.

-
1. B. Kazan and F. H. Nicoll, "An Electroluminescent Light-Amplifying Picture Panel," Proc. IRE, 43, 1888, Dec. (1955).
 2. B. Kazan and F. H. Nicoll, "Solid-State Light Amplifiers," JOSA 47, 887, Oct. (1957).

Several types of monochrome light amplifiers are described by Kazan and Nicoll^{1,2} but the grooved photoconductor type illustrated in Figure 1 seems most suitable for the present application. It has the advantages of high gain, high resolution and a fabrication technique which has been fairly well worked out. This technique is described in the following paragraph with reference to Figure 1.

A transparent conducting coating on a glass plate is sprayed with a thin (about 1 mil thick) layer of electroluminescent phosphor in plastic. After covering the phosphor layer with an opaque layer (lampblack in Araldite plastic, 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

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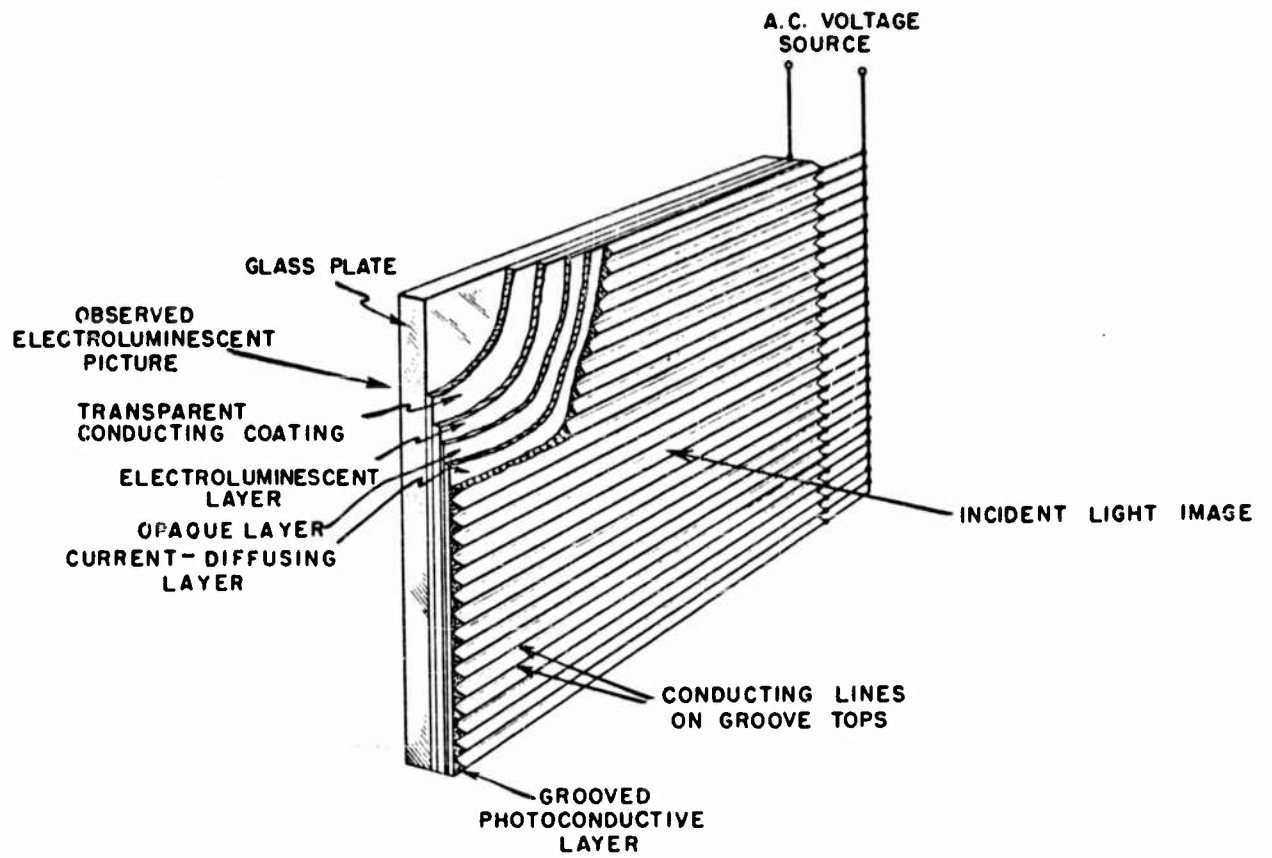


FIGURE 1. GROOVED PHOTOCONDUCTOR TYPE LIGHT AMPLIFIER

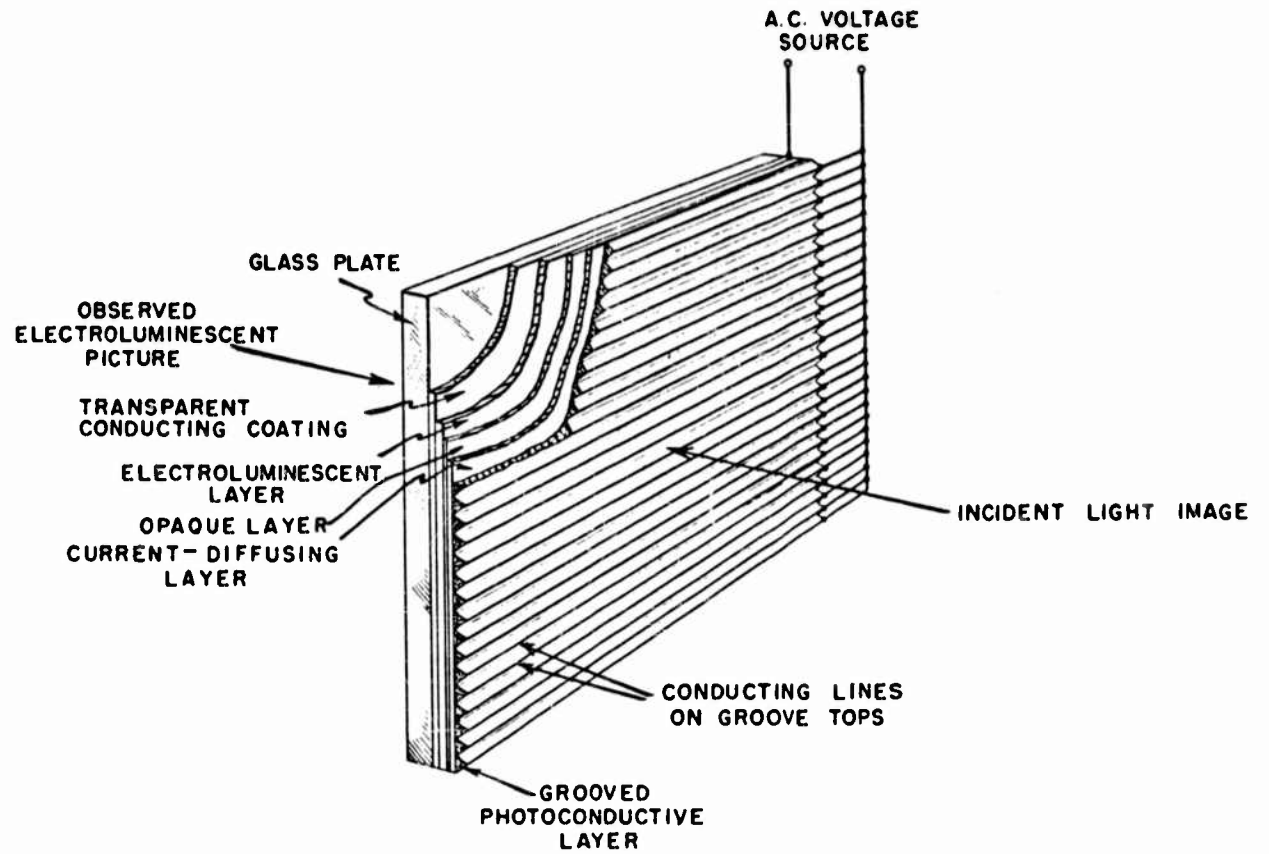


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cuts slightly into the conducting CdS layer and the tops of the grooves are left with narrow conducting silver lines, several mils wide, which, connected to a common terminal, act as one electrode for the device.

In this structure high gain is obtainable because the photoconductor surface is completely illuminated from the silver lines to the CdS conducting powder layer. Thus, there is no unilluminated photoconductor in the circuit which would introduce a series high impedance and reduce gain. The conducting powder layer or current-diffusing layer, as it is called, is used for two reasons. First, it allows the grooving to be carried completely through the photoconductor layer, and secondly, it spreads out the photocurrent from the bottoms of the grooves so that line structure is not visible in the output with uniform light on the input.

II. TWO-COLOR INPUT TWO-COLOR OUTPUT LIGHT AMPLIFIERS

A. GENERAL PRINCIPLES

If it is desired to make a light amplifier which is sensitive to images in two or more discrete colors on the input and will reproduce these in two separate color output images, certain structure modifications to the usual amplifier are required. In addition, the components of the amplifier must meet certain requirements before a color-type amplifier is possible. For example, the photoconductor spectral response must be broad enough that two or more separate color responses are possible. On the output separate colors must be obtainable either by filtering action or the use of separate phosphors. Presentation of two or more superimposed color images on the same panel require first that the input and output areas be made up of discrete, uniformly distributed color areas of small size, and secondly, that the discrete color areas on the input register accurately with the color areas on the output. These color areas could have any of several forms but because of the structures usually used in the light amplifier an assemblage of interdigitated lines of appropriate color on input and output seems to be desirable. This has the added advantage that electrodes in the form of lines on input and output may be used thus allowing the use of separate electrical connections for the different colors if this is desired. Such separate connections are

essential if the various colors are to be independently controlled from the power supply in addition to being controlled by the input light.

B. IMAGE SEPARATION BY FILTERS

One method of obtaining a two-color input and a two-color output is to use filters. Thus, at the input, if the response of the photoconductor is sufficiently wide, it can be divided into two portions by means of suitable filters. Transmission filters such as those used in Ektochrome color film are a possibility. These were examined for use with the electroluminescent layer and with the photoconductor layer. The transmission curves were measured and indicated that the use of filters was limited because of the width of the separate response curves and because of the inability to shift the peaks as desired. In addition, there were problems in making line structures with these filters, and in getting sufficiently high light transmission.

The use of dichroics was somewhat more promising. By suitable choice of colors a reasonable separation of currents in the CdS photoconductor was possible, although an infrared blocking filter was necessary to prevent cross talk. Figure 2 shows transmissions of these filters. Difficulties in making large line filters of this type and the advent of more promising methods of making the two-color light amplifiers caused

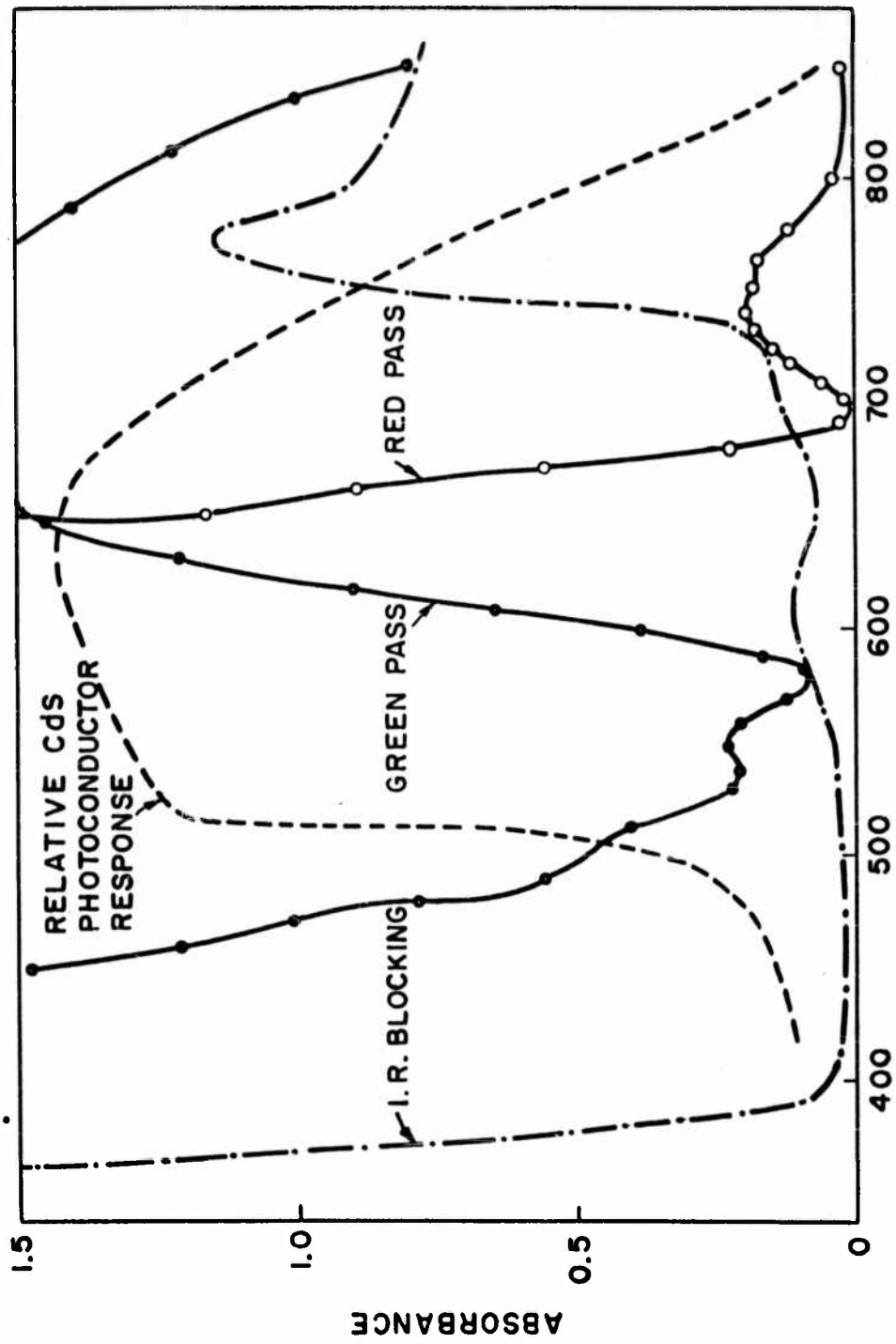


FIGURE 2. DICHOIC SPLITTING OF PHOTOCONDUCTOR RESPONSE

this method to be dropped after the preliminary investigation.

C. IMAGE SEPARATION BY SHADOW MASK

There is a certain similarity between color kinescopes and color light amplifiers. In both cases the output must be divided up into discrete color areas which are in registry with discrete exciting means on the input side. One means of making such a separation on the input side is to use a shadow mask technique similar to that used in color kinescopes. The color kinescope uses three electron beams passing through a perforated shadow mask in such a manner that one beam can only strike phosphor dots of one color. Three phosphor dots are located under each aperture in the mask so that this result is accomplished. A similar method can be used with light amplifiers where the electron beams are replaced with directional light beams which impinge on the uniform photoconductor input. However, where two colors only are required, strips of phosphor may be used on the output and the shadow mask then becomes a simple strip mask. This arrangement is shown diagrammatically in Figure 3, and is self-explanatory. Actual color separation was obtained from two images projected on a two-color output light amplifier.

If a single scene is to be observed with a single lens on this type of shadow mask presentation then it is necessary to do some beam

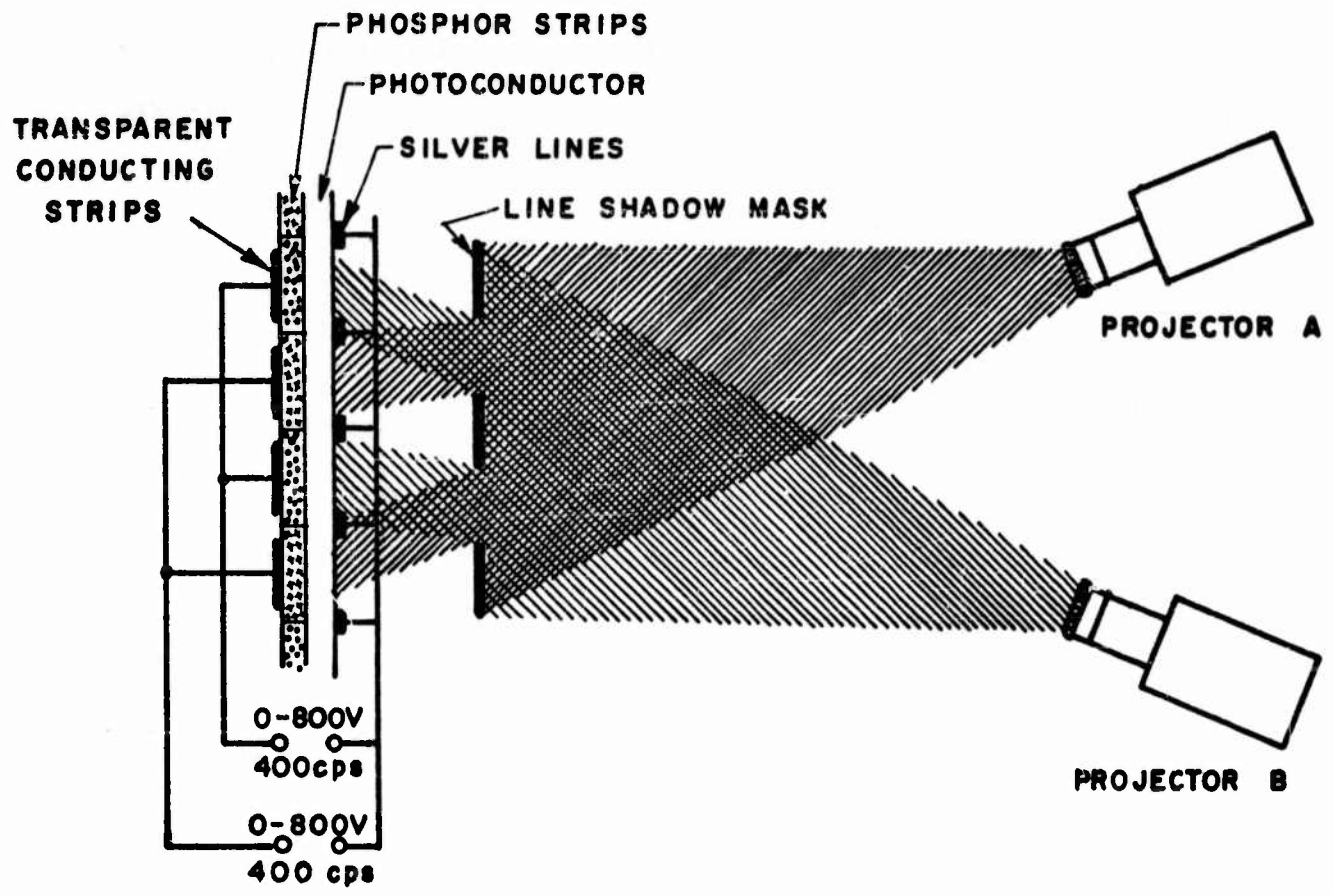


FIGURE 3. DIAGRAM SHOWING SHADOW MASK OPERATION OF TWO-COLOR LAYER-TYPE LIGHT AMPLIFIER

splitting with mirrors between the lens and light amplifier, but this becomes cumbersome and not entirely satisfactory for the present application. For this reason, and the fact that a still better approach to the problem was worked out, the shadow mask approach was not carried further, although separation of images was demonstrated.

