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SOLID STATE RADIOGRAPHIC IMAGE AMPLIFIERS

FINAL REPORT Phase A-

Word done by: Zoltan Szepesi
Michael Novice
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OCT 1969
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Prepared for:

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

Contract No.: NAS8-21206

Approved by: R A Shaffer
R. A. Shaffer, Manager
Image Tube R & D Dept.

MAY 1968

WESTINGHOUSE ELECTRIC CORPORATION
ELECTRONIC TUBE DIVISION
ELMIRA NEW YORK

FACILITY FORM 602

N70-11281	
(ACCESSION NUMBER)	(THRU)
35	1
(PAGES)	(CODE)
NASA CR-102299	14
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

SQ759098

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SECTION I

INTRODUCTION

This report gives an account of the work performed on Contract No. NAS8-21206 from July 1, 1967 to April 30, 1968. It describes the design, the fabrication process, characteristics and testing procedure of the radiographic image amplifier which was delivered to the Marshall Space Flight Center.

The work on this program was performed at the Electronic Tube Division of the Westinghouse Electric Corporation in Elmira, New York by M. A. Novice, T. G. Keeton, C. A. Lepkowski and M. M. Morseman with Z. Szepesi as project engineer. Managerial supervision was provided by G. W. Goetze, R. A. Shaffer, and A. B. Laponsky. The report was written by Z. Szepesi.

SECTION II

TECHNICAL DISCUSSION

The brightness of a fluoroscopic (Patterson) screen, used for the direct observation of a radiographic image, is very low. This is true even when high X-ray intensities are employed. To increase the image brightness and/or diminish the X-ray intensity, vacuum tube type X-ray image intensifiers were developed which can be used for direct viewing or in combination with a closed circuit TV system for remote observations. Direct X-ray sensitive camera pick-up tubes of the vidicon type are also available for small area radiographic examinations. The objectionable characteristics of all these systems are the limited size or excessive weight, the intricate electronic circuitry needed and the high expense of the equipment.

With the advent of solid state display techniques, it is possible to fabricate a flat, light weight, large size, direct viewing and comparatively inexpensive X-ray image intensifier. Though some characteristics of this solid state radiographic amplifier display panel are inferior to those of the vacuum tube type systems and restrict their application, the development of appropriate characteristics for radiographic non-destructive testing seemed within the reach of the present state-of-the art.

A. Objectives

The goal characteristics of the radiographic image amplifier for non-destructive testing are listed in Table 1. A radiographic amplifier with characteristics approaching those of Table 1 had to be delivered to the Marshall Space Flight Center at the end of the work.

Table 1. Goal Characteristics of Radiographic Image Amplifiers

Characteristics	Specification
Size of active area	75 in^2 minimum
Resolution	1000 TV line minimum
X-ray intensity range	1 to 100 r/min. from a 60 keV X-ray source
Maximum output brightness	1 ft-L minimum
Contrast sensitivity	2% aluminum penetrameter
Rise time constant	10 sec maximum
Storage time	10 min minimum
Erasure time	5 sec maximum

Also a self-contained solid state power supply with rechargeable batteries had to be delivered. The weight of the complete system could not exceed 10 pounds and the volume 1 cubic foot.

B. Method of Approach

1. Principles of Solid State Intensifiers

The most promising construction of a solid state radiographic intensifier involves the use of an X-ray sensitive semi-conductive; i. e. photoconductive (PC) detector and an electroluminescent (EL) light emitter. It has been found that PC materials highly sensitive in the visible region of the spectrum are also the most sensitive for X-ray photons.

The fundamental principle of the PC-EL radiographic intensifier element can be demonstrated by the series connection of an X-ray sensitive PC and EL cell as Figure 1 shows. If the dark resistance (at $X_{inp} = 0$, when no X-rays are incident on the PC element) of the PC cell is high, and the capacitance ratio $p = C_2/C_1$ is high, the impedance ratio of the PC cell to the EL cell will be high. In this case, the voltage distribution is such that the EL cell has very low voltage; therefore, the light output is very low. When the X-ray intensity increases, the impedance of the PC cell decreases, the voltage on the EL cell increases and the light output B_{out} increases. If the appropriate impedance and sensitivity conditions are satisfied, the brightness of the EL cell could be much higher than that of a fluoroscopic screen.

In the case that the PC cell is sensitive to the light of the EL cell, the feedback light from the EL to the PC cell has to be eliminated by the application of an opaque wall between the two cells.

By building a two-dimensional mosaic of such intensifier elements, or simply sandwiching continuous PC and EL layers between two electrodes, a radiographic intensifier panel can be constructed.

A wide variety of intensifier panel constructions has been patented, but the sandwich type construction as shown in Figure 2, is by far the simplest and most ideal way of building radiographic image intensifiers.

Such image intensifiers have been developed and described (see Ref. 1 to 12). The most objectionable characteristics of these intensifier panels for radiographic application were their slow response (build up and decay time constants in the order of minutes) and low sensitivity (about 1 r/min X-ray intensity with 100 keV) when CdS was used as the sensing element. With special construction and circuitry, the erasure time could be diminished to a few seconds. But using CdSe instead of CdS, build-up times of seconds and decay times of tenths of a second were reached with the simple sandwich type construction at around 1 r/min X-ray intensity. At higher radiation intensities, the response time is still shorter.

Another problem of these solid state image intensifiers is their resolution limit which depends on the thickness of the layers in the sandwich construction. However, a resolution of the order of 200 lines/inch was reached in practice.

A specially worthy characteristic of the solid state radiographic intensifier for non-destructive testing application is its high contrast. Contrast values (γ) in excess of three are easily attainable due to the exponential brightness vs. voltage dependence of the EL layer and due to the possibility of having a superlinear relation in the current vs. X-ray intensity of the PC layer.

C. Storage

Special consideration is needed in the discussion of the temporal characteristics of the radiographic amplifier. As it is seen in Table I, a fast response, slow decay (storage) and fast erasure time is required for the practical application.

These characteristics depend principally on the sensing (PC) material. The PC material, used in our previous work (Ref. 5 to 10) was cadmium selenide, which needs a reasonably short exposure time (rise time constant), but has no storage (fast decay time).

Various ways for obtaining storage in solid state image intensifiers were already described in a number of publications which may be summarized as follows:

(1) Using a long persistence photoconductor as the sensing material offers the simplest solution. Published data (Ref. 1-4) on cadmium sulfide photoconductors suggest the use of this material. However, the long erasure time associated with the storage is a highly objectionable characteristic to this approach.

(2) Excellent storage properties of fine grained Zn activated ZnO powders have been described[13]. Kazan and Winslow at Electro-Optical Systems, Inc. are developing a storage intensifier panel for the Army Electronics Command where the sensing material is ZnO[14-17]. The unsatisfactory features of this construction at the present state of the work are: low X-ray sensitivity, low contrast, and some construction problems.

(3) The "Libracoat" display panel, developed by the General Precision Inc., Librascope Group[18-20] is another storage intensifier, using a phosphorescent material with stored latent photoconductivity (probably manganese activated ZnS) for the sensing layer[21]. The presently available panel has a disturbing background light, low contrast, and low sensitivity to X-rays. These characteristics probably could be improved resulting in a practically useful radiographic amplifier system.

(4) Nicoll described the hysteresis and storage properties of specially prepared CdSe material[22]. Using this as a sensing element, a storage amplifier could be built. However, the stability, uniformity and reproducibility have to be improved before a useful display panel can be built with this hysteretic CdSe.

(5) Thorn Electrical Industries, Ltd. in England is marketing an "image retaining panel" which consists of only one layer, has a long storage time, and can be erased rapidly[23-26]. The long storage time (longer than 10 minutes) and fast erasure (shorter than 1 second) are very attractive characteristics of this panel, but its sensitivity and contrast do not satisfy the requirements.

D. Contrast Sensitivity

The contrast sensitivity of the radiographic system, i.e., the ability to detect small thickness differences (defects in practice), depends (1) on the wavelength of the X-ray and (2) on the "contrast" of the image amplifier panel.

