FEASIBILITY STUDIES OF
MULTISPECTRAL MOSAIC IMAGE
CONVERSION PANELS

FOR PERIOD 1 FEBRUARY 1971 TO 31 JANUARY 1972

OFFICE OF NAVAL RESEARCH

CONTRACT N00014-71-C-0188
TASK NO. NR 215-165

DR. D. E. ANDERSON, PRINCIPAL INVESTIGATOR

MR. R. L. SWISHER, CO-INVESTIGATOR

30 MARCH 1972

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

G. T. Schjeldahl Company
Northfield, Minnesota 55057
Attn: Advanced Programs Division

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

Feasibility Studies of Multispectral Mosaic Image Conversion Panels

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Technical Report for Period 1 February 1971 to 31 January 1972

5. AUTHOR(S) *(First name, middle initial, last name)*

Donald E. Anderson & Richard L. Swisher

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
30 March 1972	120	

8a. CONTRACT OR GRANT NO.

N00014-71-C-0188

b. PROJECT NO.

Task No. NR 215-165

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

Reproduction in whole or in part is permitted for any purpose of the United States Government.

12. SPONSORING MILITARY ACTIVITY

Department of the Navy
Office of Naval Research

13. ABSTRACT

A development program is described in which the feasibility of mosaic EL/PC image conversion panels sensitive to UV, near IR, X-rays, and visible light was studied. Thin Film photoconductors are electroded in a regular array with unit cells 0.020" on centers. These arrays are connected to opaque electrode arrays forming the back pads of an electroluminescent (EL) lamp array through the use of microglass spacer sheets. Both thick film EL and thin film (TFEL) lamp arrays were prepared and studied. Useful near IR response was obtained for inputs of 10^{-6} w/cm^2. Useful visible light response was obtained for 5×10^{-4} ft-cd input. Peak optical gains of 500 were achieved with thick film EL and optical gains of 3000 using TFEL output.

The combinations of materials used were prepared in test sample form, electrically and optically parameterized, and then computer simulations were performed to determine the range of parameters needed for a successful assembly. The computer models simulate the transient or steady state optical stimulation of EL/PC cells with simple sinusoidal power applied or more complicated waveforms. All computer programs used are documented.

DD FORM 1 NOV 65 1473

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electroluminescence						
Photoconductors						
Mosaic Image Conversion Panels						
Electronic Assembly Simulation						
Infrared Image Conversion						
Displays						
UV Image Conversion						

FEASIBILITY STUDIES OF

MULTISPECTRAL MOSAIC IMAGE

CONVERSION PANELS

FOR PERIOD 1 FEBRUARY 1971 TO 31 JANUARY 1972

OFFICE OF NAVAL RESEARCH

CONTRACT N00014-71-C-0188
TASK NO. NR 215-165

DR. D. E. ANDERSON, PRINCIPAL INVESTIGATOR

MR. R. L. SWISHER, CO-INVESTIGATOR

30 MARCH 1972

III

Reproduction in whole or in part is permitted for any purpose of the United States Government. This research was sponsored by the Office of Naval Research under ONR Contract Number N00014-71-C-0188, ONR Contract Authority Identification Number NR 215-165/10/30/70 (461).

N O T I C E

Change of Address

Organizations receiving Reports on the initial distribution list should confirm correct address. This list is located at the end of the report. Any change of address or distribution should be conveyed to the Office of Naval Research, Code 461, Arlington, Virginia 22217.

Disposition

When this report is no longer needed, it may be transmitted to other organizations. Do not return it to the originator or the monitoring office.

Disclaimer

The findings in this report are not to be construed as an official Department of Defense or Military Department position unless so designated by other official documents.

V

PREFACE

This document covers research as to the feasibility of multispectral mosaic image conversion panels carried out at the G. T. Schjeldahl Company, Inc. during the twelve months from 1 February 1971 to 31 January 1972.

The research was directed by Dr. Donald E. Anderson; co-investigator was Richard L. Swisher. The research staff during all or part of the period covered by this report included Robert Mracek, Eugene Hildreth, Lloyd Schultz and John Rooks.

ABSTRACT

A Development program is described in which the feasibility of mosaic EL/PC image conversion panels sensitive to UV, near IR, X-rays, and visible light was studied. Thin Film photoconductors are electroded in a regular array with unit cells 0.020" on centers. These arrays are connected to opaque electrode arrays forming the back pads of an electroluminescent (EL) lamp array through the use of microglass spacer sheets. Both thick film EL and thin film (TFEL) lamp arrays were prepared and studied. Useful near IR response was obtained for inputs of 10^{-6} w/cm^2. Useful visible light response was obtained for 5×10^{-4} ft-cd input. Peak optical gains of 500 were achieved with thick film EL and optical gains of 3000 using TFEL output.

The combinations of materials used were prepared in test sample form, electrically and optically parameterized, and then computer simulations were performed to determine the range of parameters needed for a successful assembly. The computer models simulate the transient or steady state optical stimulation of EL/PC cells with simple sinusoidal power applied or more complicated waveforms. All computer programs used are documented.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS Cont.

1.0 General Introduction

1.1 General Description of Construction and Operation of EL/PC Image Conversion Panels

A solid state electroluminescent-photoconductor (EL/PC) image converter is a device which responds to radiation of a certain intensity and wavelength distribution by emitting radiation of higher intensity and/or different spectral distribution. Our studies have concentrated on image conversion panels having a structural geometry consisting of layers of mosaic patterned cells. All photoconductors studied were deposited as thin films with mosaics of patterned electrodes. Input radiation is incident normal to the PC film and photocurrent flow is in the plane of the PC film. Figure 1 is a back-lighted photomicrograph of a mosaic electroded PC layer fabricated in our laboratory. The opaque material is the molybdenum electrodes.