D. IMAGE SEPARATION USING TWO PHOTOCONDUCTORS

At the beginning of this project two sensitive photoconductive powders were in existence, CdS and CdSe. They are of special interest because of their different spectral responses shown in Figure 4. Here it is quite apparent that two colors at the input should be separable if suitable spectral sources are chosen. The choice of these sources and the separation obtained is described later in Section IV.

In order to use two photoconductors for separating two color input images, a structure such as shown in Figure 5 must be used. This shows the structure for the input only and shows the alternate ridges of CdS and CdSe that are necessary to give alternate lines or strips responsive to different input colors. An amplifier made in accordance with this drawing would have an output in monochrome, since a continuous, uniform electroluminescent layer is used.

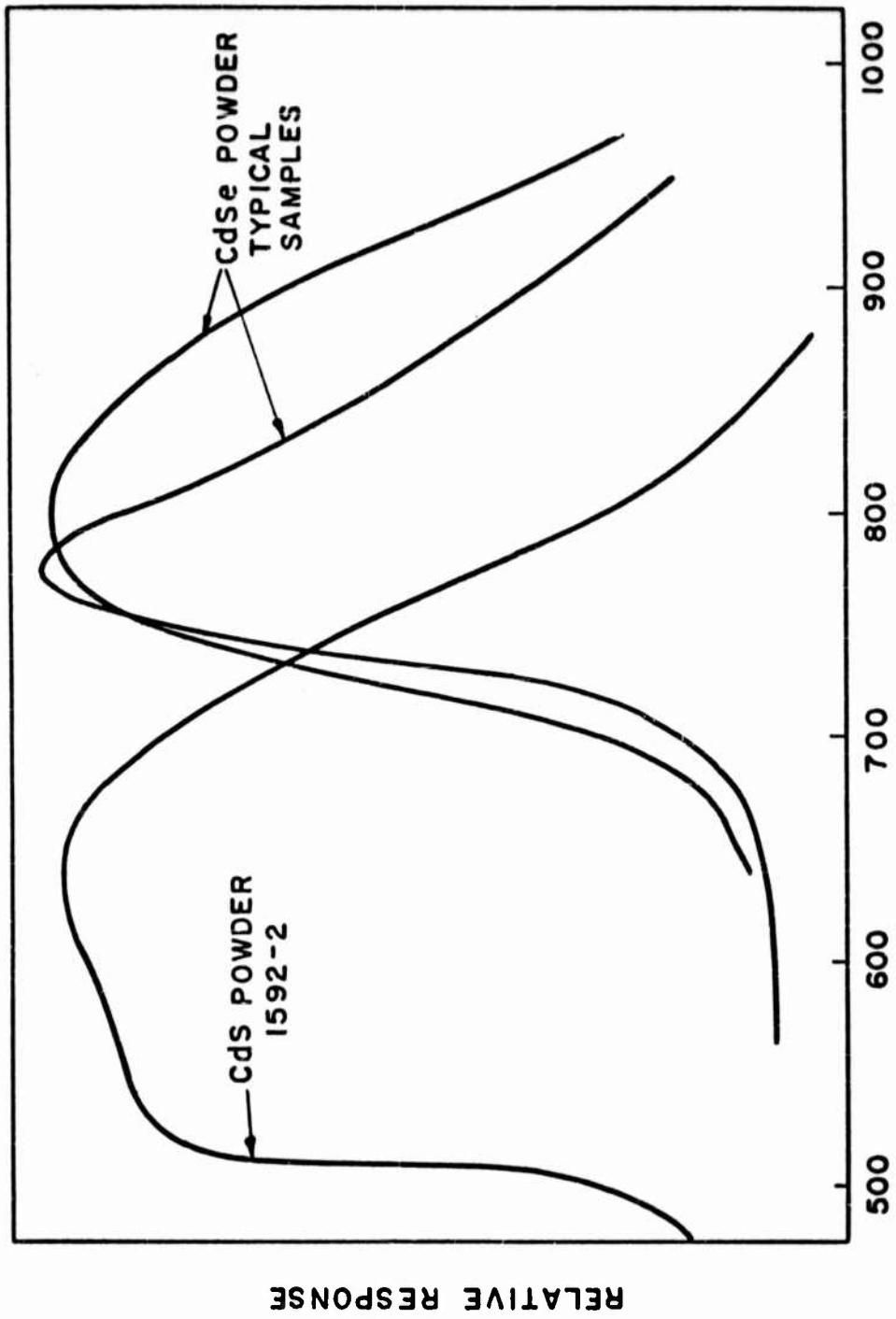


FIGURE 4. SPECTRAL RESPONSE OF PHOTOCONDUCTIVE POWDERS

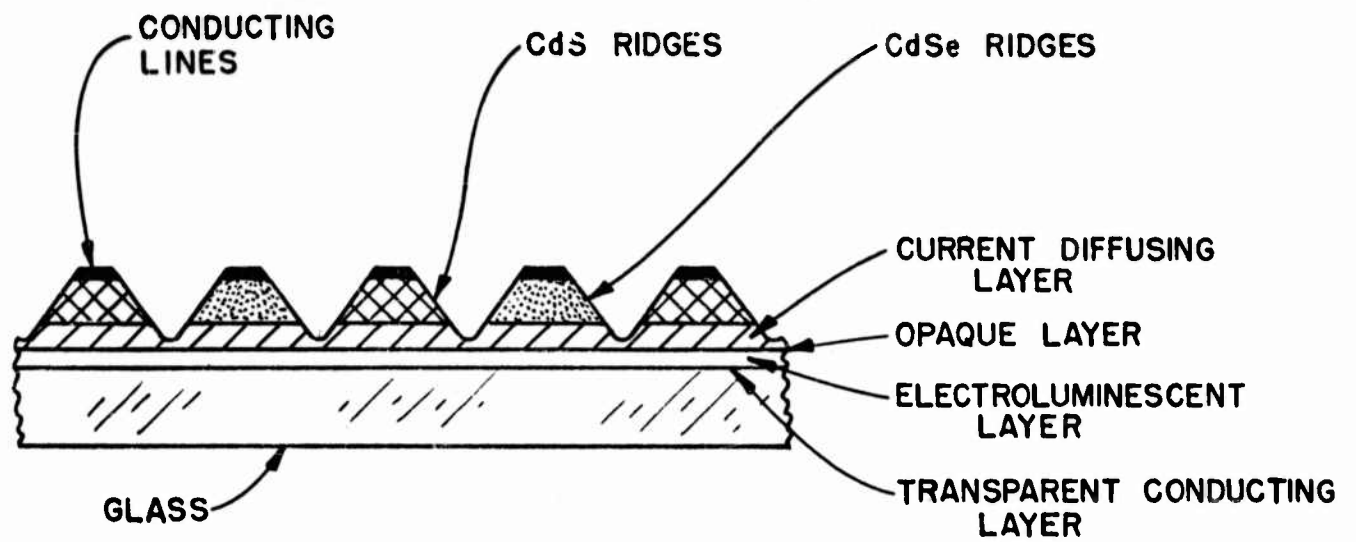


FIGURE 5. TWO-PHOTOCONDUCTOR LIGHT AMPLIFIER (SCHEMATIC)

III. DESIGN OF TWO-COLOR LIGHT AMPLIFIER USING TWO PHOTOCONDUCTORS

A. GENERAL CONSIDERATIONS

The two-photoconductor input approach to the problem of a two-color light amplifier was chosen as the most promising for several reasons.

1. It involves simple line or ridge construction capable of being fabricated by the usual machining operations.
2. No filters are required on the imaging device.
3. The response of the two photoconductors is such that one can be used to respond to the near infrared (invisible) and the other to a region in the visible. This division of the input response is more desirable than having two visible inputs on one photoconductor.
4. The fact that no filters are needed and no shadow mask technique is used means that a single conventional lens can be used to focus the image on the amplifier.

These four items add up to considerable advantage for this particular design, which was followed through from the first small monochrome output devices to the final 6" x 6" two-color input, two-color output panels.

B. TWO-COLOR ELECTROLUMINESCENT PANELS

As an essential step in the development of the final amplifier panel, methods of making the two-color electroluminescent layer alone were evolved. Such a panel was made to illustrate the features of a two-color output. A complete panel USAF-5509-2 was mounted on a small control box arranged so that voltage could be varied on the two sets of color phosphors, thus changing the area from yellow through white to blue. The two phosphors used are described in Section VII-A on materials and the method of making the interdigital strips is covered in Section IV-A.

C. TWO-COLOR LIGHT AMPLIFIER

Before attempting to make any large light amplifiers, many problems had to be solved, both in making the two-color electroluminescent output and in making the two-photoconductor input.

In the ridged photoconductor type of construction indicated in Figure 5 it is essential that light resulting from current flow in a particular ridge should be emitted from the electroluminescent layer directly underneath. This was not the case in the early monochrome light amplifiers, so a number of experiments were performed to determine the conditions necessary to give this result. The results indicated that the current diffusing layer should be thin and that it

should be cut almost through to the black layer in order to divide the conducting layer more efficiently into strips. In this connection, the use of threads positioned in the grooves was tried as one method of reducing cross talk due to excessive lateral conduction. Later in the work difficulty was experienced with excessive conductivity in the opaque layer. This is referred to in Section IV, B and C.

Work on the two-photoconductor light amplifier began with a 3" size and a monochrome output. As work progressed in making the two-color electroluminescent panels, the two-color input and two-color output were combined to make a single light amplifier panel. A 3" prototype US-AF-5509-5 was supplied at the end of the first year's work. Color pictures of the results were also obtained.

IV. CONSTRUCTION OF 6" x 6" TWO-COLOR LIGHT AMPLIFIER

The construction of this larger and final design of a two-color input, two-color output light amplifier follows the design of the smaller samples and benefits from the techniques developed for them. The details of construction of the 6" x 6" panel are given under a number of subheadings, referring to the various layers as one moves from the glass substrate to the photoconductive layers. Further details of the processing can be found on page 70, Appendix I. It should be mentioned that the machining operations involving the conducting layer and the photoconductors produce hazardous dust; a vacuum cleaner with water tank trap (Rexair) was used to pick up all chips and dust.

A dimensional sectional view of the light amplifier is shown in Figure 6. A color photomicrograph of an actual section of a complete amplifier is shown in Figure 7 compared with a sectional drawing to the same scale.

A. TWO-COLOR ELECTROLUMINESCENT OUTPUT LAYER

1. SUBSTRATE PREPARATION

The glass substrate is made of 1/4" "Paralleloplate" made by Libbey Owens Ford. This is very flat and varies in thickness by less than a mil on a 6" x 6" plate. One edge of this plate is ground flat and square

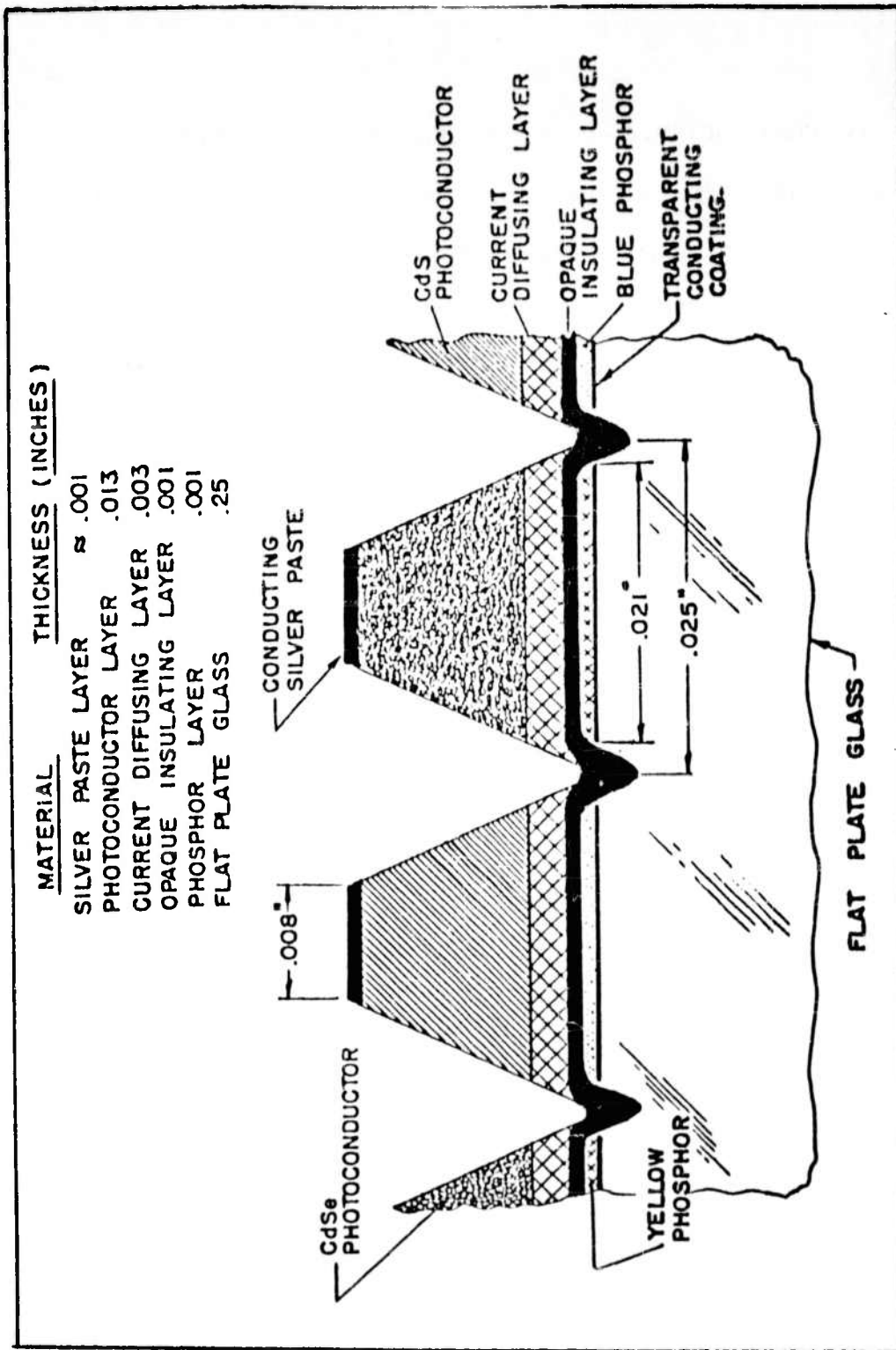


FIGURE 6. CROSS SECTION OF TWO-COLOR INPUT, TWO-COLOR OUTPUT LIGHT AMPLIFIER

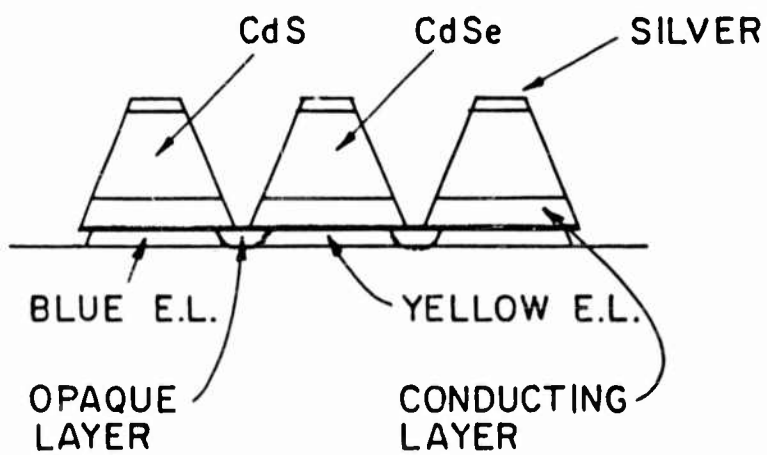
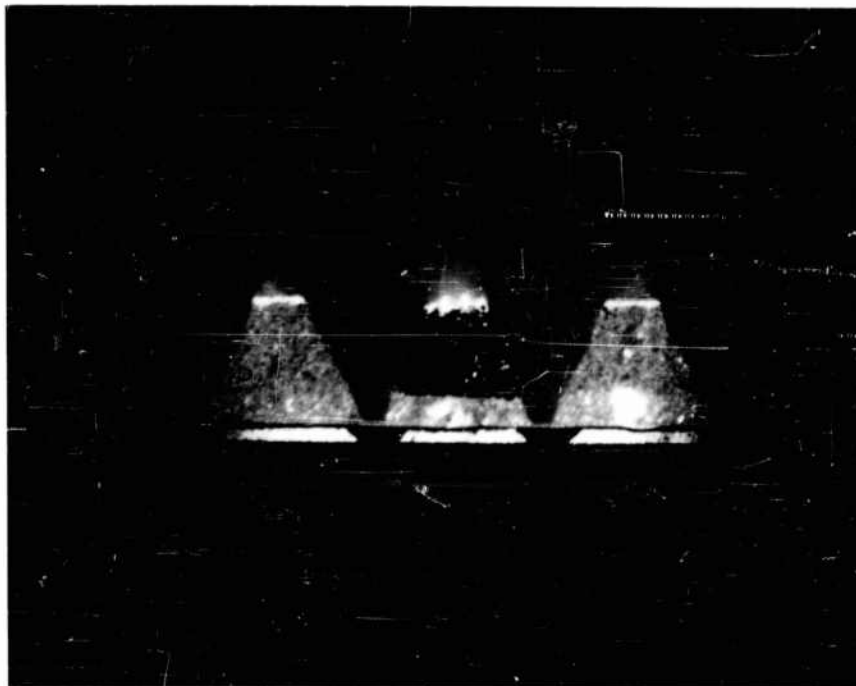


FIGURE 7. PHOTOMICROGRAPH OF EDGE SECTION OF TWO-COLOR LIGHT AMPLIFIER, STANDARD TYPE

as a reference edge for later registration of various processes.

The glass is next given a transparent conducting coating by the usual tin oxide process where tin chloride in ethanol is sprayed on the hot glass. This coating is applied to one side only and is masked to give uncoated glass about 1/4" in from the ground edge and the opposite edge.

The next operation is evaporation of 25 mil lines of aluminum about 1000 A thick and on 50 mil centers. These are deposited accurately parallel and spaced a known distance from the reference edge. The purpose of the aluminum is to provide a separable bond between phosphor and glass which will permit later removal of phosphor strips above these lines. This evaporation is done through an accurate line mask made of one mil copper by a photoengraving technique; the black line-mask master was machined from a lucite block. A photograph of the mask is shown in Figure 8. For easy removal of the phosphor the aluminum should not stick to the glass too well, and it has been found that evaporation on imperfectly cleaned glass and at a pressure just sufficient to give shiny aluminum is best.