The wavelength dependence can be derived from the absorption equation of the X-rays, which expresses the intensity of the X-ray beam after traversing a material of thickness t as

$$L_1 = L_o e^{-\mu t} \quad (1)$$

where L_o is the incident intensity and μ is the absorption coefficient of the material. If an additional small thickness Δt of the same material is attached to the original thickness, the X-ray intensity through this $t + \Delta t$ thickness will be

$$L_2 = L_o e^{-\mu (t + \Delta t)} \quad (2)$$

The ratio of the two intensities is

$$\frac{L_1}{L_2} = e^{\mu \Delta t} \quad (3)$$

This equation shows that the X-ray intensity ratio through different thicknesses of a given material exponentially increases with the absorption coefficient and the thickness difference of the material. Since the absorption coefficient increases with the wavelength, the detection of smaller thickness differences should be possible at longer wavelengths.

Calculating L_1/L_2 for 60 keV X-rays (equivalent wavelength $\lambda = 0.2$Å= 20pm) and for 0.25" (0.635cm) thick 2% aluminum penetrameter, where Δt = 0.005" (1.27×10^{-2} cm), using $\mu = 0.732\ \mathrm{cm}^{-1}$, it is found that L_1/L_2 is about 1.008; i.e., the intensity difference to be detected is about 0.8%. For a 1/2" thick aluminum penetrameter, this value is about 1.6%. If the wavelength of the X-ray source is longer, the X-ray intensity difference is accordingly higher, but with shorter wavelengths (higher X-ray voltage), it is smaller.

The contrast of the image intensifier panel is defined as the γ (gamma) of the transfer characteristic. The transfer characteristic is the curve representing the output brightness (B) as a function of the input intensity (L) and is described by the equation:

$$B = cL^{\gamma} \quad (4)$$

If the transfer characteristic is drawn on a double logarithmic coordinate system, it is similar to the "film density chart" and the contrast is given by the slope of the curve, as can be derived from equation (4):

$$\gamma = \frac{d\ (\log B)}{d\ (\log L)} \quad (5)$$

If the X-ray intensity difference was p%, the output light intensity difference will be $p\gamma$%.

Considering the threshold contrast of the eye, one can have an idea what γ value is needed for the detection of a 2T hole in a 2% 1/4" aluminum penetrameter if λ = 20 pm (60 keV). The size of a 2T hole in the above penetrameter has a diameter of 0.02" (as specified in MIL-STD-453). The viewing angle of this hole from 10" distance is about 6.8 minutes; thus the area is viewed at 46 square minutes. Table 2 contains some data on threshold contrast of the human eye which depends on the viewing angle, intensity and wavelength of the light. The figures at 17.5 ft-L white light illumination were taken from the paper of Lamar et als[27]. The figures of the last two columns were estimated from the curves of Figure 24 of Reference 28. Data of Reference 29 also seem to confirm these figures.

Table 2. Threshold Contrast for Different Spot Sizes and Illuminations, Viewed from 10" Distance

Hole Size on 1/4" or 1/2" Thick 2% Penetrameter	Threshold Contrast		
	White Light		Yellow Light
	17.5 ft-L	1 ft-L	1 ft-L
1T	6%	12%	24%
2T (46 square minutes)	3%	6%	12%
4T or larger	2%	4%	8%

We can see from Table 2 that, to be able to detect a 2T hole in a 1/4" or 1/2" thick penetrameter, one needs a 12% light contrast in yellow light at 1 ft-L, and 6 to 3% in white light (or with colors at the lower waveband of the visible spectrum) at 1 to 17 ft-L.

Since the X-ray intensity difference to be detected is about 0.8% with the 1/4" and about 1.6% at the 1/2" thick penetrameter, a $\gamma = 6$, which could be obtained in practice with a PC-EL image intensifier, would make possible to satisfy the requirements for the contrast sensitivity of the image intensifier provided the output brightness is high enough.

The conditions are still better when detection is made with photons of lower energy (longer wavelength; i.e., lower voltage on the X-ray tube).

SECTION III

DESIGN OF A RADIOGRAPHIC IMAGE AMPLIFIER SYSTEM

After considering the different approaches for meeting the specifications listed in Table I, it seemed that it would be extremely difficult to satisfy all the requirements in one panel. Accepting as a compromise a longer erasure time, the slow decay PC-EL amplifier (see Section II, part C-I) appeared to offer the best solution. Some ideas for diminishing the erasure time supported also the decision to start work with this construction. However, it was soon realized that this system had several shortcomings: (1) inconvenience of the slow rise (too long exposure time); (2) fast loss of resolution, even when the decay time is long. It was also obvious that long storage and high contrast sensitivity are not compatible in this approach. It was found, for instance, that long decay time of the CdS (the PC material used here) can be obtained with high donor and low acceptor impurity concentrations, resulting in a sublinear characteristic of the current vs. X-ray intensity, consequently giving a low gamma in the intensifier panel which is not desirable.

Searching for another approach, an ideal solution appeared possible by separating the requirements for contrast, sensitivity, and speed from those for storage and fast erasure time. This could be realized by cascading two panels, each of which satisfies one group of the requirements. The first panel should give high contrast, sensitivity, and speed and the second panel should offer the storage.

The PC-EL image intensifier with CdSe sensing layer as developed in an NTDC supported program[5-10], after some development work, could offer the characteristics required for the first panel and a Thorn image retaining panel could serve as second panel. This combination system would ideally combine reasonably fast exposure with long storage and fast erasure; it would have enough gain and high contrast sensitivity also. However, the brightness of the Thorn panel is somewhat low and the color is not the optimum for the best contrast threshold. These characteristics could probably be improved in further development work.

Therefore, at the beginning of the second phase of this work, it was decided to follow the above approach: (1) to develop a PC-EL sandwich type image intensifier with good radiographic sensitivity, reasonably fast exposure time and high contrast sensitivity; (2) to cascade this panel with a Thorn image retaining panel as shown in Figure 3. When the Thorn panel is touching the output side of the image amplifier, only the thin cover glass separates the two panels. This cover glass should be as thin as possible to diminish the loss of resolution. It seemed that a 0.003" thick microsheet glass (Corning type 0211) would not significantly diminish the 180 lines/inch resolution.

The characteristics of the developed PC-EL panel are discussed in the next section. The preparation method of the PC and EL layers and the fabrication schedule is described in Appendices A, B, and C. Appendix D specifies the cleaning method of the substrate glass. The characteristics of the storage panel are to be found in Reference 23.

SECTION IV

CHARACTERISTICS OF DEVELOPED RADIOGRAPHIC IMAGE AMPLIFIER SYSTEM

The radiographic amplifier system is composed of three parts:

(A) the PC-EL image amplifier
(B) the image retaining panel (Thorn)
(C) the power supply unit.

A. PC-EL Image Amplifier

The specific characteristics of the delivered PC-EL image amplifier are listed in Table 3.

Table 3. Characteristics of Delivered Image Amplifier Panel

Characteristics	Data
Size of active area	75.5 in.^{2} (7-3/4" x 9-3/4"
Size of glass substrate	8" x 10.25"
Size of frame, holding panel	8-3/4" x 10-3/4" x 1/2" (outside dimensions)
Resolution	1400 TV lines (180 lines/inch)
X-ray intensity range	2 x 10^{-1} to 20 r/min (60 keV X-ray source)
Maximum output brightness	7 ft-L at 115 V, 400 Hz
Contrast sensitivity	3% on 0.4" Al at 50 keV
Rise time constant	0.5 to 5 sec, depending on X-ray intensity
Decay time constant	0.1 to 0.5 sec

Comparing Table 3 with Table 1, it is seen that all the goal characteristics of the radiographic image amplifier were surpassed, excepting the contrast sensitivity.

The data of Table 3 are those of the PC-EL panel without the storage panel. The attachment of the Thorn image retaining panel results in attaining a storage time of about 10 to 20 minutes, in increasing the rise time to about 10 to 20 seconds, and in decreasing somewhat the resolution. The erasure time is less than 1 second.

Figure 4 shows the transfer characteristic curves of the delivered image intensifier (No. II-936). They are drawn on double logarithmic coordinate system, both for visible input light (2870°K color temperature), and for X-rays generated by a self-rectifying tube with 60 kV peak voltage. Measurements were made at 60, 400, and 2000 Hz driving voltages on the image amplifier for the visible light, but at 400 Hz only for the X-rays.