2. PHOSPHOR APPLICATIONS

Application of the phosphor can best be followed from the steps shown in Figure 9. Figure 9a shows the aluminum on the transparent conducting coating. Blue-emitting phosphor is now sprayed onto the whole plate (Figure 9b) in a dilute suspension of thermosetting Araldite and

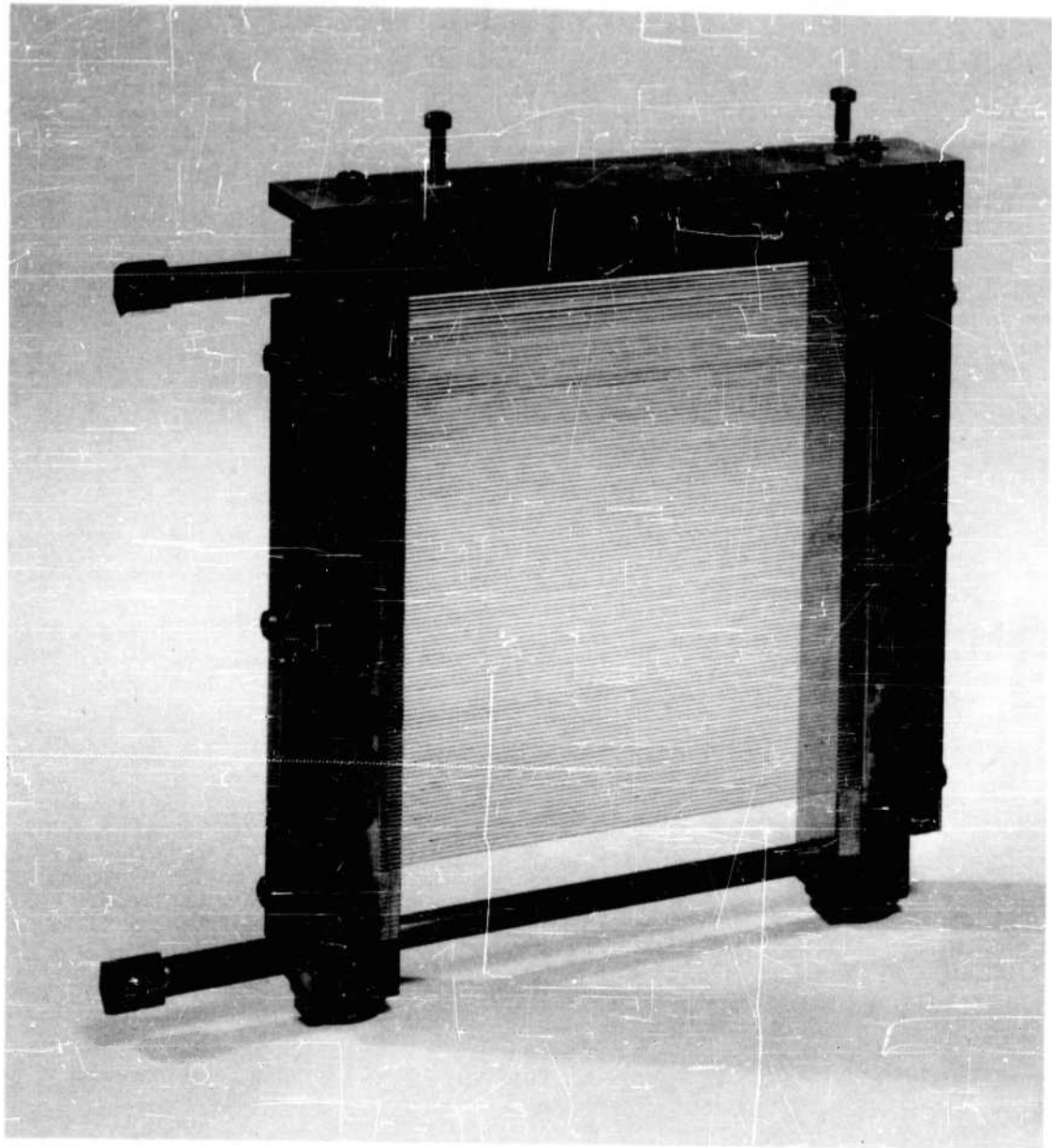


FIGURE 8. COPPER LINE MASK FOR EVAPORATION OF ALUMINUM STRIPS

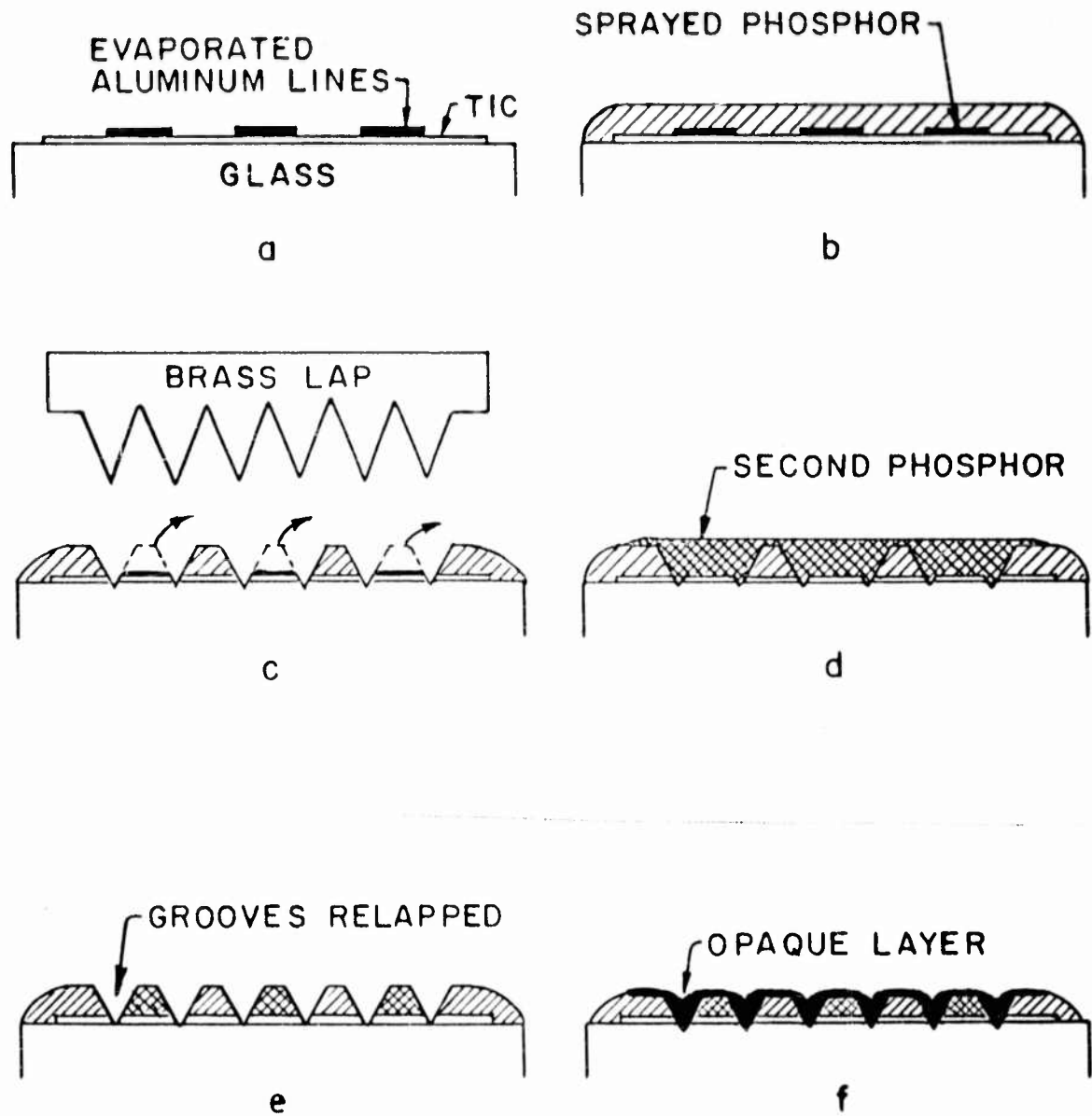


FIGURE 9. STEPS IN FABRICATION OF MULTI-STRIP TWO-COLOR PHOSPHOR PANEL

0.005"
 ↕
 .025"
 SCALE

and cured (Appendix I). A brass lap having 60 teeth on 25 mil centers is registered with the edges of the aluminum strips and, using emery powder, the plate is wet-lapped through the phosphor conducting film and into the glass (Figure 9c). This allows the alternate strips to come off as the bond between the aluminum and glass separates. Because some of the strips wedge between the teeth and cause trouble, a better method of lapping is to use an alternate tooth tool in two operations. The freed strips are then removed readily without damaging adjacent strips. Following the lapping operation, a layer of yellow emitting phosphor is applied as before and cured (Figure 9d). This is surface lapped to the same thickness as the first layer, then the grooves are relapped with the brass tool in order to give symmetrical strips of the two colors as in Figure 9e.

B. OPAQUE LAYER

The opaque layer (Appendix I) is next sprayed on to cover the phosphor strips and fill in the grooves as in Figure 9f. This opaque layer should be glossy in appearance and non-conducting. When the layer is sprayed on a lapped (rough) phosphor layer some conductivity can develop. It was definitely shown that there is a maximum conductivity which must not be exceeded if crosstalk from this source is to be avoided.

C. CURRENT DIFFUSING OR CONDUCTING LAYER

As pointed out earlier, this layer serves the purpose of conducting current under the ridges. It is made from CdS conducting powder

embedded in Araldite plastic (Appendix I). It has the property that current varies as a high power of the applied voltage. Conductivity through the layer is therefore much greater than laterally where the field is smaller. This layer is spread between two tape dams as shown in Figure 10a to give a layer several mils thick as in Figure 10b. This is then machined flat and about 3 mils thick as in Figure 10c. This can be done most conveniently by using the alternate tooth tool described in IV-D and shown in Figure 11a which has a large flat cutting edge. This machining operation and those described in Section IV-D for cutting grooves in the photoconductor are precision machining operations and special precautions are required to get the necessary precision. For this reason a small shaper was modified as shown in Figure 12. The motor drive was removed and a hand crank was added for moving the ram. Improved cross feed and vertical movement micrometers were added with zero sets on the drums. An 8" x 8" work bed was added and scraped flat and adjusted so that under light loads the cut was parallel to the bed. The tools 6" long were mounted on a turret head so either one could be used. The glass plate was held firmly by clamping strips on two sides and was pressed up against a reference strip on the right side which is accurately parallel to the movement of the tool.

D. PHOTOCODUCTIVE LAYER AND ELECTRODES

1. CADMIUM SELENIDE POWDER LAYER

Cadmium selenide is a black photoconductive powder of high

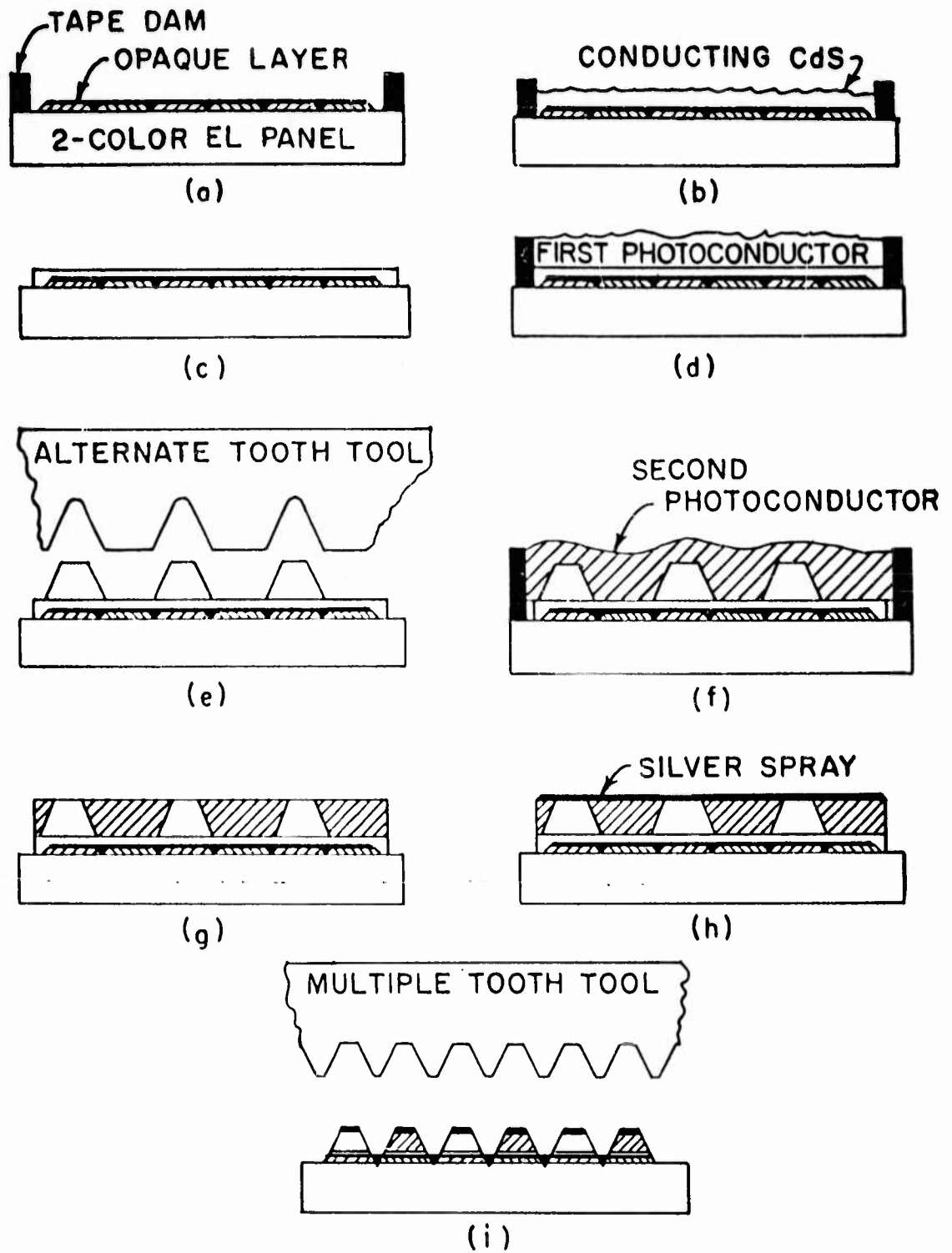
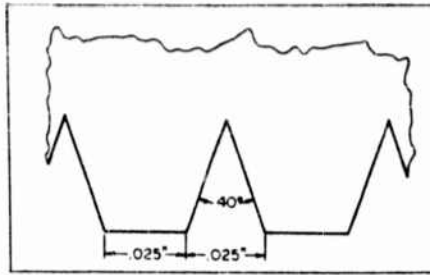
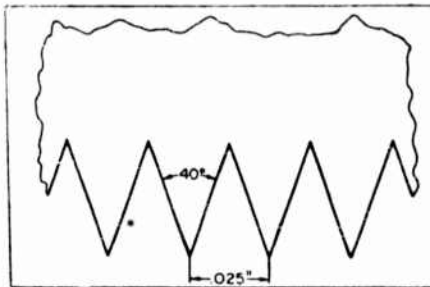


FIGURE 10. STEPS IN FABRICATION OF TWO-PHOTOCONDUCTOR LIGHT AMPLIFIER



a. Alternate tooth tool profile



b. Multiple tooth tool profile

FIGURE 11. PHOTOCONDUCTOR GROOVING TOOLS



FIGURE 12. MODIFIED SHAPER WITH TWO SIX-INCH TOOLS

WADD TR 60-147

sensitivity and small particle size - about 1 mil. It is only available at RCA and there only on an experimental basis. It has some unique bistable properties⁴ which must be avoided when the material is used for a light amplifier (Section 7C-3). This is done by keeping the applied field below the critical value for bistable operation.

(a) DEPOSITION AND MACHINING

The cadmium selenide powder is used in a plastic binder and is applied as a thin layer. For compatibility reasons the cadmium selenide layer is applied first and the binder used is diluted Araldite (Appendix I). It is applied by spreading a 24 mil layer between tape dams as in Figure 10d on top of the flat current diffusing layer. After drying and curing the layer is machined to 19 mils thick and this is grooved with the alternate tooth tool as in Figure 10e. The cut is made just into the current diffusing layer and in registry with the grooves in the phosphor layer, such that the selenide ridges are left above the yellow phosphor strips. This grooving operation is carried out to 1/4" of the end of the selenide layer at which point the tool is withdrawn. In this way a flat strip of selenide is left on which to make the electrical connection with the silver layer which is applied later.

These two machining operations leave the tops of the CdSe ridges

4. F. H. Nicoll, "A Hysteresis Effect in Cadmium Selenide Powder and its Use in a Solid-State Image Storage Device," RCA Review, Vol. 19, No. 1, March, 1958, pp. 77-85.

flat but somewhat higher than will be needed finally. In this condition it is ready for the application of the CdS powder layer.

2. CADMIUM SULFIDE POWDER LAYER

Cadmium sulfide is a brown photoconductive powder of high sensitivity and small particle size, about 1 mil. It was originally developed at RCA Laboratories and is now available for purchase from the RCA Electron Tube Division, Lancaster, Pa. and is designated F2103. This is similar to the material used in the original RCA light amplifier.¹

(a) DEPOSITION AND MACHINING

The addition of a plastic embedded CdS layer between the existing CdSe ridges imposed a strict requirement on the plastic and solvent used with the CdS powder: viz., that it should not alter the CdSe ridges with respect to photoconductivity, dark current, or mechanical properties. A number of different solvents and plastics were tested by this criterion. The satisfactory material was found to be 5% solution of polystyrene in pentachlorethane. The layer of CdS powder is spread (Appendix I) in a thick mixture between two tape dams as shown in Figure 10f, the CdS layer covering up the selenide layer completely. This layer is dried and cured and is then machined flat with the alternate tooth tool to a thickness of 13 mils above the current diffusing layer as in Figure 10g. This operation exposes a narrow flat portion on the top of

1. B. Kazan and F. H. Nicoll, "An Electroluminescent Light-Amplifying Picture Panel," Proc. IRE, 43, 1888, Dec. (1955).

the CdSe ridges ready for the application of a silver conducting coating.

(b) SILVERING AND MACHINE GROOVING

Silver paint (Appendix I) is sprayed on the top surface of the two photoconductors, using care to avoid making the surface too wet which might cause loss of sensitivity by solvent penetration into the powder. The silver layer on the photoconductive layers is shown in Figure 10h. This layer is masked 1/16" in from the edge of the photoconductor all around. The plate is next placed on the shaper machine with the ground edge in registry with the positioning plate on the work bed of the machine. The multiple tooth tool is then registered with the grooves in the glass plate as in Figure 10i. The profile of this tool appears in Figure 11b. The cutting operation starts about 1/8" in from one end of the silver layer. The tool is lowered, moved forward to within 1/8" of the other end and then withdrawn. This procedure of lowering the tool, cutting and withdrawing the tool is continued until the current diffusing layer is practically cut through and the silver lines are about 8 mils wide on top of the ridges. At the two ends the silver lines are now connected by a continuous band of silver paint about 1/8" wide located on sulfide material only at one end and on selenide only at the other.

The final operation is the use of the alternate tooth tool to interdigitate the silver lines near the two ends of the silver layer.

This leaves the plate with the silver lines on the selenide layer all joined together to a 1/8" band of silver supported by the solid selenide layer at one end. The silver lines on the sulfide layer are joined together by a 1/8" band of silver supported by the solid sulfide layer at the opposite end. This separation of the connections to the sulfide and selenide layers allows independent electrical control of the two layers.

V. MOUNTING AND TESTING EQUIPMENT FOR TWO-COLOR PANELS

A. GRAFLEX ADAPTOR

To facilitate testing amplifiers in conjunction with camera optics, an adaptor back was built which permits using the 6" x 6" amplifiers with any camera that will accommodate a 4" x 5" film holder. This back is illustrated in Figure 13.