Figures 5 and 6 show photographs of output images taken from the image amplifier. The input for Figure 5 was a projected slide with a standard TV test pattern, while for Figure 6, an etched thin stainless steel metal sheet was irradiated with X-rays (50 kV peak). On the radiographic picture, one sees clearly the fine lines of the scale having a width of about 0.004'' and the holes of the shadow mask with 0.010'' diameter.

The panel II-936 was covered with a 0.01'' thick microsheet glass. This thickness caused too much degradation of the resolution when the storage system was used. Therefore, another smaller size (3'' x 3'') image amplifier (II-937) was also delivered. Its characteristics were similar to those of II-936, except that the gain was somewhat higher and the uniformity (background spottiness) was better. This panel was covered with a 0.005'' thick microsheet glass.

B. Image Retaining Panel

A 7'' x 9'' image retaining panel, made by Thorn Electrical Industries, Ltd, was also delivered. The characteristics of this panel were described in Reference 23.

C. Power Supply Unit

The circuit diagram and the list of components of the power supply unit, which was delivered to the MSFC, are shown in Figures 7a and 7b.

The power supply proper (PS on Figure 7a) is a sealed unit made by Abbott Transistor Laboratories, Inc. It satisfies environmental testing specifications MIL-E-5272C. It is powered by a 30 volt Ni-Cd rechargeable battery of about 0.75 A-hour capacity. It delivers 400 Hz, 115 V and about 200 mA. The output voltage can be changed from zero to 115 V with a powerstat. A battery charger is also built into the unit. One full charge is sufficient for about 30 minutes continual operation.

Figure 8 is a photograph of the power supply and image amplifier panel.

SECTION V

DISCUSSION, RECOMMENDATIONS

A radiographic image amplifier system was developed consisting of PC-EL sandwich type image amplifier and an image retaining panel in cascade. This system ideally combined reasonably short exposure time with long storage and fast erasure, had good gain and high contrast sensitivity.

This radiographic system is designed for the direct viewing of radiographic images and serves as a substitute for the photographic or fluoroscopic method of radiography. It can be used in two different ways: (a) as an instantaneous fluoroscopic amplifier, using the PC-EL panel alone and (b) as a storage system cascading the PC-EL amplifier and the image retaining panel. In the latter case, the proper X-ray intensity to be used for optimum imaging has to be experimented on the PC-EL panel first. Placing the image retaining panel on top of the PC-EL panel, the PC-EL panel can be switched off after about 10-20 second exposure time. The image retaining panel can be removed and a mirror image can be viewed for about 5 to 10 minutes. Disconnecting the voltage on the image retaining panel erases the picture and it can be used again for another radiographic image.

The development of the PC-EL amplifier panel was based on techniques resulting from a program on light sensitive image intensifiers, supported by the Naval Training Device Center, Orlando, Florida (Ref. 5-10). The image retaining panel was bought from Thorn Electrical Industries, Ltd.

The results of the reported contract were improvements in:

(1) picture quality (lower graininess and spottiness)
(2) contrast sensitivity (3% detected)
(3) size (8" x 10-1/4")
(4) incorporating storage with long holding and fast erasure times.

This system is, at present, useful for some radiographic applications. However, to increase the field of applications, the following are recommended:

(1) improve further the spottiness and uniformity
(2) increase the contrast sensitivity to detect a 2T hole in a 1/4" to 1/2" thick 2% aluminum penetrameter.
(3) integrate the storage panel with the amplifier panel
(4) eliminate the effect of ambient light
(5) construct the system from space qualified components.

To satisfy requirement (2), it is recommended to cascade a light sensitive PC-EL image intensifier with the storage panel (proposed by R. L. Brown of NASA). This goal and goal No. 3 could be more easily satisfied if an all plastic construction of the amplifier panel system would be developed. Therefore another goal is:

(6) development of plastic embedded photoconductors and storage phosphors.

It is believed that there is a high probability that all these goals can be reasonably approached with an effort of about 6 man-year program.

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APPENDIX A

PREPARATION OF SINTERED CdSe PC LAYERS

The preparation of the sintered CdSe layer can be divided into three parts. Accordingly, the schedule of preparation is described below:

a. Mixing and Prebaking the Powder.

1. Weigh 90 grams of CdSe and 10 grams of CdS powder (G.E. electronic grade) and mix it in a pyrex beaker.
2. Place the well mixed powder in a quartz boat and heat it slowly in nitrogen atmosphere until the temperature reaches 1075°C. Bake it for 30 minutes at this temperature and cool down still in nitrogen atmosphere.
3. Grind the material in diamonite mortar.
4. Weigh 4 grams of dry $CdCl_2$, place it in a 100 ml pyrex beaker and dissolve it in about 20 ml deionized water.
5. Weigh 10 milligrams of $CuCl_2 + 2\ H_2O$ (Fisher Certified), transfer to a clean 15 ml beaker and dissolve it in about 5 ml deionized water.
6. Add enough deionized water to the CdSe + CdS baked powder to form a very thick paste.
7. Add the $CdCl_2$ solution to the CdSe + CdS paste with thorough stirring.
8. Add the $CuCl_2$ solution to the CdSe-CdS-$CdCl_2$ mixture with thorough stirring.
9. Evaporate the water from the mixture in a forced draft oven at 100°C.
10. Prebake at 505°C for 1 hour in a quartz dish with a cover.
11. After cooling, grind the material in a diamonite mortar, and sieve through a 200 mesh screen.

b. Settling

1. Weigh about 50 grams of the prepared CdSe-CdS powder, transfer it to a ceramic ball milling jar, mix about 100 ml Xylene to it and ball mill for five to sixteen hours.
2. Clean the substrate glass plates as described in Appendix D.
3. Place the substrate glass plates in a perfectly horizontal plane at the bottom of a 10" x 12" glass jar.
4. Fill the jar with a 0.1% ethyl cellulose Xylene solution to about 5" height above the substrate glasses.
5. Pour the ball milled PC mixture in the settling jar and let it settle until the Xylene clears up (about 1 to 2 hours).
6. Siphon off cushion and let panels dry in tank 10 to 16 hours.
7. Remove panels from tank and preheat slowly to about 100°C on a hot plate for about half hour.
8. Transfer panels to forced air oven and bake at 135°C for 1/2 hour.

c. Sintering

1. Place panel on a Vycor Plate and cover with a pyrex dish.
2. Bake in a furnace of 510°C for 40 minutes.
3. Remove panel from furnace and allow to cool under a strong airflow on the pyrex dish.

APPENDIX B

PREPARATION OF PLASTIC EMBEDDED EL LAYERS

The EL layers were deposited by spray coating. A "deVilbiss" type EX spray gun with suction feed and a pressure of 18 psi nitrogen was normally used.

The schedule of the preparation of the EL layer was the following:

1. Spray a layer of spray mixture No. 1 (see below) onto the substrate. The layer should be good and wet but not running.
2. Let the layer air dry for a minute or two and bake it in a forced air furnace at 135°C for 10 minutes.
3. Repeat steps 1 and 2 three to four times so that altogether four to five EL layers were sprayed.
4. Bake for 30 minutes instead of 10 after the spraying of the last layer.
5. Spray a thin layer (3 to 4 layers) of clear coat (mixture no. 2) on top of the phosphor layer for increased electric strength and smoother surface.
6. Give a final heat cure of 30 minutes at 135°C.
7. Evaporate a semi-transparent conductive lead-oxide and gold film in high vacuum on top of the sprayed layers. With a substrate to boat distance of 18 inches, 64 mg of PbO is evaporated first, followed by the evaporation of the Au. Latter evaporation is monitored by measuring the resistance of the deposited layer on a microscope slide and the evaporation is stopped when this resistance is about 50 ohms/square.

Composition of spray mixtures:

(1) Phosphor-plastic spray mixture:
27g Westinghouse VB-241P EL phosphor.
90 ml 5% solution of cyanoethyl starch (CS)*
90 ml 5% solution of cyanoethyl sucrose (CES)*

(1a) Plastic solutions (5%)
40g plastic (CS or CES)
220 ml dimethyl formamid (DMF)
580 ml acetonitrile

(2) Clear coat:
1:1 mixture of 5% CS and 5% CES solutions (see formula 1a)

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*Sold by Eastman Chemical Corporation

APPENDIX C

FABRICATION SCHEDULE OF RADIOGRAPHIC IMAGE AMPLIFIER

1. Substrate Preparation
   - a. Clean panel as described in Appendix D.
   - b. Platinum coat center two-thirds of two opposing edges.
   - c. Fire platinum coat at 525°C - 1 hour in air.

2. Settling of the PC powder.

   See Appendix A, part (b).

3. Sintering

   See Appendix A, part (c).

4. Evaporate 1.5g CdSe at 18 inch distance in high vacuum on top of the sintered CdSe layer.

5. Spray 3 layers of 5% Ucilon.

6. Bake in forced air oven at 135°C for 30 minutes.

7. Brush 3 layers of 25% Ucilon on 4 edges.

8. Repeat step 6.

9. Spray 4 layers of green EL phosphor Westinghouse type VB241-P and 3 layers of clear coat (steps 1 to 6 of Appendix B).

10. Brush 3 layers of clear coat on 4 edges only.

11. Bake 135°C for 30 minutes in forced air oven.

12. Apply Emerson Cumings V-91 silver epoxy to two opposing edges, not covered with platinum, with rubber pad applicator. This will connect to evaporated gold.

13. Bake 135°C for 1 hour.

14. Evaporate top transparent gold electrode PbO + Au (step 7 of Appendix B).

15. Pretest
    a. Sensitivity
    b. Time response
    c. Imperfections, spots, bright edges

16. Cover electrode edges on substrates with 1/16 inch wide masking tape to protect electrode from epoxy.

17. Spray 15 coat Ucilon on top of gold.

18. Bake panel for 30 minutes at 100°C.

19. Apply appropriate amount of Emerson-Cummings #1266 epoxy to the center of the coated substrate.

20. Place a precisely cut cover glass against the epoxy on substrate and carefully align.

21. Wipe excess epoxy from edges as it squeezes out and apply a flat plate, larger than the panel, on top of cover glass, heavy enough to hold cover glass parallel and near the panel.

22. Allow to cure at room temperature for 16 hours and remove excess epoxy with razor blade, taking care not to damage electrodes.

23. Remove masking tape from edges.

24. Attach wires to two electrodes (one to tin-oxide, other to gold) with Emerson-Cumings V-91 silver epoxy.

APPENDIX D

CLEANING OF GLASSWARE AND SUBSTRATES

1. Place glass in a beaker of deionized water dependent upon the size of the piece and rinse thoroughly by overflow.

2. Drain off the rinse water to allow introduction of approximately 5-10% water solution of each of formic acid and hydrogen peroxide. The following solution was generally used:

   1250 cm^3 water
   100 cm^3 formic acid
   250 cm^3 hydrogen peroxide

3. Heat this solution to the 70-80°C range, being careful not to allow the temperature to exceed 80°C. When over 75°C has been reached, remove the beaker from the hot plate and allow to react at least for 30 minutes. The temperature will maintain itself for this period in a useful range. At the end of this time overflow deionized water rinse for 15 minutes.

4. Ultrasonic clean in deionized water for 5 minutes.

5. Ultrasonic clean in electronic grade isopropanol for 5 minutes.

6. Place glass piece above a boiling isopropanol, where it will heat up and when taken out dries immediately.

APPENDIX E

TESTING PROCEDURE OF IMAGE AMPLIFIERS

The sensor (PC) layer of the radiographic image amplifier detects the visible and near infrared region of light also. Characteristics measured in this light region are correlated to those in the X-ray region. Since some measurements are more conveniently carried out with light than X-rays, they were frequently used in testing the radiographic amplifier. Specifically, tungsten light (mostly 2870 K color temperature) was used in measuring the resolution, transfer characteristic curves, spottiness, graininess and uniformity of the image amplifier. A few points of the transfer characteristic curves and the contrast sensitivity were measured with X-rays.

Specifications of the testing procedure are described in the following. The usual driving voltage and frequency of the image amplifier were: 115 Volts and 400 Hz, unless otherwise specified.

(1) Resolution. A RETMA TV resolution chart was projected with a slide projector onto the image amplifier and the resolution limit was evaluated visually from the output image.

(2) Transfer Characteristic Curves.

(a) A 2870K color temperature tungsten light source with continually changeable calibrated light intensity was used for input at intensities of 10^{-2}, 2×10^{-2}, 5×10^{-2}, 10^{-1}, 2×10^{-1}, and so on. The output brightness was measured with a Spectra brightness meter, type UC1/2. Curves with driving frequencies of 60, 400, and 2000 Hz were measured.

(b) The X-ray output of a 50 keV self-rectified X-ray generator was used for 3 points of the transfer characteristic curves at 400 Hz driving frequency on the image amplifier. The

X-ray intensity was measured with a Victoreen electrostatic dose-meter.

(3) The contrast sensitivity was evaluated visually by imaging a set of 4 aluminum discs 0.1 inch thick each, having about 1/4" x 1/2" size holes corresponding to 3, 4, 5, and 6% defects.

(4) Time Constants. The time constants were measured with visible light at around the center point of the transfer characteristic. The equipment used for these measurements was: a millisecond fast pneumatic shutter on the calibrated light source (used in test procedure (2a), and a storage cathode ray oscilloscope. The measurement of the storage time and erasure time of the image retaining panel did not need any special equipment.