Electrical connections to the panel are completely internal to the adaptor back, which, in addition, is grounded for safety. The panel itself is mounted in a Bakelite frame shown in Figure 14. The complete assembly of panel, adaptor and Graflex camera is shown in the photograph of Figure 15. In order to produce the correct size of image in the focal plane of the camera a 2-1/2" diameter 9" E.F. Bausch and Lomb Series II Cinephor was used without a diaphragm.

B. POWER SUPPLY FOR PANEL

A power supply for operating the two-color light amplifier was designed in accordance with the following considerations: 1) Each set of lines must be operable separately at voltages which may vary from panel to panel. 2) On-off is to be achieved by means of push buttons. 3) The panel is to be protected from sudden surges of voltage which could cause failure by burnout. The circuit diagram of the supply, and parts

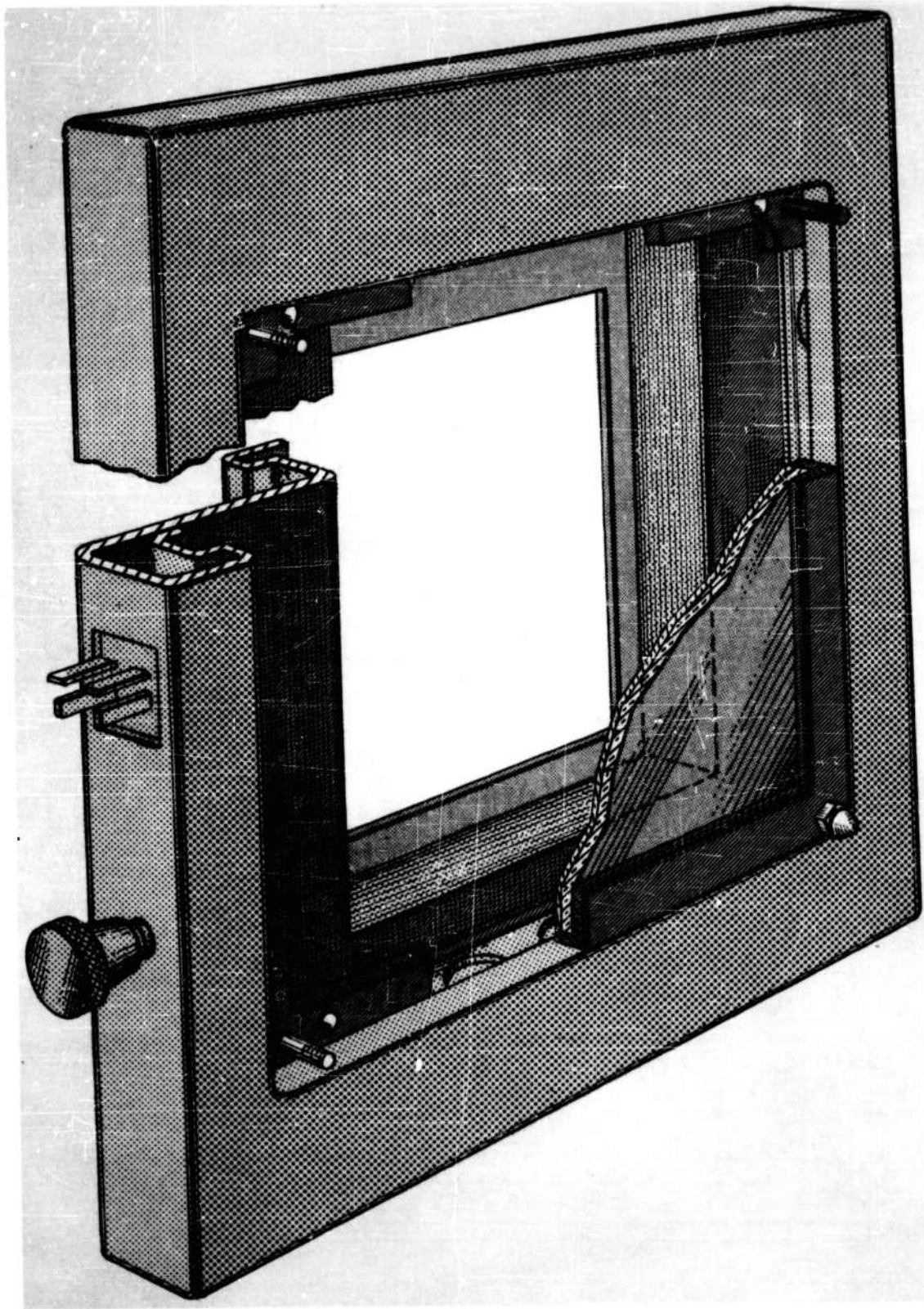
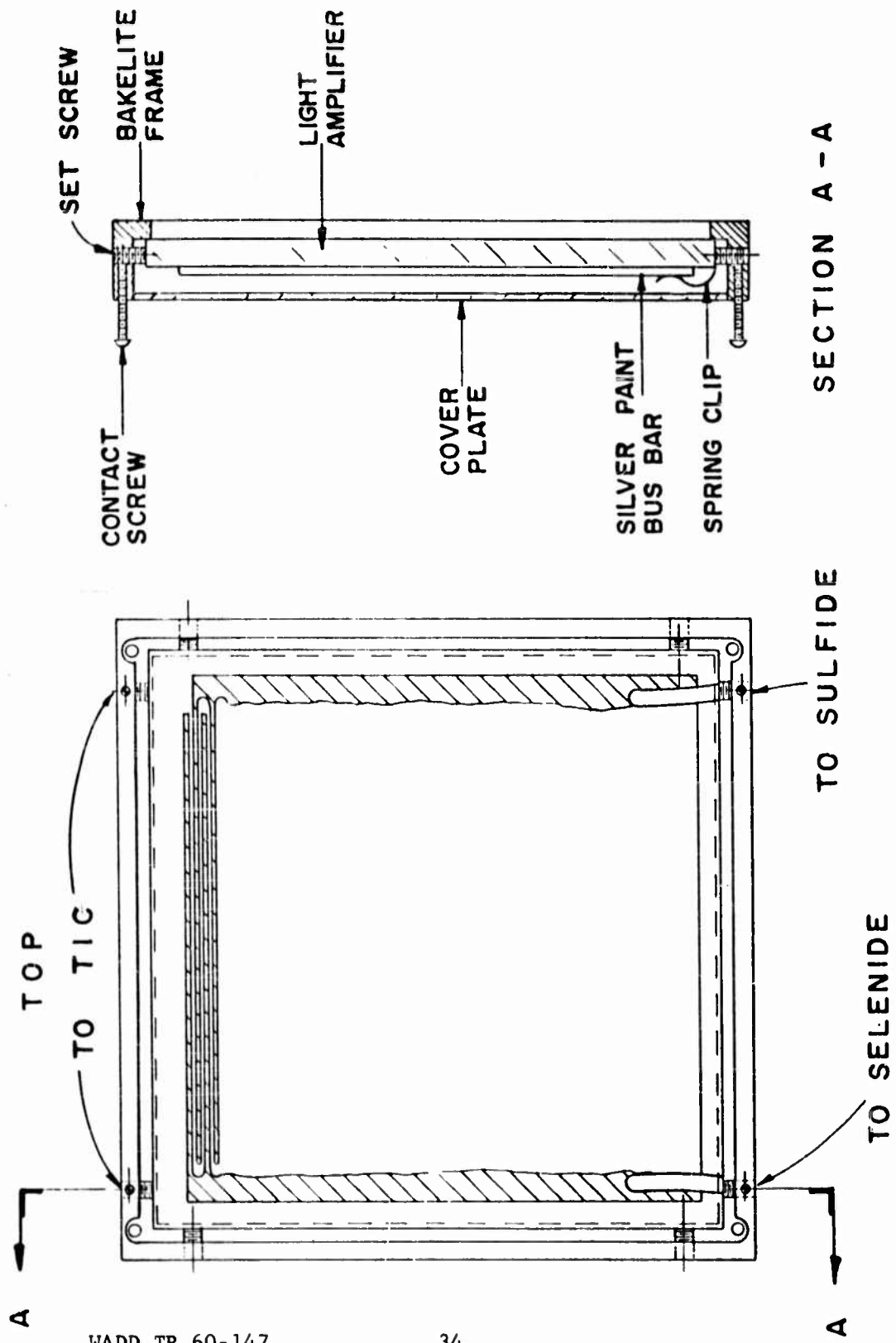


FIGURE 13. DRAWING OF GRAFLEX ADAPTER FOR PANEL

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FIGURE 14. MOUNTING FRAME FOR AMPLIFIER PANEL

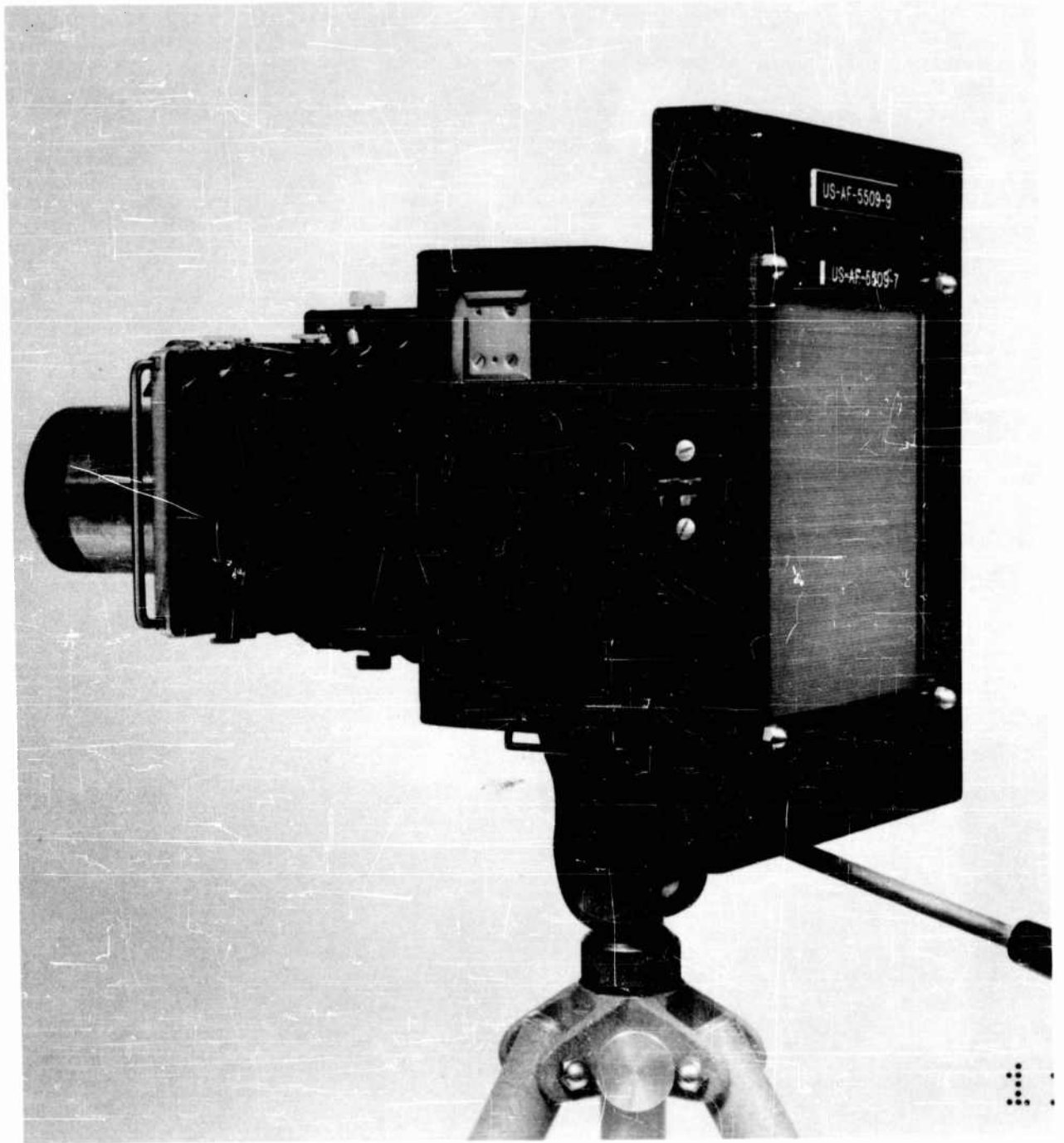


FIGURE 15. PHOTOGRAPH OF PANEL MOUNTED ON GRAFLEX CAMERA

list appear in the Appendix III. A photograph of the panel control box is shown in Figure 16. This supply is designed for operation only on a 110 V 420 cycle AC supply capable of delivering 1 amp.

C. LIGHT SOURCES FOR TESTING PANELS

1. UNIFORM ILLUMINATION SOURCE

A source of uniform illumination which would affect either the visible sensitive photoconductor, or the infrared sensitive photoconductor independently was constructed as an aid in testing the light amplifiers. It consists of a Sylvania Daylight fluorescent lamp plus a tungsten source with infrared transmitting filter, Corning No. 2540. A photograph of the lamp, designated USAF-5509-4 appears in the Figure 17. When placed in front of the camera and close to the lens a uniform illumination of the focal plane is made, thus allowing one to test the panels for uniformity.

2. IMAGE SOURCE

(a) DESCRIPTION

An image source for testing the amplifiers was built to satisfy the following requirements: 1) The amplifier must be able to show an infrared image with visible light present or with visible light absent, 2) The source should present a picture in order to demonstrate half tone response of the amplifier, 3) The spectral output of the source should match the spectral sensitivity of the photoconductors. P3, pp. 8-11,