APPENDIX F

ILLUSTRATIONS

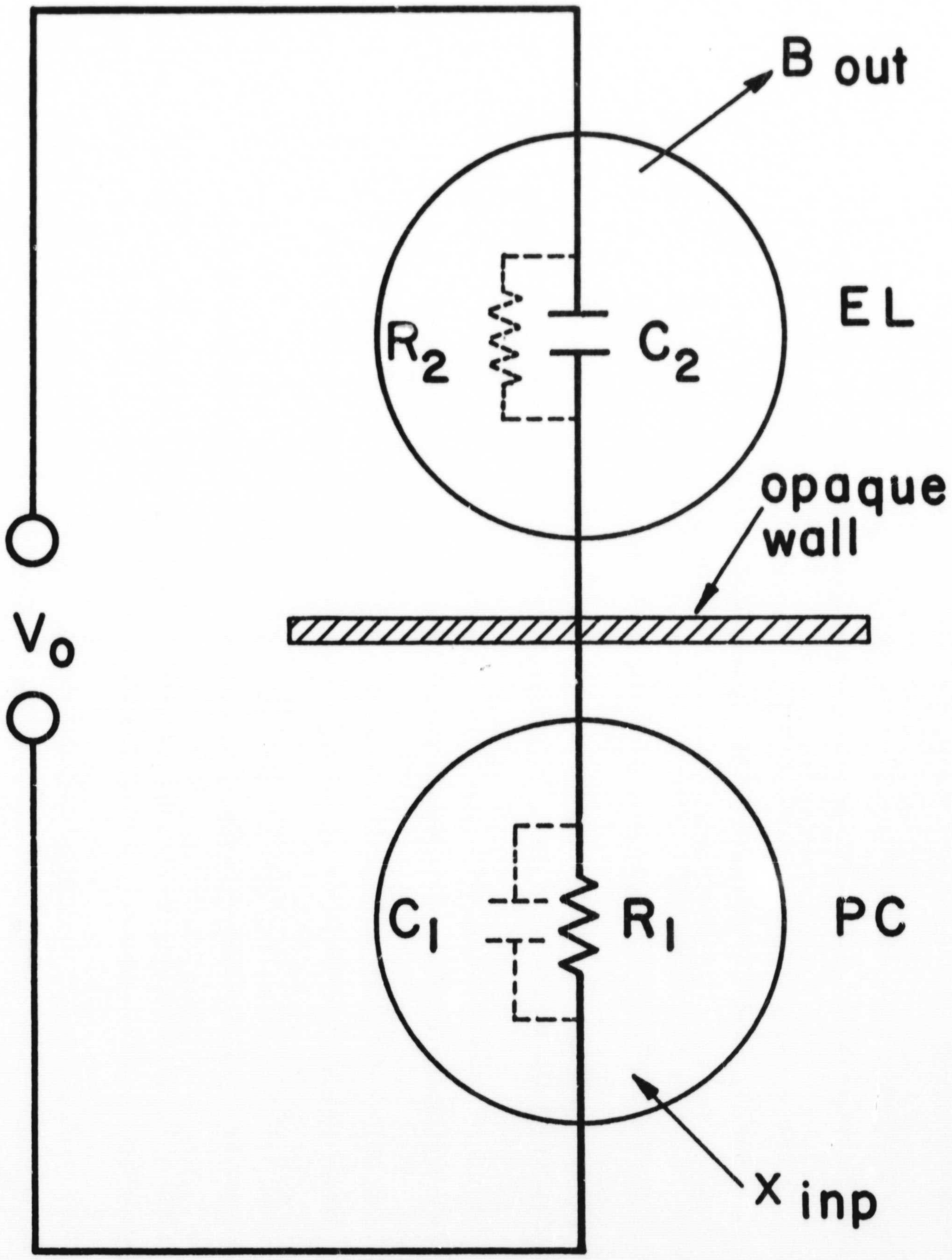

Figure 1. Basic Circuit of PC-EL Radiographic Intensifier Elements

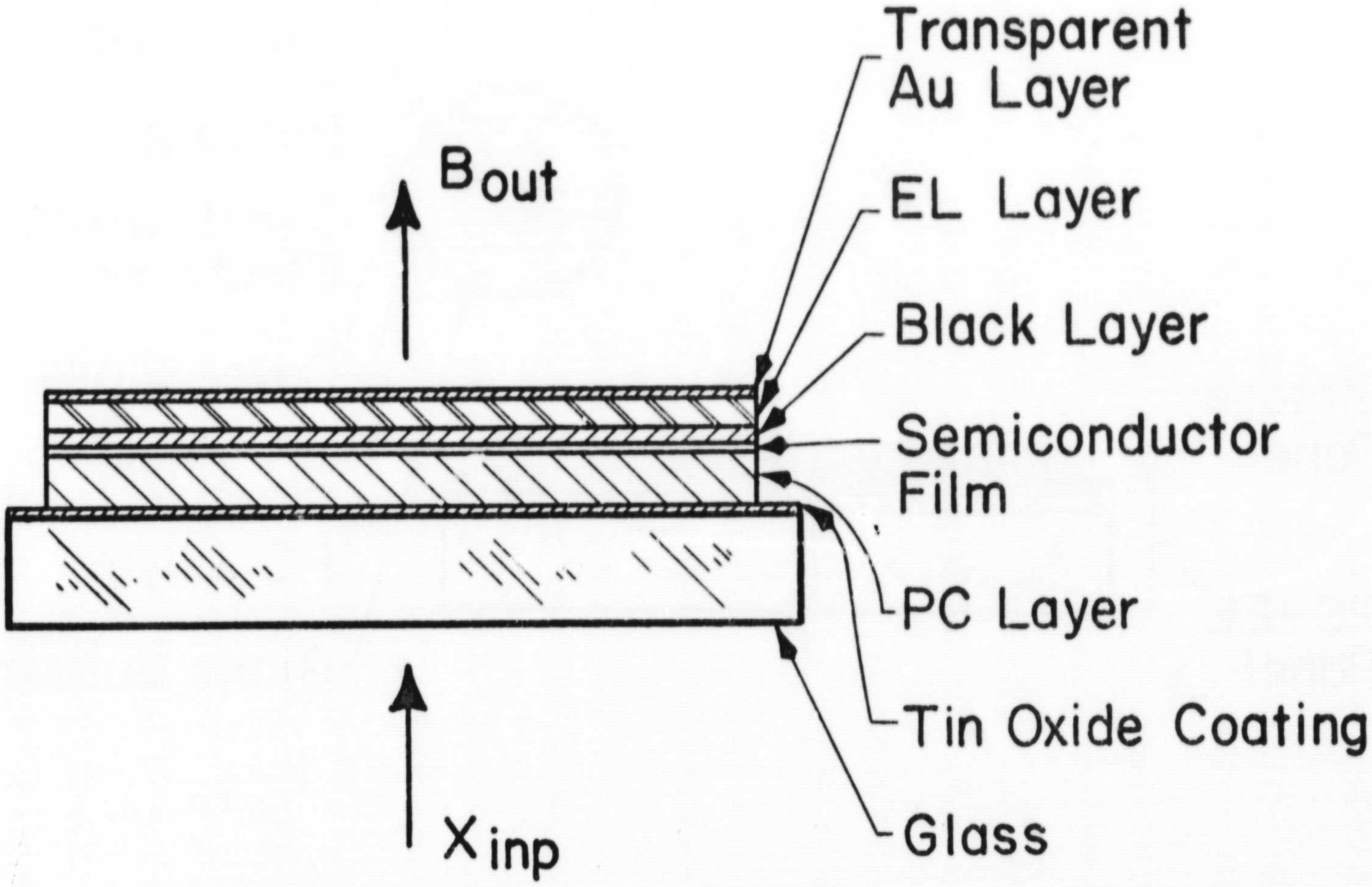

Figure 2. Construction of PC-EL Type Radiographic Amplifier

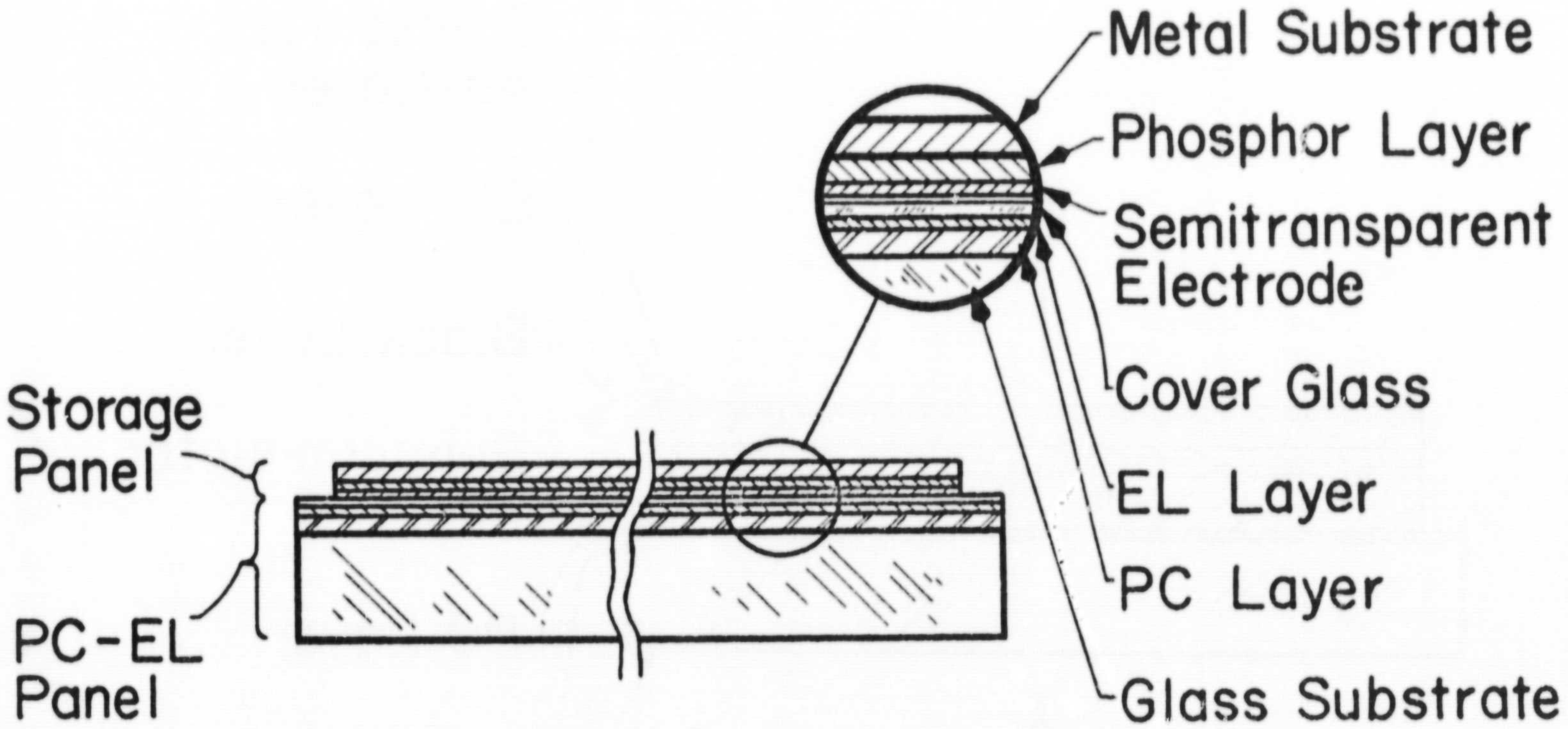

Figure 3. Construction of Storage Radiographic Amplifier System