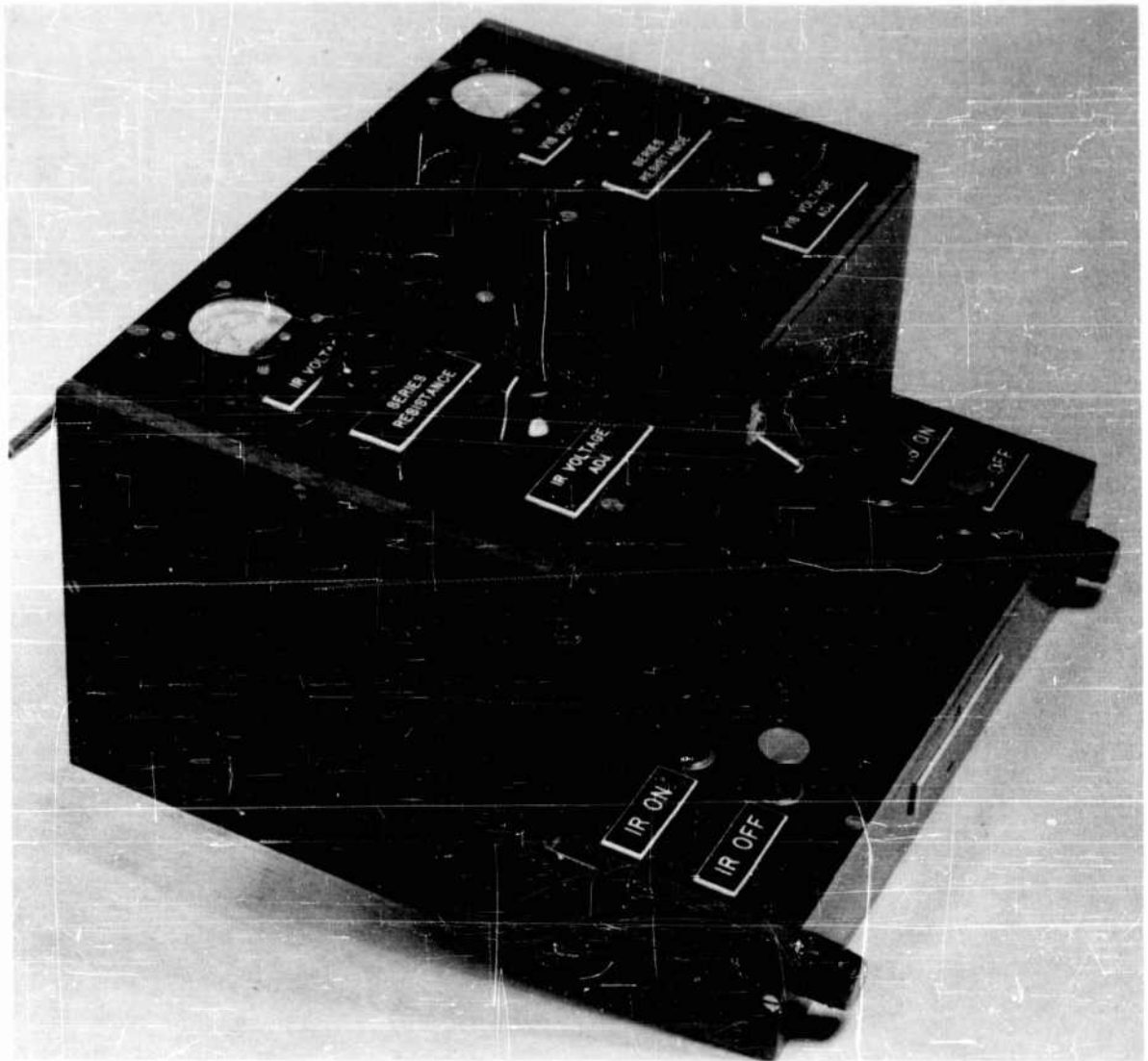


FIGURE 16. PHOTOGRAPH OF CONTROL BOX FOR PANELS

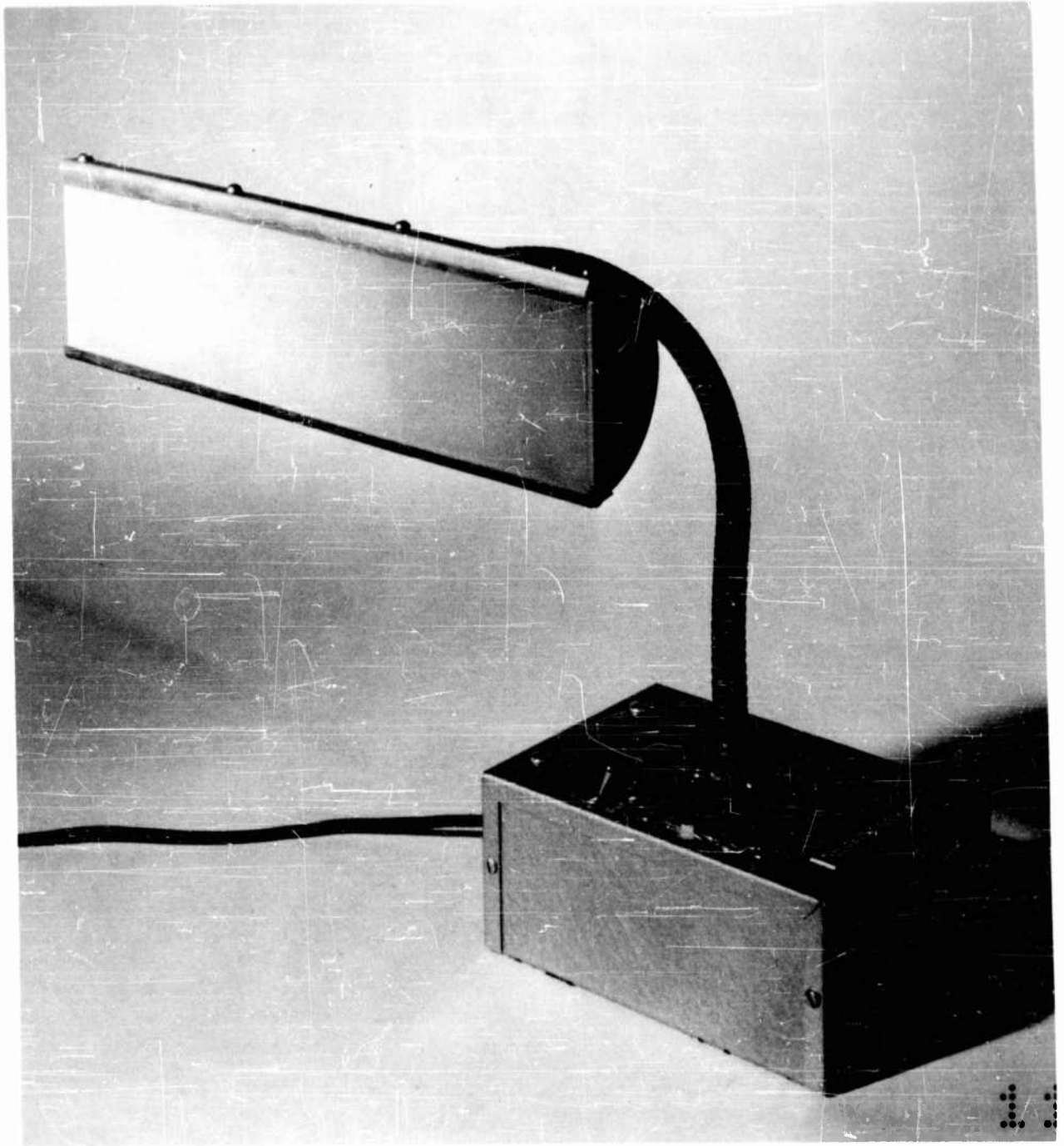
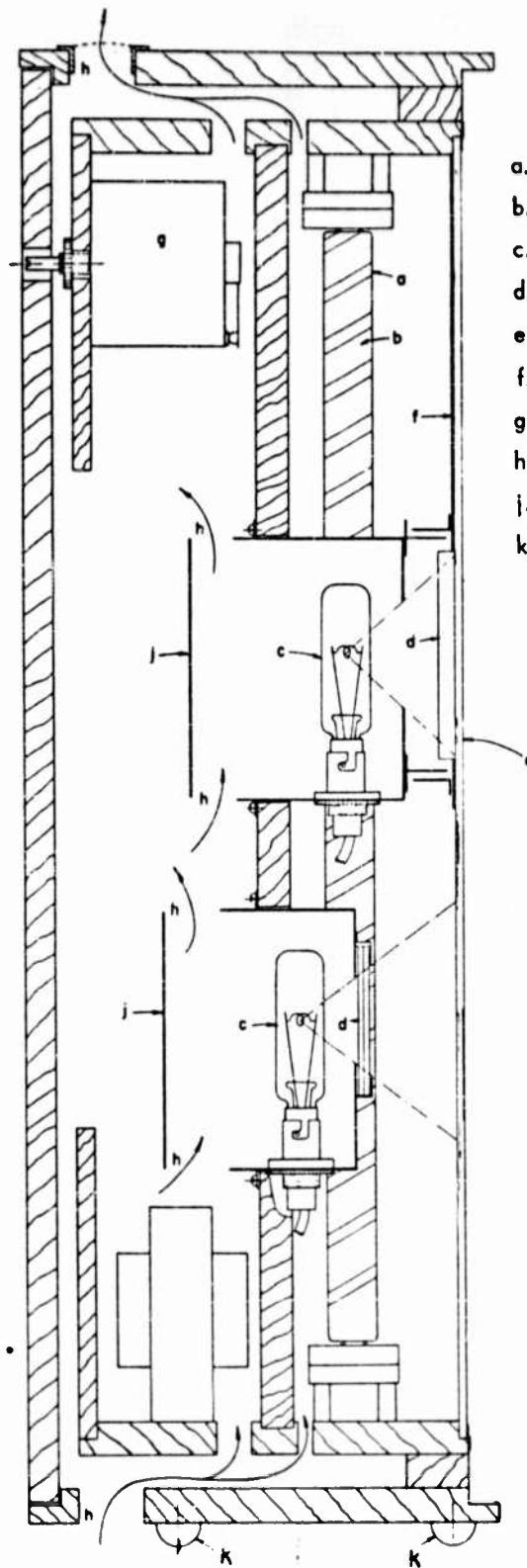


FIGURE 17. FLAT FIELD ILLUMINATOR SOURCE

The image source itself contains both infrared and visible light sources with controls to vary the brightness of each source over a limited range. Figure 18 illustrates the cross section of the box, Figure 19 shows the image as presented, and Figure 20 shows the front of the box with opal glass image removed. The fluorescent tubes (Sylvania daylight) used to supply visible light are much too bright and are therefore tapped to reduce the light. The infrared sources are 10 V lamps (GE 7.5A/T85C) operated at about 7 V maximum, with 1/4" thickness of infrared transmitting filter (Corning No. 2540) to cut out the visible light. The picture itself is made to simulate a view that might be seen by an aerial observer; in it are two regions of infrared, one in a brightly illuminated area and the other in a dark region.

(b) OPERATION

The visible and infrared sources are controlled separately, either from the box itself or by means of a remote switch. The intensity can be controlled by means of built-in variable transformers, one for the infrared sources and one for the visible (fluorescent) source. The circuit diagram and parts list for the box appears in Appendix IV. This image box is designed for operation from 110 V AC, 60 cycles.



- a. Fluorescent Tube
- b. Black Tape
- c. G.E. 7.5A./T85C
- d. IR Trans. Filter, Corning 2540
- e. Cpal Glass
- f. Opaque Area
- g. Variac
- h. Vent Holes
- j. Curved Reflector
- k. Rubber Feet

FIGURE 18. DIAGRAM OF LIGHT BOX CONSTRUCTION



FIGURE 19. PHOTOGRAPH OF OPAL SCREEN LIGHT-BOX IMAGE

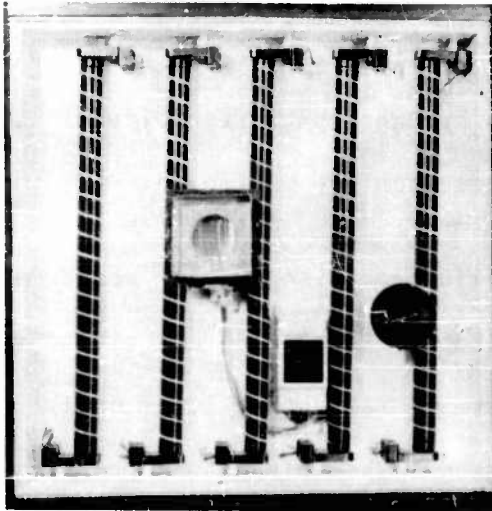


FIGURE 20. PHOTOGRAPH OF LIGHT SOURCES IN LIGHT BOX

VI. TWO-COLOR 6" x 6" PANEL PERFORMANCE

A. OPERATING CONDITIONS FOR PANELS

Operating conditions for the amplifiers were determined as follows: With no light on, the maximum voltages for no background-light are limited in the sulfide and selenide lines by the dark current and storage phenomenon respectively. A certain amount of dark-current light is tolerable, however, so the maximum voltage is chosen as that point at which the light first appears to the non-dark adapted eye. When a single set of lines is at this full voltage, there was no appearance of light when the other set was then brought up to its voltage. Thus, the maximum operating voltage for each set was found.

In order to determine actual operating voltages, the following procedure was adopted. With the visible source on, the voltage was raised on the infrared sensitive (selenide) lines until an image of the visible source barely appeared. The voltage was then lowered slightly. Likewise, the voltage of the visible-sensitive lines was adjusted to give no light with the infrared source only on. These voltages were lower than the maximum dark-current-limited voltages.

The actual operating conditions for the two 6" x 6" panels are given in the following table.

TABLE 1

Panel	Volts (Visible) RMS, 420 cps		Volts (infrared) RMS, 420 cps	
	Operating	Maximum	Operating	Maximum
USAF 5509-7	500	550	300	350
USAF 5509-11	300-400	600	250-300	400

As has been previously mentioned, the voltage supply for the panels is adjustable so that each set of lines can be run properly. To operate the panels using the supply, first the voltage for each set of lines is adjusted to the desired value using the knobs marked "visible voltage adjustment" and "infrared voltage adjustment". With the supply off, the panel is then plugged in, and the supply is turned back on. Then with the panel in the dark, the button marked "IR on" is depressed and held down, while adjusting the series resistance knob so the panel is just below lighting up in the dark. The button may then be released, putting the IR lines into operation. Pushing the "IR Off" button turns off the IR input lines. The same procedure is followed for the visible input lines. It is not possible to turn the panel on without using the pushbuttons each time because of interlocked relays, although it may be turned off by turning the main switch.

B. PANEL CHARACTERISTICS

1. INPUT

The illumination for the image source was chosen to match the spectral sensitivity of the light amplifier photoconductors (as well as possible). Figure 21 shows the output of the fluorescent light, the output of tungsten light multiplied by the transmission of the Corning 2540 filter and the spectral response of the cadmium sulfide and cadmium selenide photoconductors.

From Figure 21, it will be noticed that there is good separation of response by the use of the light sources previously mentioned. Some of the sensitivity of the photoconductor is unused, resulting in lower efficiency than could be obtained with lights that more accurately matched the photoconductors. This extra sensitivity was sacrificed in order to keep the inputs separated, eliminating cross-talk and insuring independent operation.

2. OUTPUT

The blue and yellow strips of electroluminescent phosphor are the output of the panel. These two colors were chosen because of their high brightness compared to the other phosphors, combined with their spectral outputs. This permits using a filter over the whole panel to produce a redder output from the yellow phosphor than could be obtained

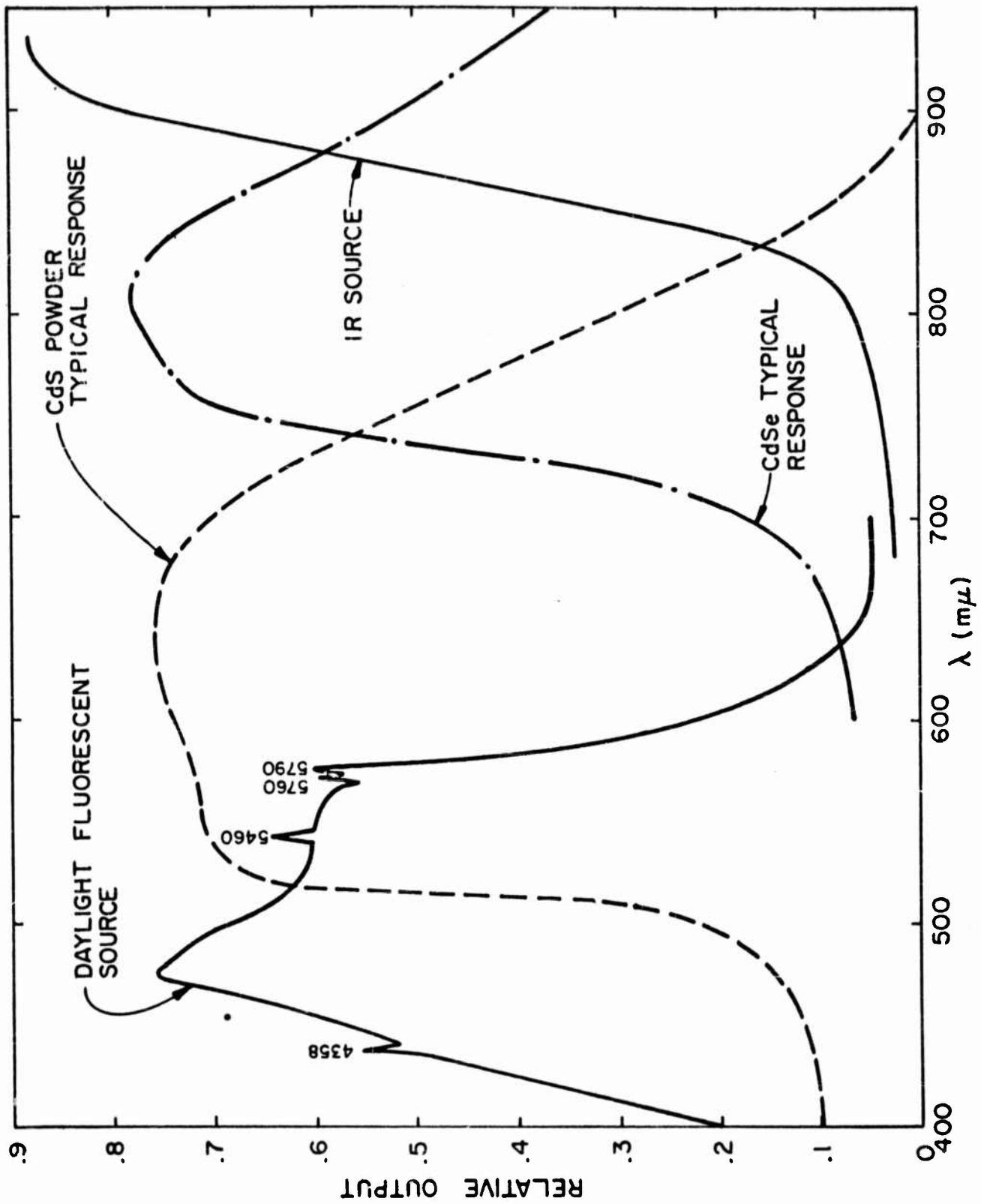


FIGURE 21. RELATIVE SPECTRAL OUTPUT OF LIGHT BOX

from a red phosphor, and without interfering with the blue output very much, Figure 22. The enhancement of the red output will be discussed in Section VII, A-2.

3. GAIN

The gain of the panels must be rather carefully defined, since it is measured with tungsten light input for both the infrared and visible-sensitive photoconductors, and the output of these two sets of lines is yellow and blue respectively, measured with an eye-corrected photomultiplier. This, of course, gives the luminous output, which when divided by the luminous input gives the luminous gain of the panel for tungsten light input. In measuring the actual panels, the gain must be multiplied by two to make a comparison with a monochrome output panel because only half the output area is active, while the photomultiplier measures the average brightness.

The input-output and gain curves of prototype panels USAF-5509-7 are given in Figures 23 and 24 respectively. Similar results for USAF-5509-11 are shown in Figures 25 and 26.

Another thing to be noted is that the luminous gain for tungsten light has no meaning when the panel is used for the infrared, where the true measure of gain would be the ratio of (light energy out) to (light

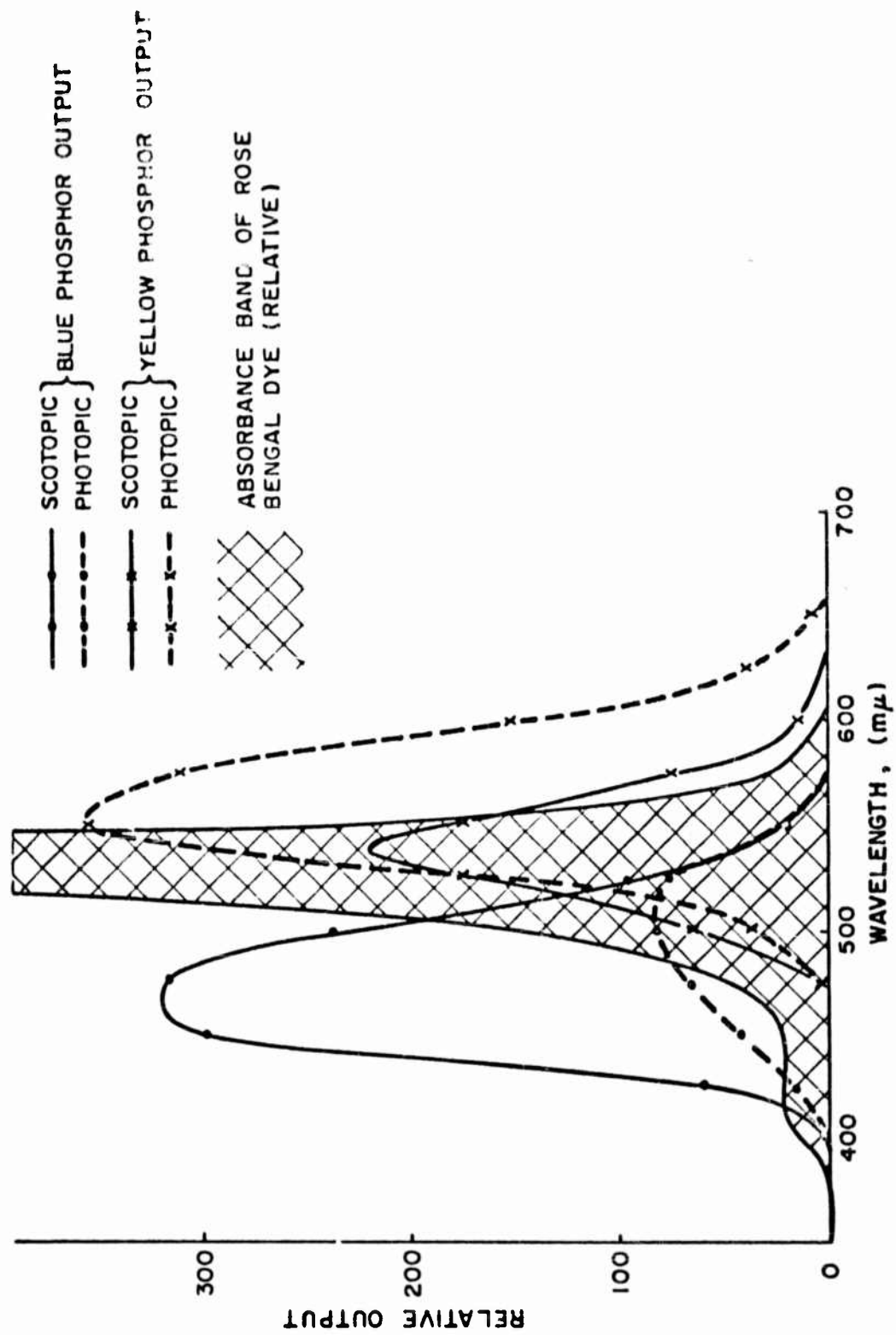


FIGURE 22. PHOTOPIC AND SCOTOPIC OUTPUT CURVES FOR YELLOW AND BLUE PHOSPHORS WITH ABSORPTION CURVE FOR ROSE BENGAL DYE

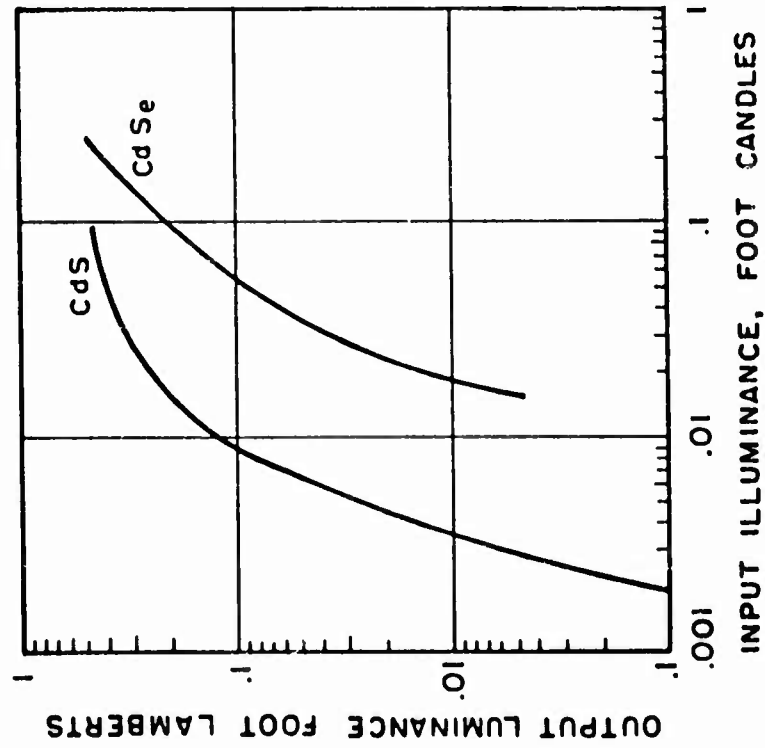


FIGURE 23. INPUT-OUTPUT CURVES FOR PROTOTYPE LIGHT AMPLIFIER USAF-5509-7

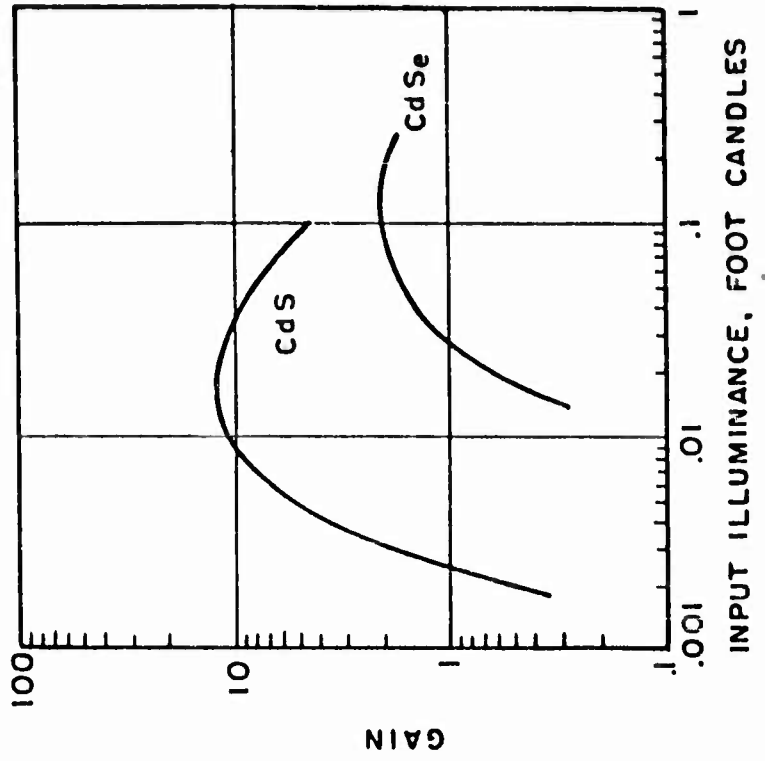


FIGURE 24. GAIN VS. INPUT ILLUMINANCE FOR PROTOTYPE LIGHT AMPLIFIER USAF-5509-7

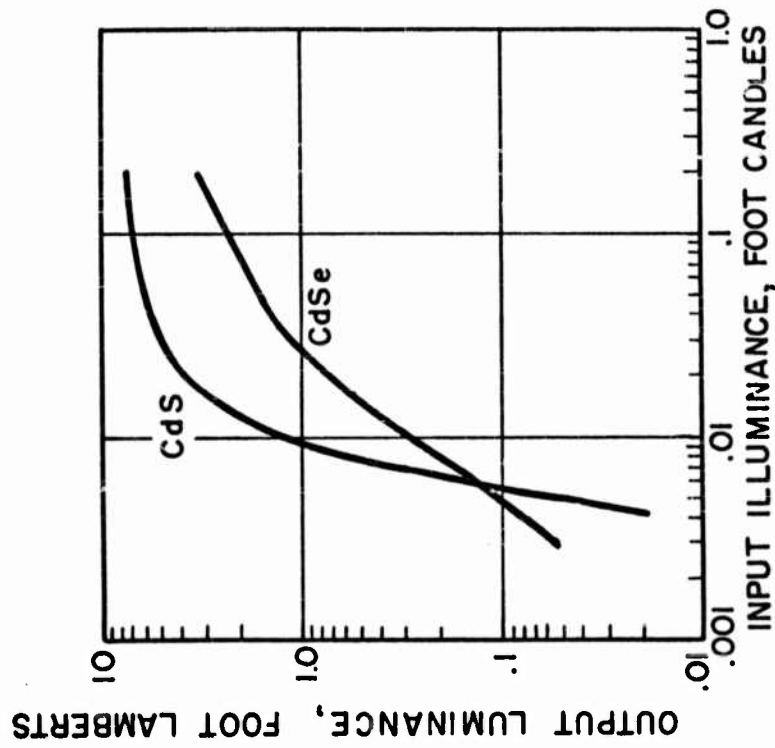


FIGURE 25. INPUT-OUTPUT CURVES FOR PROTOTYPE LIGHT AMPLIFIER, USAF-5509-11

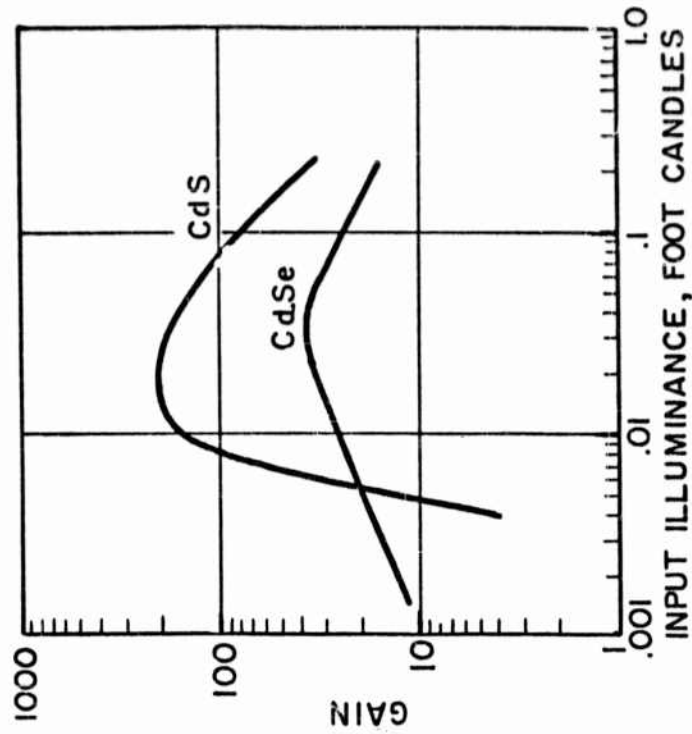


FIGURE 26. GAIN VS. INPUT ILLUMINANCE FOR PROTOTYPE LIGHT AMPLIFIER, USAF-5509-11

energy in). It has somewhat more meaning when the panel is used with the fluorescent light, although the source lacks luminance values in the red. However, these gain measurements do permit a comparison of one amplifier with another.

4. COLOR PHOTOGRAPHS OF OUTPUT

The output of Panel USAF-5509-7 was photographed in color under three conditions of operation. Figure 27 shows the panel with infrared and visible lines activated, but with visible input only; Figure 28 is the same, but with the infrared input only, and Figure 29 shows the panel with both inputs active. These photographs were taken as a time exposure, and under those circumstances, the color values of the Ektachrome film are not too reliable, so these colors are not exactly faithful. There is also some crosstalk apparent, especially in Figure 29, where there is some blue output along with the yellow. This is usually not as evident when the panel is operating and viewed by eye.

5. SPEED OF RESPONSE

The speed of response of the photoconductors as mentioned in Section VII, C, varies both with the kind of material and with the physical conditions, such as binder, temperature, light intensity, etc. It is a general rule, however, that the sulfide materials are slower in response and in decay than the selenides. At present, there is no simple means to change the response time. In the input light range where the



FIGURE 27. COLOR PHOTOGRAPH OF OUTPUT IMAGE FOR VISIBLE INPUT ONLY



FIGURE 28. COLOR PHOTOGRAPH OF OUTPUT IMAGE FOR INFRARED INPUT ONLY

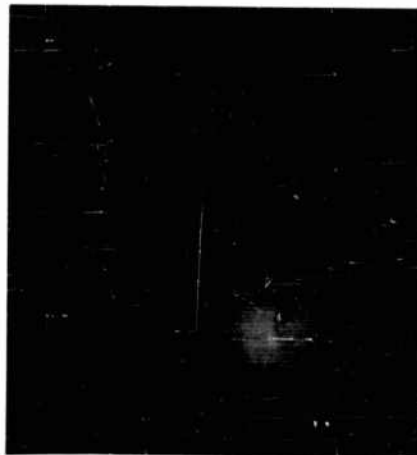


FIGURE 29. COLOR PHOTOGRAPH OF OUTPUT IMAGE FOR BOTH VISIBLE AND INFRARED INPUT IMAGES

two color panel operates the infrared image has a speed of a fraction of a second whereas the visible image persists for seconds.

VII. PROPERTIES OF MATERIALS

A. AC EXCITED ELECTROLUMINESCENT PHOSPHORS

1. SPECTRAL CHARACTERISTICS

AC operated electroluminescent cells are now relatively commonplace. They consist of plastic embedded phosphor sandwiched between two electrodes, one of which is transparent. The cells are usually about 2 mils thick and require one hundred volts or more to operate them. In general, the light output increases with the voltage to the third power and increases somewhat less than linearly with frequency.

Many electroluminescent phosphors are now available both from RCA and elsewhere. The spectral curves for several RCA phosphors with their associated number designation are given in normalized form in Figure 30. The red emitting material is very low in output and therefore of little use.

From the point of view of a two color device the yellow emitting 2099 gave the best contrast in color without resorting to filters. Actually the relative response of the different colors at the eye depends on whether the response of the eye is scotopic or photopic. Since the output of the panels is in the luminance range of 1-5 foot Lamberts

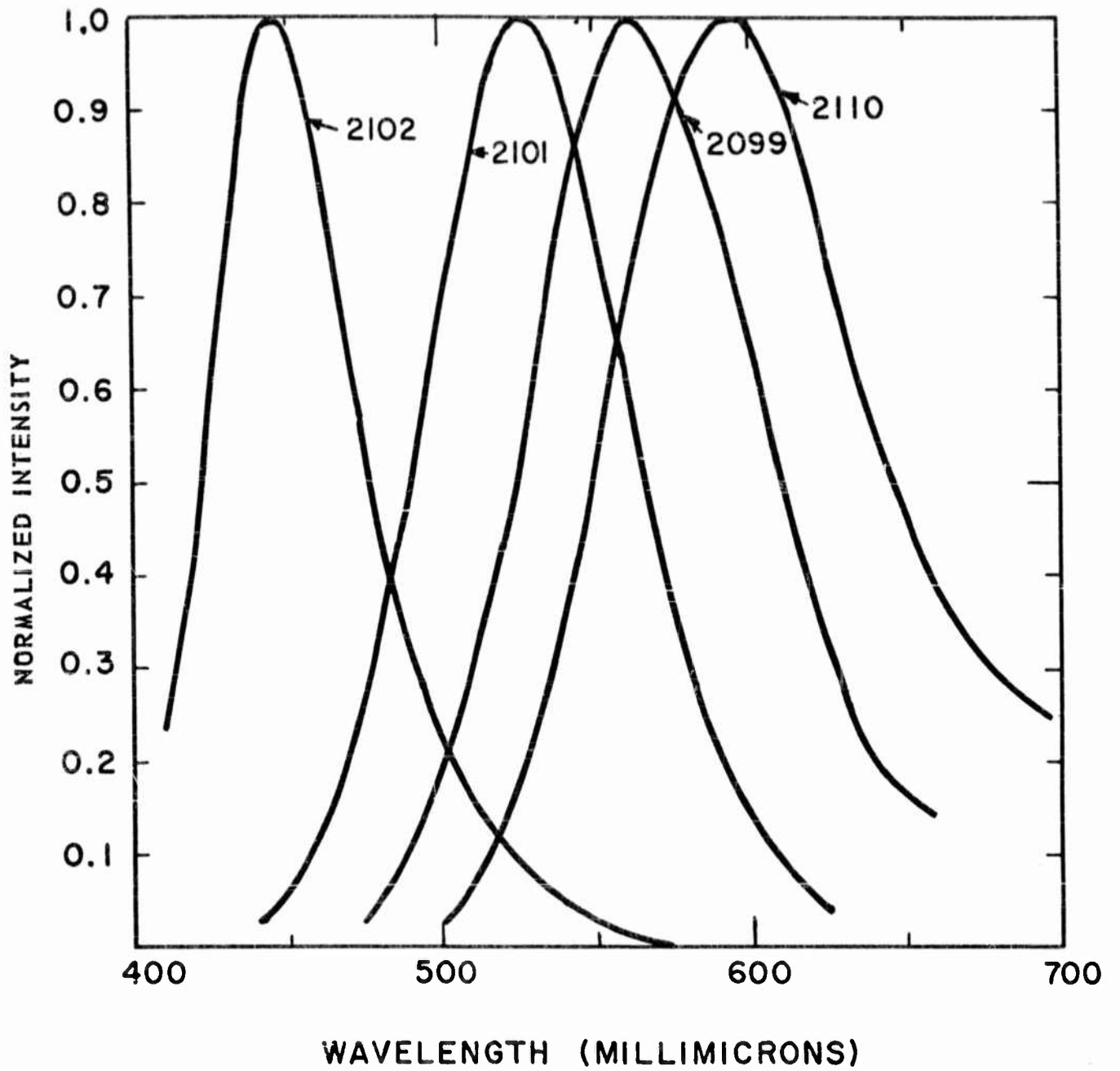


FIGURE 30. SPECTRAL EMISSION OF ELECTROLUMINESCENT PHOSPHORS

the photopic response of the eye is an approximation to the actual response. It has been used in Figure 31 to show the relative photopic output of the various phosphors.

2. ENHANCED RED OUTPUT

The use of a blue and yellow output on the two color light amplifier was reasonably satisfactory but interest was expressed in having a redder output than is obtained with yellow phosphor alone. Some effort was therefore expended on study of means for achieving this color shift. The study included the use of dyes incorporated in the phosphor and also the use of Rose Bengal embedded in a thin plastic layer to form an external filter (Appendix II) which reddens the yellow output without affecting the blue output very much. Figure 22, Section VI, B2 shows the photopic phosphor output and the Rose Bengal absorption.

An attempt was made to provide a better red output by combining the blue phosphor with a strongly red luminescent powder. In this approach the blue light emitted by the electroluminescent powder is expected to excite the second luminescent powder. Two difficulties were encountered with this approach. First, the red output was not sufficiently high and secondly the red luminescent material was excited by ambient light when the electroluminescent phosphor is not operating. The final conclusion on enhanced red output is that the use of a filter similar to Rose Bengal is the only useful method with existing phosphors. Such a

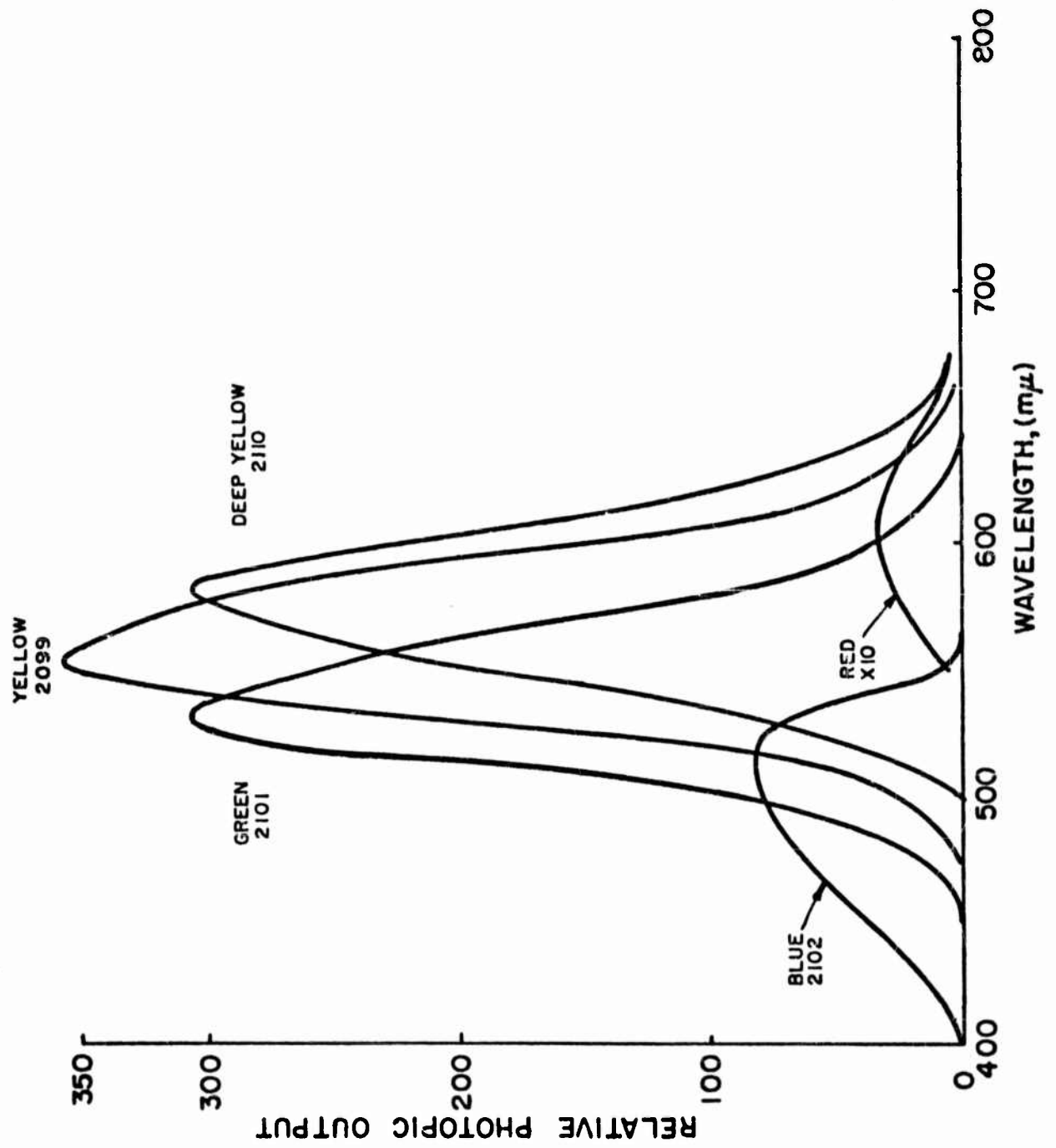


FIGURE 31. RELATIVE PHOTOPIC OUTPUT OF ELECTROLUMINESCENT PHOSPHORS

red filter is supplied with the prototype panels in 6" x 6" size.