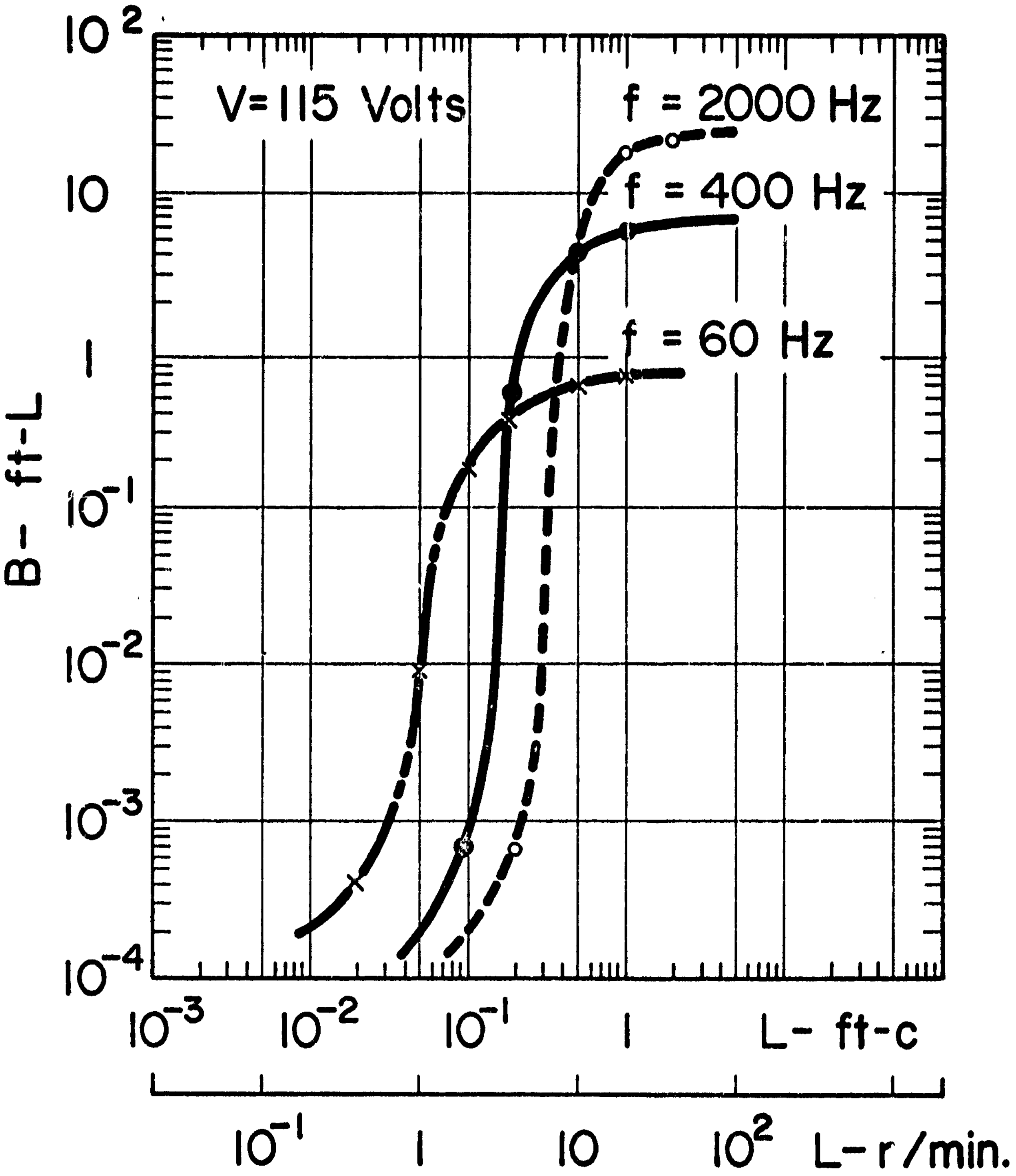

Figure 4. Transfer Characteristic Curves of Delivered Image Intensifier Panel (II-936)

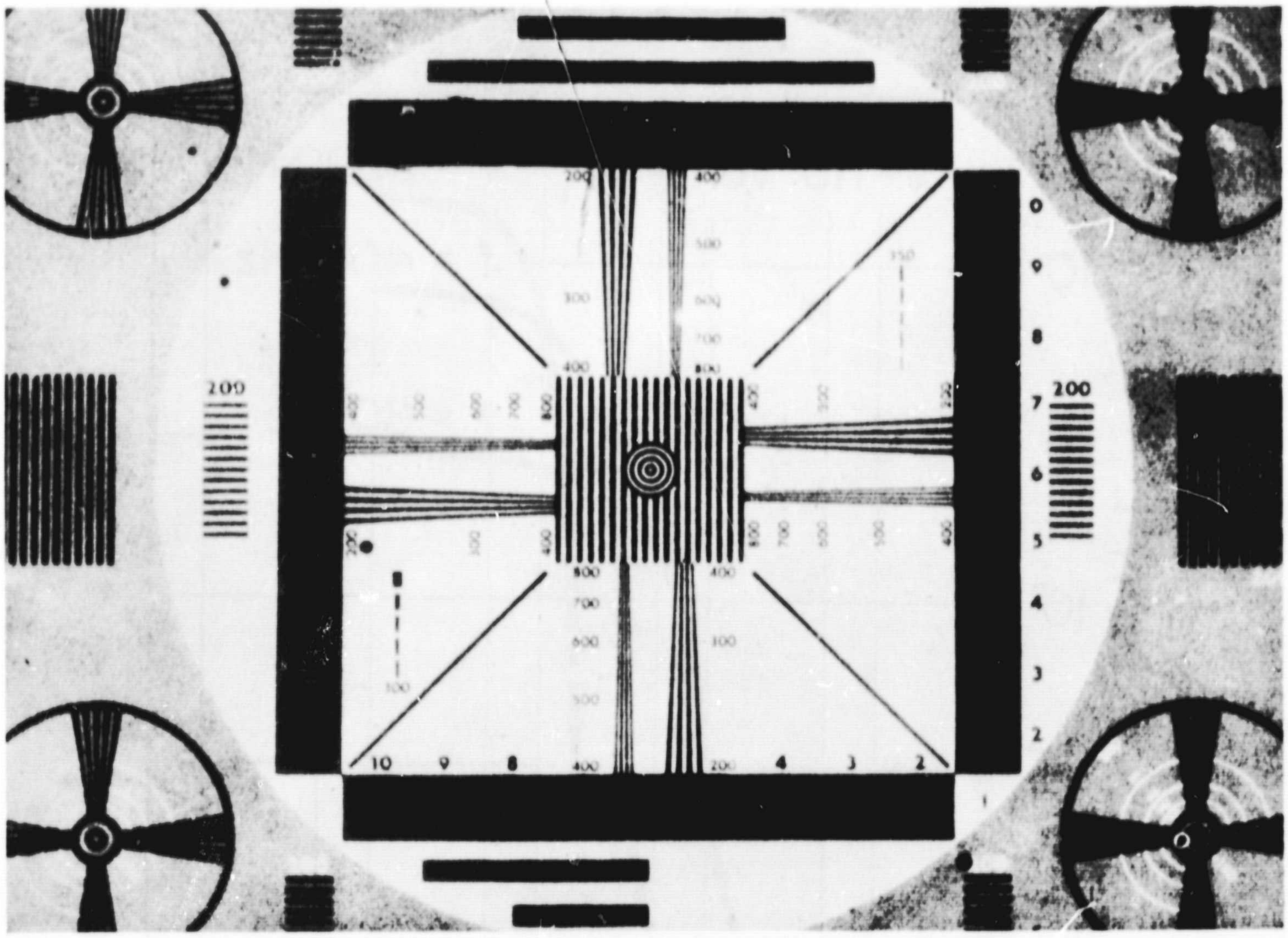

Figure 5. Photograph of Output Image of a TV test-Pattern on II-936. $V = 115V$, $f = 400$ Hz, $L_{max.} = 5 \times 10^{-1}$ ft-c, $B_{max.} = 5$ ft-L.