3. COLOR CHANGE WITH FREQUENCY

It has been known for a long time that some electroluminescent phosphors change color with operating frequency and some attempts to use this as a practical two color output for the light amplifier were made. The effect can be seen on yellow phosphor 2099 as a shift toward the blue as frequency is increased from 60 to 10,000 cps. The shift, however, is too small to be useful and does not compare with the color contrast to be obtained by using two separate phosphors operated at the same frequency. The frequency change method of operating phosphor layers was therefore dropped as being unsuitable for the two-color light amplifier.

B. DC EXCITED PHOSPHOR LAYERS*

1. ADVANTAGES

There are several reasons why a DC operated phosphor layer would be advantageous in a light amplifier. It was this possible utility that prompted further work on these phosphors beyond that done by RCA prior to the contract. One of the advantages of DC operation is that the photoconductor is more sensitive when operated with DC. A second reason is that with DC operation it is not the capacitance of the two active layers (photoconductor and electroluminescent layers) that determines

*This section contains work done during the seventh quarter, and, therefore, has not been reported on previously.

the voltage division in the dark but rather the resistance. Because of the low dark current of photoconductors this allows the use of very thin photoconductive layers. This in turn assists in obtaining more complete light penetration of the layer. Finally, the use of DC is beneficial if it is desired to make use of voltage reversal as a means of reducing decay (Section VII, C-5).

2. EXPERIMENTAL RESULTS

The emission of light from a powder phosphor experiencing a high DC electric field was first reported by F. H. Nicoll and B. Kazan³ where it was observed in aluminized cathode ray tubes when a field was applied between the aluminum film on the phosphor and the outside of the tube face, with the face heated. Under these conditions very high fields can be applied to the phosphor particles since they are more insulating than the hot glass and therefore have most of the voltage across them. On the other hand if a phosphor particle becomes very conducting the voltage across it falls because of the series resistance of the glass, but the voltage across the remainder of the phosphor is not reduced. This protective action of the conducting glass is very important.

³F. H. Nicoll and B. Kazan, "Observations of Electroluminescence Excited by D. C. Fields in Cathode Ray Tubes," Proc. IRE, August, 1955.

The use of hot glass as a protective resistive layer is not very satisfactory so a special conducting glass (X-857A, supplied by Corning) was used instead. This has a resistance of approximately $10^8 \Omega$ -cm. It was also provided with a transparent conducting coating on one side to permit viewing the emitting phosphor.

Samples were ordinarily prepared by settling a phosphor on the uncoated side of the 1 mm thick conducting glass and then aluminizing on top of a thin collodion film spread across the phosphor. With this arrangement about 750 volts was required to obtain light from the sample. The magnitude of the DC current and the light output are functions of humidity and of the gas surrounding the phosphor particles. Humid air causes more current to flow and gives a greater output luminance than dry air. Similarly argon is much better than dry air. On the other hand, helium and dry nitrogen are very poor. The reason for the improved operation in argon has not been established but it would seem to be connected with making contact by gas discharge between the phosphor and the aluminum. There may also be a question of surface states on the phosphor since in air a good deal of ozone is formed which very probably affects the phosphor performance.

The light output is a function of DC polarity and time, and also depends on the past history of operation. Reversal of the voltage, particularly going from positive to negative voltage on the aluminum

usually gives an initial large flash of light. An attempt was made to observe the build up and decay of the light with time and with voltage reversal. This was done with a Tektronix scope, using an electronic switch to show with a double trace, both current through the 3" square and output luminance measured with a photomultiplier. This curve shown in Figure 32 is representative of a particular set of conditions approximating those existing at the first trial of a sample. These results were obtained with 550 V applied in an argon atmosphere. After a period of time light output may drop and current rises as the glass heats and becomes more conducting.

An approximate calculation of efficiency of the 3" x 3" layer gives a value of 0.5 lumens/watt. From the device point of view this is to be compared with the efficiency of .12 lumens/VA for AC operated devices. If stable behavior could be obtained from the DC electroluminescence it could become very useful in light amplifier devices. Most of the common cathodoluminescent phosphors emit light at high DC fields, obtained by the technique just described. Tests have shown that even silicate materials (which do not give electroluminescent light in plastic embedded AC operated cells) will emit with DC, and red, green, and blue colors are readily obtained.

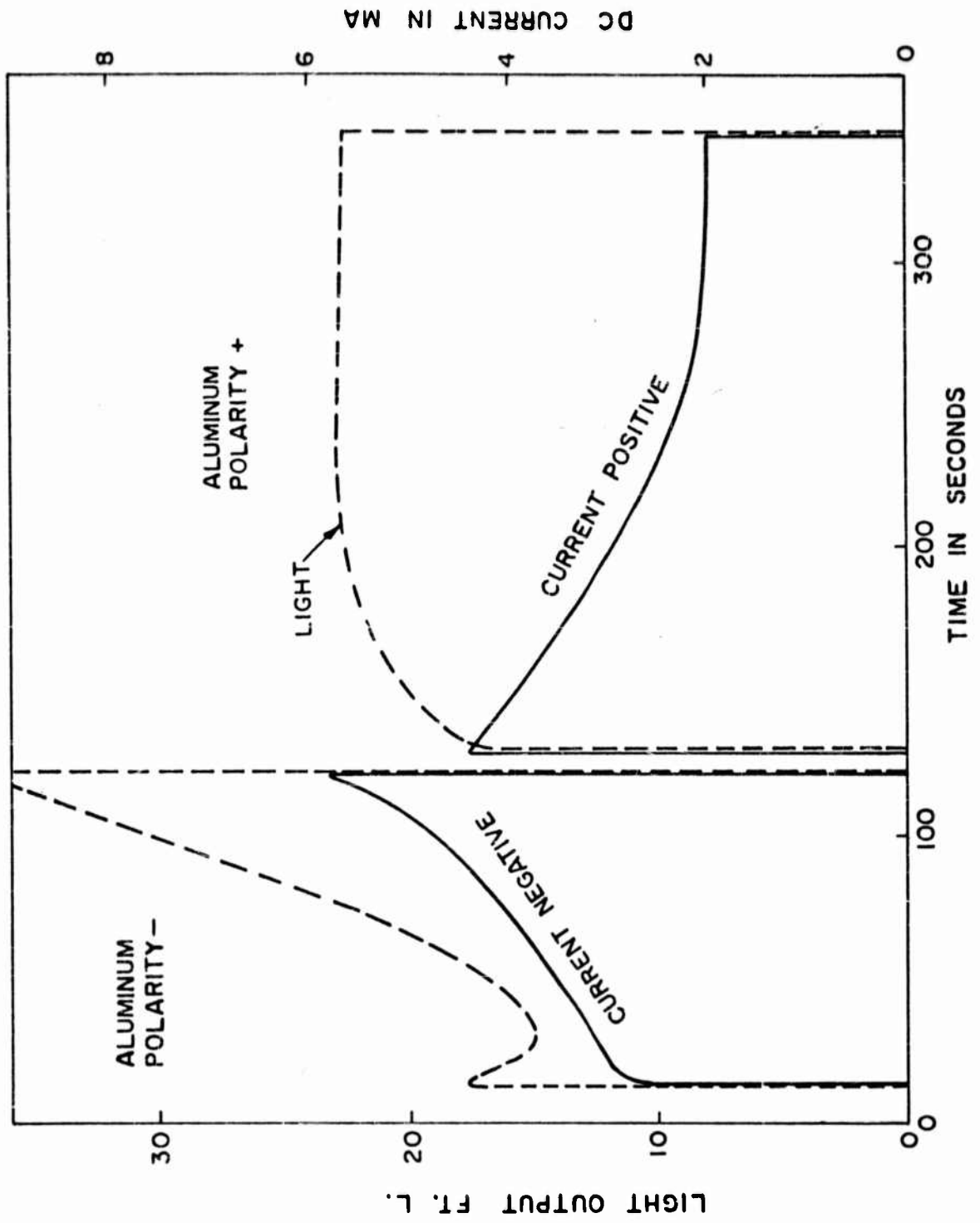


FIGURE 32. VARIATION IN DC ELECTROLUMINESCENT LIGHT OUTPUT WITH TIME AND VOLTAGE REVERSAL

C. PHOTOCONDUCTIVE MATERIALS

1. GENERAL PROPERTIES

Two photoconductive powders CdS and CdSe have been used in the work described in this report. They both have sensitivities of amperes/lumen and represent the most sensitive materials available. Their spectral responses have been given in Figure 4. The materials are usually tested by mixing powder with a one percent solution of ethyl cellulose and allowing a drop of the mix to dry on a standard gap (0.5 mm x 5 mm). Photocurrents are measured at various light levels. The powders have also been measured in other plastics, Araldite and polystyrene, since these were necessary for panel construction. Ageing time of the plastic is important as the resins continue to react for some time after setting. The optimum curing temperature was also investigated.

2. TEMPERATURE DEPENDENCE IN CdS- POWDER

The properties of CdSe powder over the range of -25°C to $+25^{\circ}\text{C}$ were investigated. The samples were tested in an evacuated thermostat or cryostat in which the temperature of the sample was adjusted by adding heat, from an electrical heater, to balance the lowered temperatures produced by conduction from a liquid air container. Using this arrangement, a number of curves of photocurrent and rise and decay times were obtained as a

function of temperature. The general characteristic of increased photocurrent at reduced temperatures is obtained. The difference in photocurrent at $+25^{\circ}\text{C}$ and -25°C is greater at low input lights. It amounts to three orders of magnitude at .0005 ft.c. and only a factor of four at 0.5 ft.c. At the .0005 ft.c. level rise time changes by about a factor of four being slower at -25°C , while decay time changes about a factor of seven. At 0.5 ft.c. rise time changes about two times and decay time four times.

The point of interest here is whether one achieves a more useful performance in the photoconductor by cooling. It would appear from the results at low light inputs that one gains a larger factor in sensitivity than one loses in slowness of response. At higher levels one gains sensitivity and loses response speed in about the same ratio. The real significance of the low level figures is somewhat in doubt because of the long response times which make it difficult to obtain reliable readings without extending the time of observations greatly.

3. CURRENT-VOLTAGE HYSTERESIS IN CdSe^*

Cadmium selenide photoconductors can exhibit a current-voltage characteristic showing hysteresis,⁴ for sufficiently high applied fields.

*See footnote, p. 57.

⁴F. H. Nicoll, "A Hysteresis Effect in Cadmium Selenide Powder and its Use in a Solid-State Image Storage Device," RCA Review, Vol. 19, No. 1, March, 1958, pp. 77-85.

As the applied voltage is increased, the current rises uniformly until a critical voltage is reached. At this point, the current increases discontinuously by a large amount. This large current persists when the voltage is decreased until, at some value below the critical voltage for increasing current, it drops back suddenly to the original curve.

Current-voltage curves for a CdSe sample were recorded on an oscilloscope, using circuitry which applied across the sample a voltage which increases from a minimum to a maximum and returns. Both increase and decrease of voltage are linear with time and each requires about 10 seconds. A representative curve for a sample in the dark is shown in Figure 33A. Here the discontinuities in current rise (at 570 volts) and current drop (at 400 volts) amount to about an order of magnitude. The lower end of the curve shows an open loop caused by the phase shift introduced by the large RC of the test gap sample in the low current range.

The high current state of the photoconductor may be induced by illumination at fields between the two critical values. It has been found that exposures as low as 0.001 foot-candle-second are sufficient to trigger the photoconductor from the lower to the higher current state. The effect of illumination is to reduce the spread between the two critical voltages. Figure 33B illustrates this, the illumination in this case being 0.0001 ft. candle.

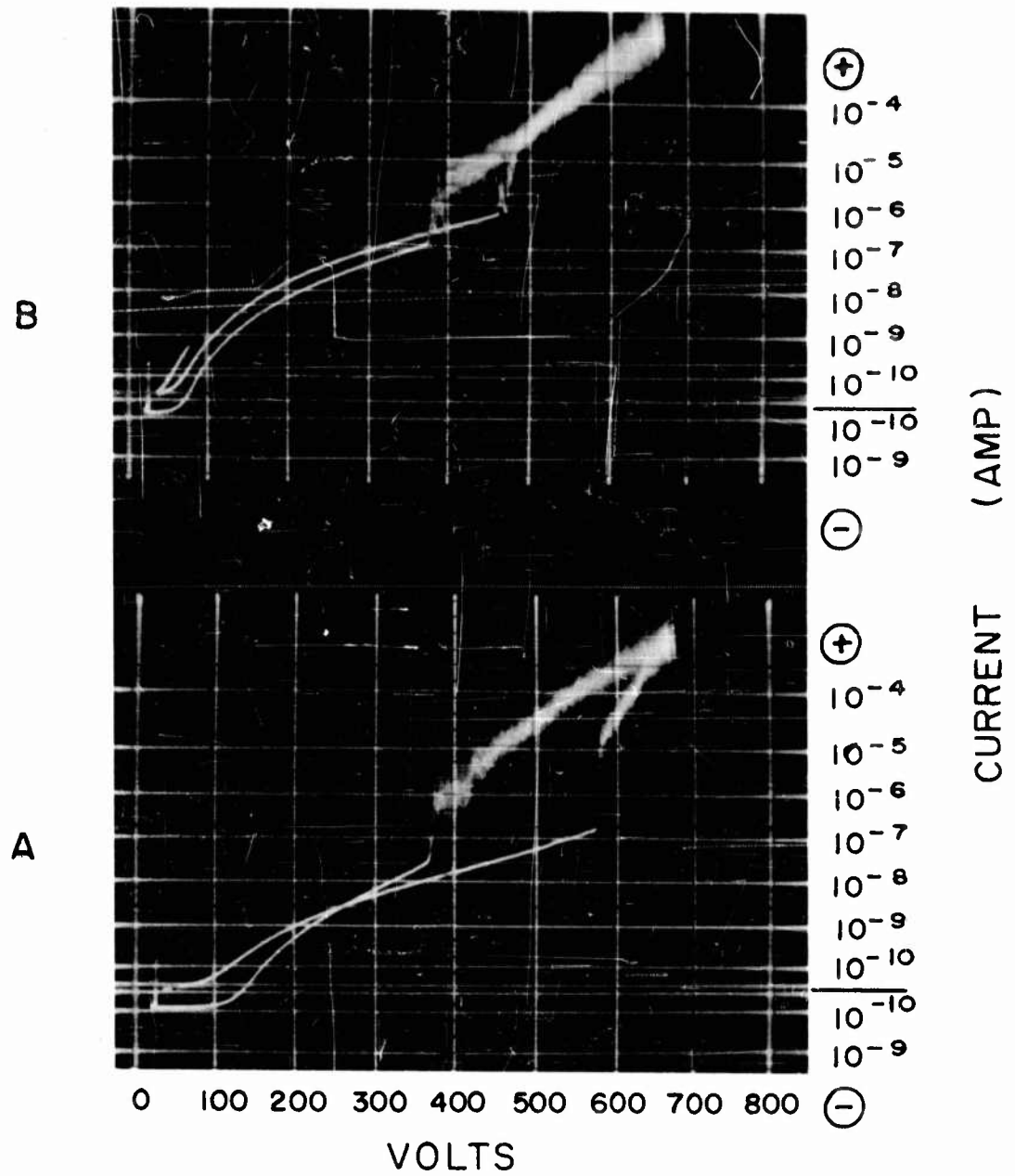


FIGURE 33. HYSTERESIS IN CADMIUM SELENIDE POWDER

A. Zero Illumination

B. 0.0001 Ft. Candel Illumination

The high current state is typically very noisy, as shown in the illustrations. Examination of the current by an oscillograph shows the form to be a succession, more or less regular, of abrupt current increases and slower decays.

4. ACCELERATED DECAY OF PHOTOCURRENTS*

The speed with which the image formed by a solid-state light amplifier can be changed is limited by the rate of decay of conductivity of the photoconductor after the light is removed. For both CdS⁵ and CdSe photoconductors with DC excitation it has been found that the normal decay can be greatly accelerated by removing or reversing the applied voltage for a short time, after the light is cut off. This is illustrated by the curves of Figure 34. Figure 34A shows a normal decay curve for CdSe powder, in ethyl cellulose binder. This is applied across a standard test gap and operated with 300 volts applied and 0.1 foot-candle illumination. Superimposed on this is a curve showing the effect of reversing the applied field for one second, starting about 0.1 second after the illumination is removed. In this case, residual current never exceeds 6×10^{-9} ampere, a value which was not reached during normal decay for a time in excess of 10 seconds. The sensitivity of the photoconductor is not affected by this operation, as is illustrated by

*See footnote, p. 57

⁵B. Kazan, "A Solid-State Amplifying Fluoroscope Screen," RCA Review March, 1958, Vol. 19, No. 1, pp. 19-34.

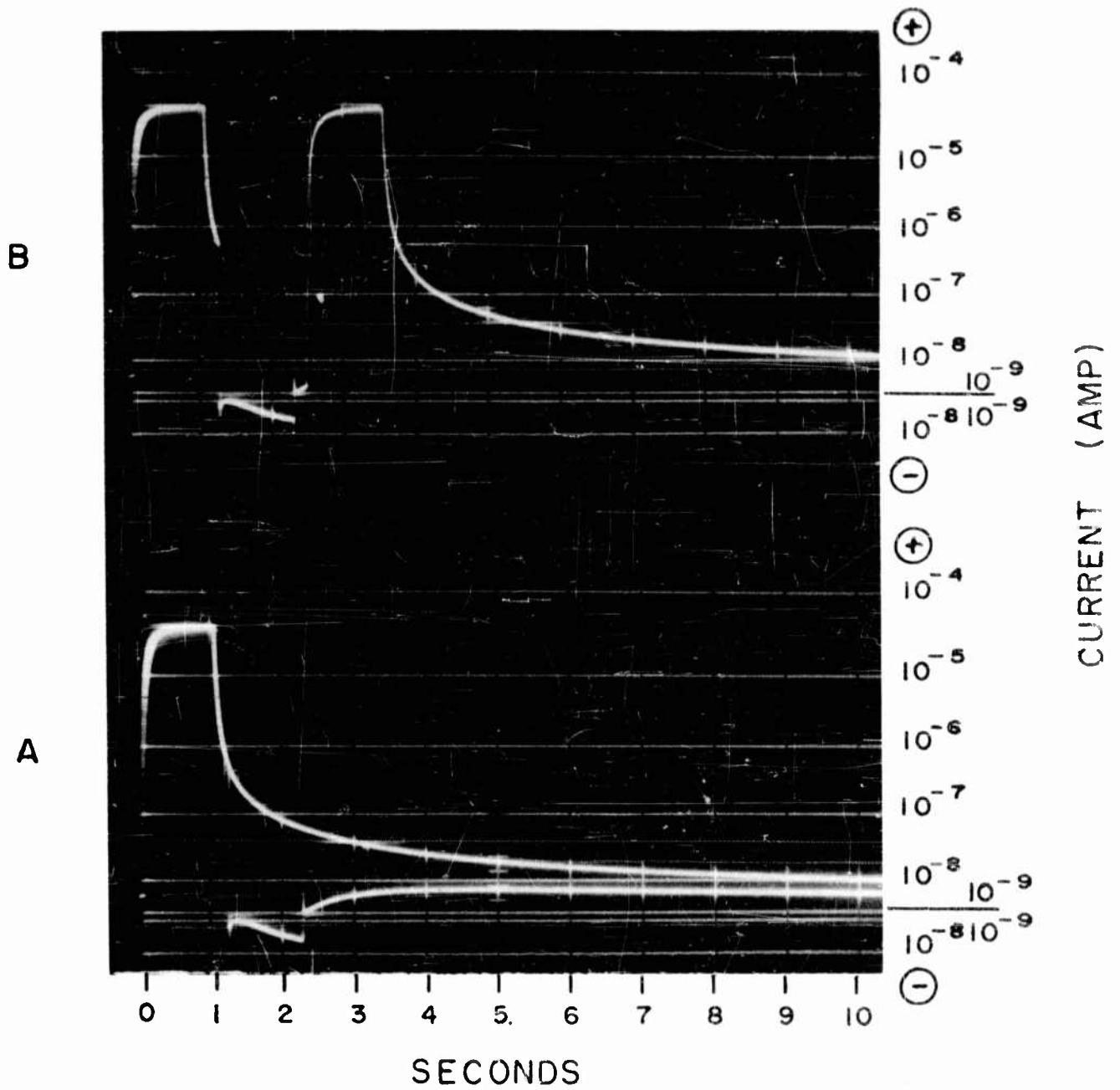


FIGURE 34. ENHANCED DECAY IN CADMIUM SELENIDE POWDER
 A. Normal Decay and Decay after Field Reversal
 B. Normal Excitation and Excitation after Field Reversal

Figure 34B. This shows the build-up of photocurrent when the light is reapplied about 1/5 second after completion of the field reversal operation. Comparison of this photocurrent build-up with the initial one indicates that the rates are substantially identical.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The work described in this report has included the fabrication of a light amplifier sensitive separately to either visible or near infrared images and having a blue output image corresponding to visible input and a yellow output image corresponding to infrared input. The feasibility of such a device has been demonstrated and its construction could certainly now be carried out by others. The performance of the panels depends to a great extent on the properties of the constituent materials. Separation of the input images depends on the spectral response of the photoconductors. Gain is a function of the sensitivity of the photoconductors and also depends on the efficiency of the electroluminescent materials. It is therefore clear that any great change in performance characteristics of the two-color light amplifier can only be achieved through improvement in materials. The mechanical and electrical design is such that larger panels should be possible with added difficulties attendant to the increase in size.