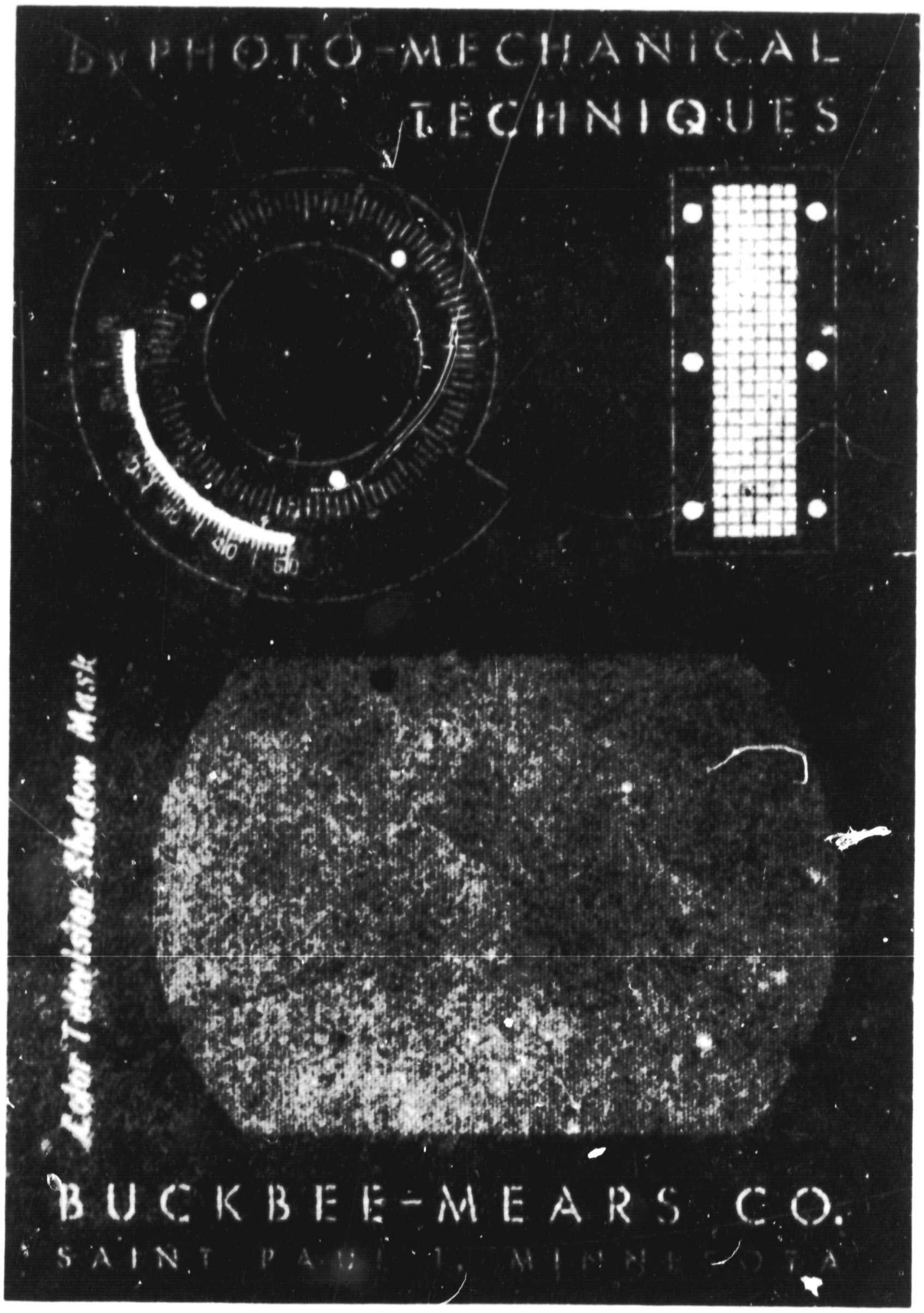

Figure 6. Radiographic Image (Original Size) of an Etched Metal Sheet

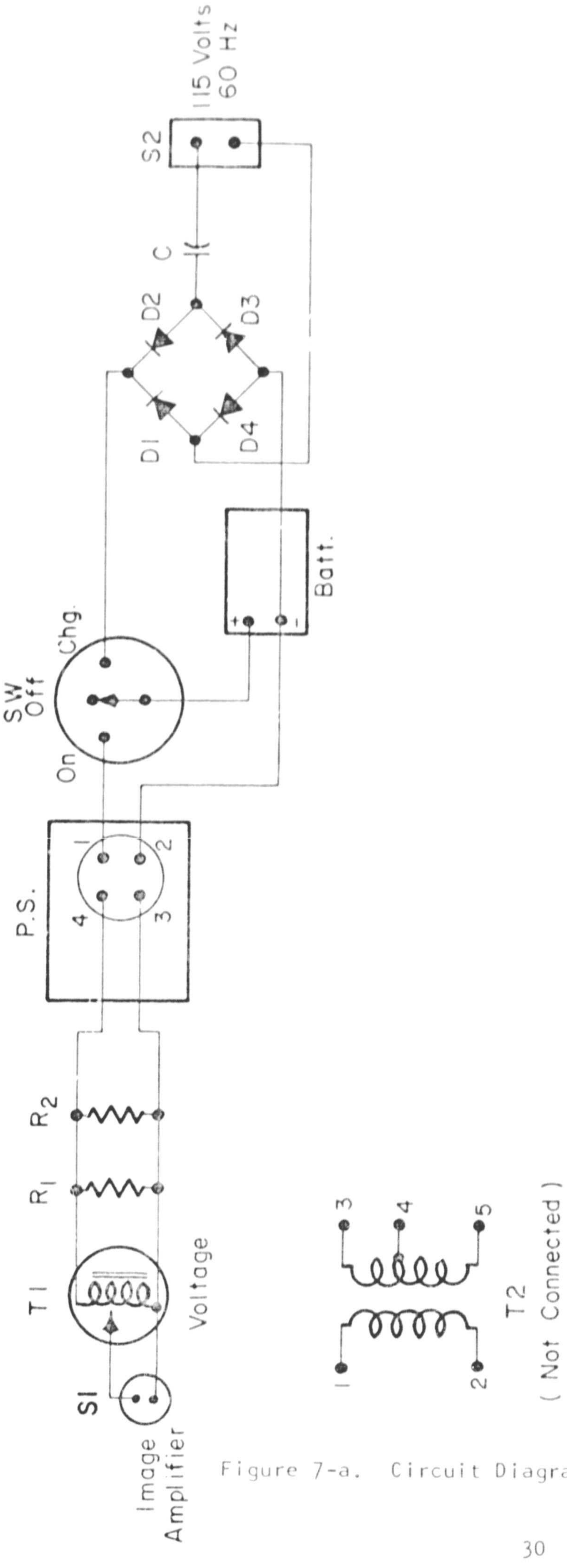

Figure 7-a. Circuit Diagram of Power Supply

ELECTRICAL BILL OF MATERIAL

ITEM No.	AMOUNT REQUIRED	SYMBOL	MANUFACTURER	CATALOG OR STYLE NO.	DESCRIPTION
1	1	P.S.	Abbott	N2D-115A-400	Power Supply
2	1	T1	Superior Electric	1HS01UK	Powerstat
3	1	Batt	Sonotone	24S-213	Battery
4	1	SW	Cutler-Hammer	7012K4	Switch
5	4	D1-D4	Westinghouse	IN 1224	Silicone Diodes
6	1	C	Sprague	2μF400V	Condenser
7	2	R1-R2	IRC	33K ohm 2W Type RC-2	Resistors
8	1	S1	Dialco	515-0012	Miniature socket
9	1	S2	Cinch Jones	2RP	Receptacle
10	1	T2	Abbott	24E157CT	Transformer