APPENDIX I

APPLICATION OF LAYERS IN LIGHT AMPLIFIER CONSTRUCTION*

1. Epoxy spray stock mix

A. Combine:

- (1) 180 grams Hysol 6101B epoxy¹
- (2) 120 grams diacetone alcohol
- (3) 30 grams toluene
- (4) 18 grams ethyl acetate

B. Store at room temperature

2. Blue or yellow phosphor spray mix

A. Combine:

- (1) 2 parts by weight epoxy spray stock mix.
- (2) 1 part by weight RCA F-2102 blue emitting electroluminescent phosphor or RCA F-2099 yellow emitting electroluminescent phosphor.

B. Blend at high speed in a blender for 2 minutes.

*The materials used in the construction of these panels are toxic, and all care should be taken not to ingest or inhale either the raw materials of the panel or waste from machining operations. The materials which are known to be toxic are: Electroluminescent phosphor-zinc sulfo-selenide; conducting layer-cadmium sulfide; photoconductor-cadmium sulfide, cadmium selenide. Other materials should be handled with normal precautions.

¹Houghton Laboratories, Inc. 322 Houghton Avenue, Olean, New York

C. Ball mill for one hour before each use.

D. Store at room temperature.

3. Opaque layer spray mix

A. Combine:

(1) 1 part by weight amorphous carbon black

(2) 25 parts by weight epoxy spray stock mix

B. Blend at high speed for 2 minutes.

C. Ball mill for one hour before each use

D. Store at room temperature

4. Casting epoxy stock mix

A. Combine:

(1) 100 parts by weight diacetone alcohol

(2) 10 parts by weight Ciba Araldite epoxy resin 502²

(3) 1 part by weight Ciba Araldite hardener 951²

B. Store at 30 to 40°F (refrigerator)

C. Discard after one month.

5. Conductive silver spray

A. Combine:

(1) 2 parts by weight DuPont Conductive Silver No. 4817³

²Ciba Products Corporation, Kimberton, Pa.

³E. I. DuPont de Nemours and Co. Inc. Electrochemicals Department.
Wilmington, Delaware.

- (2) 1 part by weight toluene
 - (3) 1 part by weight xylene
 - B. Store at room temperature
 - C. Mix well before using
6. Application of blue phosphor
- A. Using masking tape, mask the selectively evaporated aluminum-coated glass plate so that only the aluminum lines and the spaces between them are exposed.
 - B. Spray blue phosphor mix on the glass plate at room temperature using an air spray gun with 25 psig pressure. Make the spray as wet as possible without causing the phosphor to run off the glass plate. Illuminate the plate from behind to help in maintaining uniformity. Correct thickness is obtained in about 20 to 30 seconds of spraying. This corresponds to about .001" thickness after curing.
 - C. Remove the masking tape and allow the plate to dry partially on a 40° to 50°C hotplate for from one to five hours.
 - D. Clean the spray gun with diacetone alcohol and acetone.
 - E. Bake the plate in an oven, preheated to 180°C, for 30 minutes to cure the epoxy resin.
7. Application of the yellow phosphor
- A. After the alternate blue phosphor lines have been removed, mask the plate with masking tape so that the entire face of

the plate with the exception of two bands, 3/16" wide at the ends of the lapped grooves, is exposed.

- B. Spray the yellow phosphor, dry, and cure in the same manner as was done with the blue phosphor.
8. Application of the opaque layer
 - A. After the two-color phosphor plate is lapped to a uniform thickness and all of the yellow phosphor is removed from the back of the blue phosphor, mask the plate with masking tape so that only the portion that is covered with phosphor is exposed.
 - B. Spray the opaque layer fairly wet under a pressure of 25 psig until the plate appears to be opaque when illuminated from behind by a 100 W light bulb. Then dry and cure the layer in the same way as for the phosphor layers.
 9. Application of current diffusing layer
 - A. Build a dam .01" high on the opaque layer to contain the epoxy-conducting powder mixture. The area enclosed should extend to 1/2" from the edges of plate at which the phosphor lines terminate and 3/16" from the edges which are parallel to the phosphor lines. Make the dam from one layer of Scotch Electrical Tape No. 33, and one layer of Scotch Cellophane Tape.
 - B. Mix an appropriate amount of RCA F-2108 cadmium sulfide

conducting powder with enough of the casting epoxy stock mix to make a very fluid paste.

- C. Pour the paste onto the plate and using a straight edge which may be a piece of gauge stock with the edges rounded, spread the mixture until it is level with the top of the dam.
- D. Allow to dry for at least 3 hours, then place on 55°C hotplate to cure for at least eight hours. Remove the tape after the epoxy has cured.

10. Application of the cadmium selenide layer

- A. After the current diffusing layer has been machined flat (.005" above the glass surface) build another dam to contain the first photoconducting layer. This dam, about .030" high is made from four layers of Scotch Electrical Tape No. 33. It should enclose the entire current diffusing layer and a strip about 5/16" wide at the edge of the plate at which the cadmium selenide photoconductor lines are to be connected. Care should be taken that there are no holes at the tape joints through which liquid could escape.
- B. Fifty-five grams of cadmium selenide photoconducting powder are required for a 6" x 6" panel. Mix in enough casting epoxy stock mix to make a very liquid paste as before. It is very important that the paste contain no air bubbles.

Wet the current diffusing layer thoroughly with casting epoxy stock mix, but remove all excess liquid before applying the photoconductor paste. Spread the photoconductor paste in the same manner as the current diffusing layer paste.

C. Dry and cure in same manner as the current diffusing layer.

11. Application of the cadmium sulfide

A. After the cadmium selenide conductive layer has been machined flat to .024" above the glass surface and grooved, build a dam to contain the cadmium sulfide photoconductor layer. This dam should stand .025" above the glass surface on the edges parallel to the phosphor lines and .035" above the glass surface on the edges at the ends of the phosphor lines. The dam must be made from a material that will resist the pentachlorethane solvent, such as Permacel Electrical Tape No. EE384.⁴ The dam should enclose the entire cadmium selenide photoconductor layer plus a strip about 5/16" wide at the edge of the plate at which the cadmium sulfide photoconductor lines are to be connected.

B. Mix a suitable amount of RCA F-2103 cadmium sulfide photoconducting powder with a 5% solution of polystyrene in pentachlorethane to form a very fluid paste being careful to

⁴Permacel-Lepages Inc., New Brunswick, New Jersey

avoid air bubbles. Wet the substrate thoroughly with the 5% polystyrene solution, and remove the excess liquid. Spread on the photoconductor paste using first the lower dam walls as a guide, then the higher walls, adding paste as necessary. Allow to settle for about 15 minutes, in a closed container. Then scrape off the excess liquid using the lower dam walls and spread on new paste using the higher walls. Repeat this process several times.

- C. Allow to dry slowly at least for one day, then bake out on a 55°C hotplate for another day. Remove the tape when dry.

12. Application of conducting silver

- A. After the interdigital photoconductor layers have been machined flat to .018" above the glass, mask the panel 1/16" in from the boundary of the photoconductor layer.
- B. Before spraying, heat the panel with an infrared lamp until it is hot to the touch. Spraying of the silver is very critical because the solvents will destroy the photoconductivity of the photoconductor if allowed to penetrate, and the silver will flake when machined if it is sprayed too dry. Use low pressure (15 psig) and spray relatively dry at first, then increasingly wet. There is sufficient silver when the resistance between two pressure contacts on the surface is less than 50 ohms.
- C. Clean the gun with toluene and acetone.

APPENDIX II

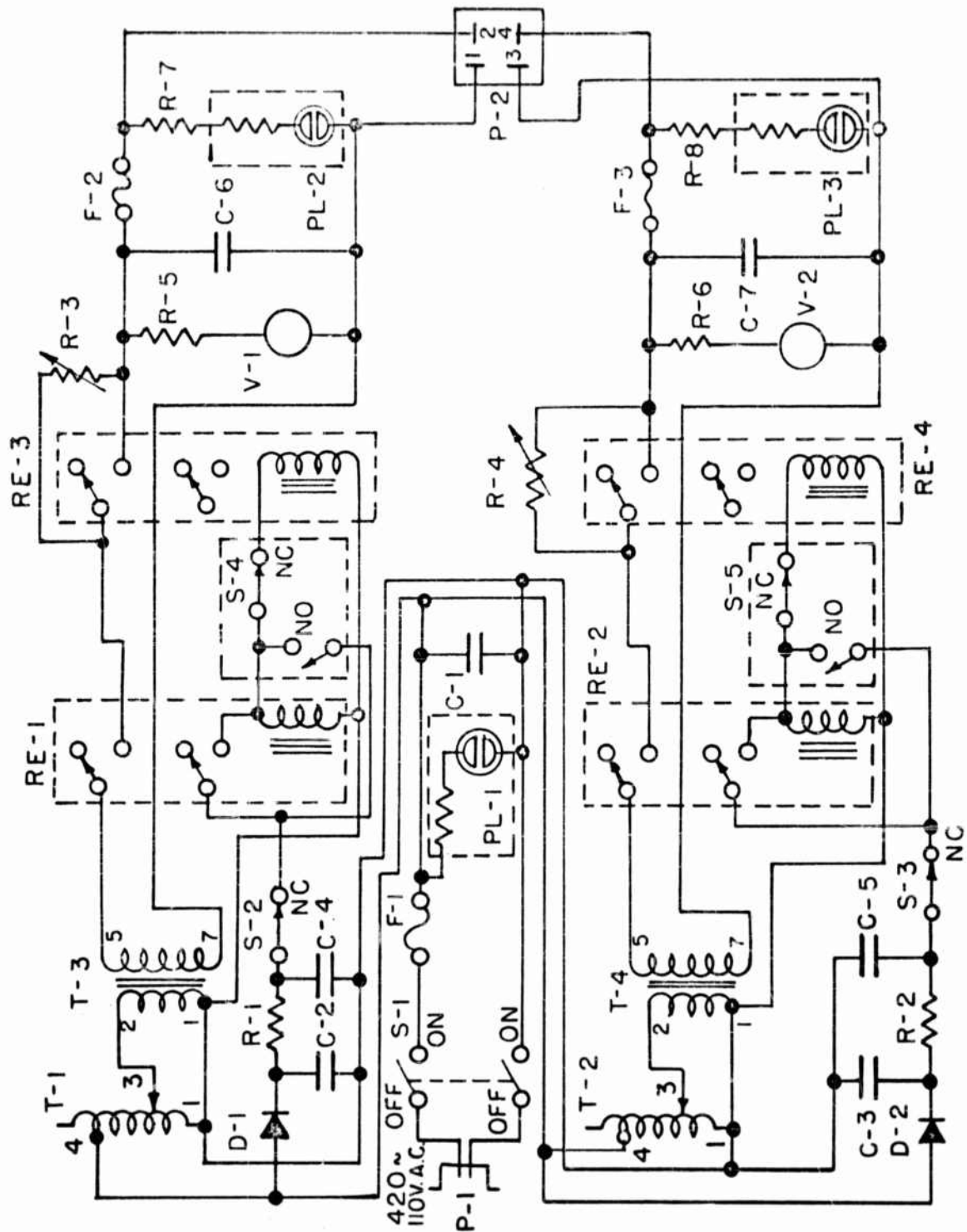
PREPARATION OF ROSE BENGAL FILTER

- A. Prepare a saturated filtered solution of Rose Bengal dye⁵ in diacetone alcohol.
- B. Mix six drops of the concentrated Rose Bengal solution with 55 grams of Ciba Araldite .502 epoxy avoiding bubble formation Mix in 5.5 grams Ciba Araldite hardener 951 just prior to use.
- C. Preparation of mold
 1. On a clean sheet of 1/4" plate glass, apply .015" thick tape spacers (two layers of Scotch Electrical Tape No 33), leaving enough room between the spacers for the size of filter desired.
 2. Apply a thin coat of Aritemp Mold Release⁶ to this glass plate and to another 1/4" sheet of plate glass. Polish clear with soft but lint free paper or cloth.

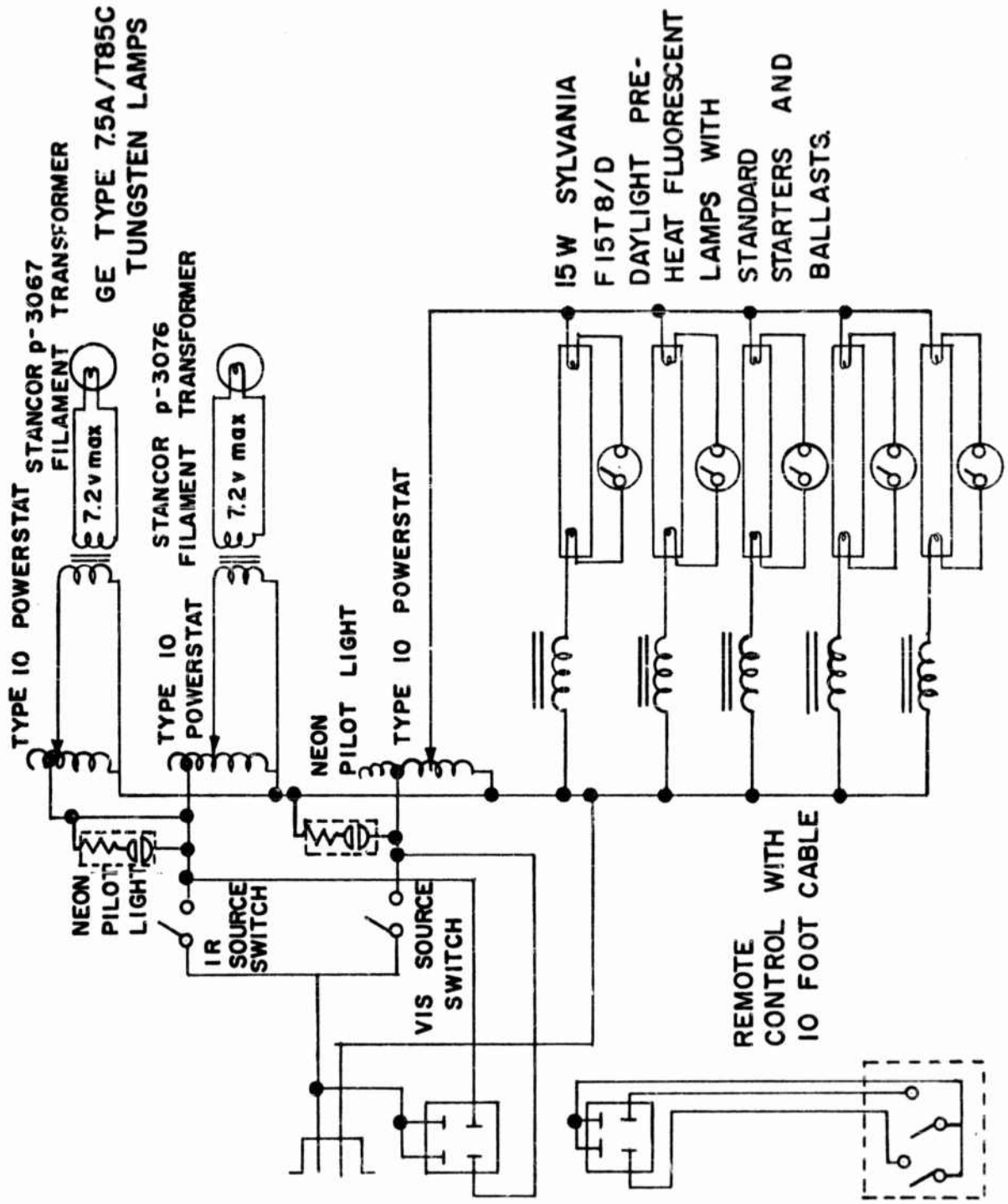
⁵Allied Chemical and Dye Corporation, 40 Rector Street, New York 6, New York.

⁶Aries Laboratories, Inc., 45-33 Davis Street, Long Island City 1, New York.

- D. Pour the dye-epoxy mixture onto the glass plate with spacers and squeeze the epoxy level with the other plate again avoiding bubble formation.
- E. Allow to cure with weights holding the top glass plate in place. Keep in darkness during curing to prevent fading.
- F. Remove filter from mold when the epoxy is firm enough to peel without stretching.



APPENDIX IV



CIRCUIT DIAGRAM OF LIGHT BOX

APPENDIX V

CATALOG OF EQUIPMENT

USAF-5509-1	Two-projector light amplifier setup less projectors
USAF-5509-2	Two-color electroluminescent panel demonstration
USAF-5509-3	Camera box
USAF-5509-4	Flat field illuminator
USAF-5509-5,6	3" x 3" two-color input two-color output amplifier (supplied to contractor)
USAF-5509-7	6" x 6" two-color input two-color output light amplifier
USAF-5509-8	Power supply for two-color amplifiers
USAF-5509-9	4" x 5" Graflex adaptor back
USAF-5509-10	Image Source for testing amplifiers
USAF-5509-11	6" x 6" two-color input two-color output light amplifier

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