Figure 7-b. List of Components of Power Supply

DRAWN PS Gable 5-16-68

CHECKED

APPROVED

USED ON SUB-ASSEMBLY

EQUIPMENT ENGINEERING
ELECTRONIC TUBE DIVISION
HORSEHEADS, N. Y.
WESTINGHOUSE
ELECTRIC CORPORATION

Power Supply

2i206-3

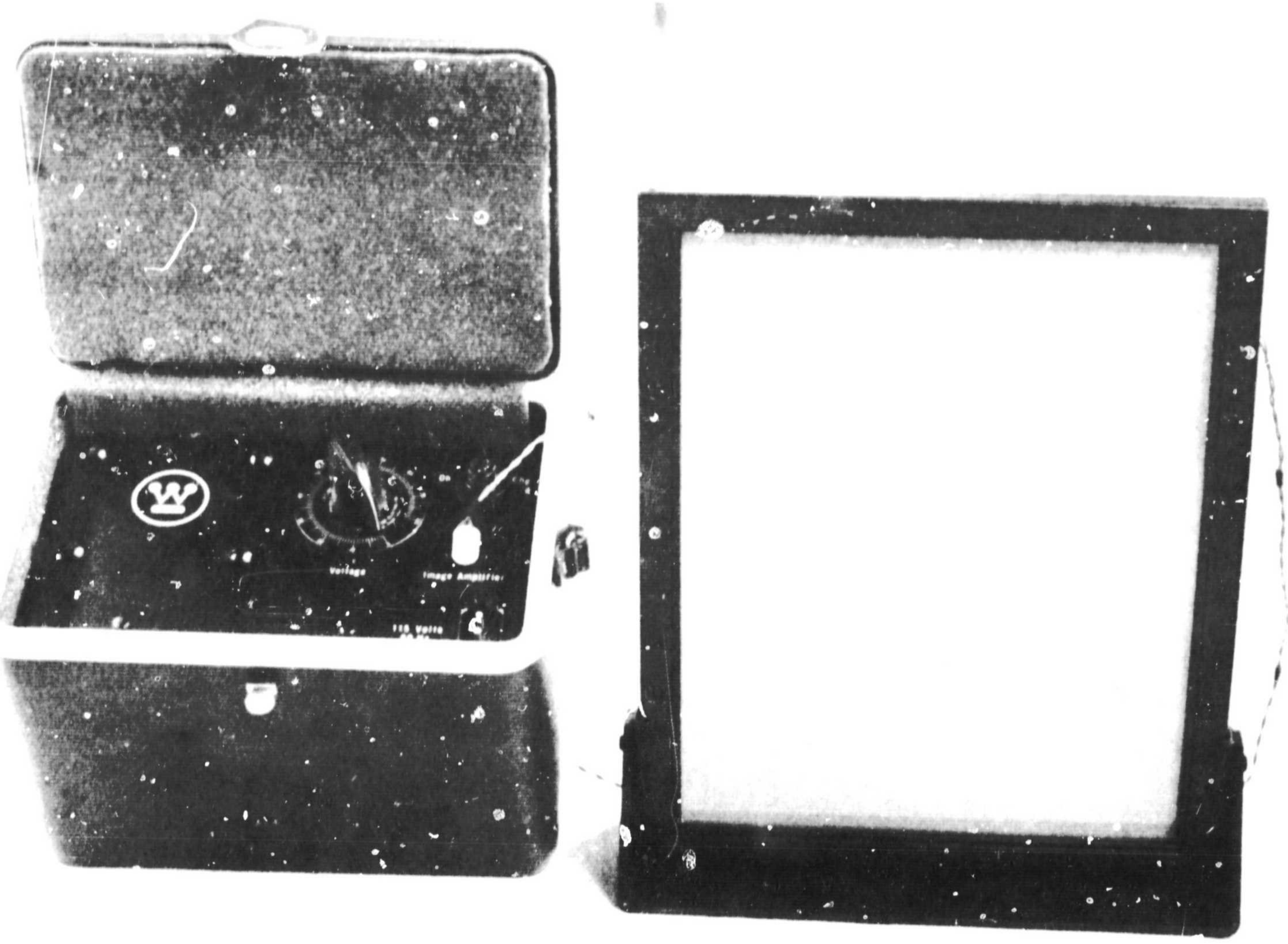

Figure 8. Photograph of Radiographic Image Amplifier System: Power Supply and Panel

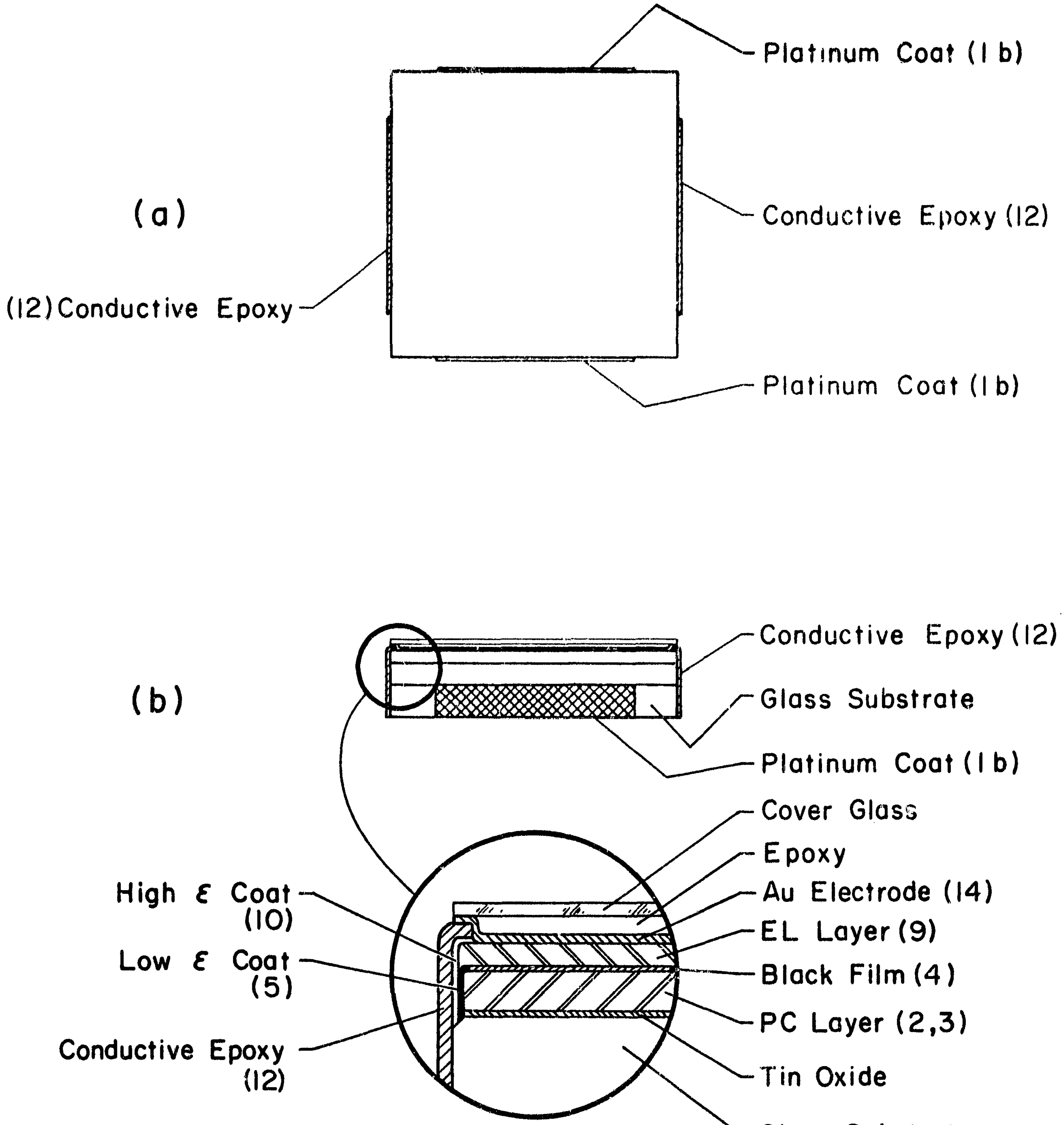

Figure 9. Construction Details of PC-EL Panels: (a) Top View; (b) Side View and Cross Section. Numbers in Parentheses refer to Appendix C.