To connect the small square electrodes of the PC layer in Figure 1 to individual EL lamps in a layer above the PC layer, we need an interface layer. One type of successful interface layer that we have previously developed is shown in Figure 2. In this photomicrograph, the round dots are "posts" of solder alloy. Each of these posts are bonded to one of the small square electrodes of the PC layer in Figure 1. The light colored matrix is 0.003" thick glass. This is used for dimensional stability of the sheet.

The forward or upper ends of the conductive posts are connected to an array of rear electrode pads for the EL output layer. If thick film EL is used, it is sprayed onto the electroded interface layer and a continuous semi-transparent front electrode is applied. Figure 3 is a photomicrograph of the light emitted by an array of thick film EL lamps fabricated in this manner. An opaque dielectric layer is usually applied behind the output EL layer to prevent light feedback to the PC layer. If thin film EL (TFEL) is used as an output media, then it must be prepared on a separate substrate and electroded and then bonded to the interface layer.

Figure 4 is a vertically exaggerated drawing of a section of an EL/PC image conversion panel using thick film EL. The operation can be visualized by tracing the flow of electrical power from the conductive lattice across and modulated by a stimulated PC cell, up a conductive post, and by means of capacitance, through the EL layer to the continuous front electrode. Figure 5 is a schematic of how one EL/PC cell operates. As radiation impinges upon the PC, its resistance decreases. This switches an increasing fraction of the applied voltage onto the EL capacitor. In response to this voltage, the EL material emits light. The image conversion panel can be thought of as an array of photoresistive voltage dividers.

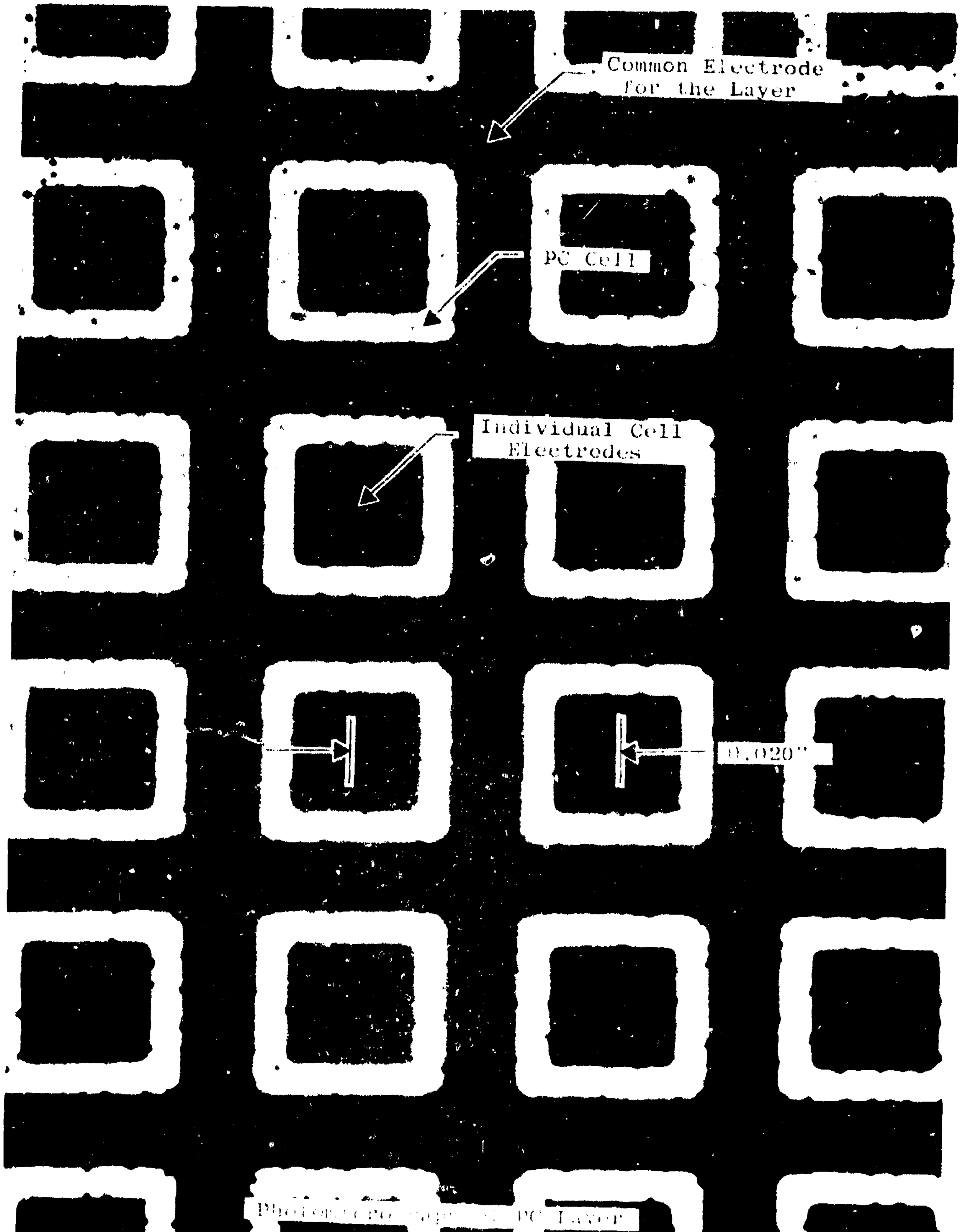
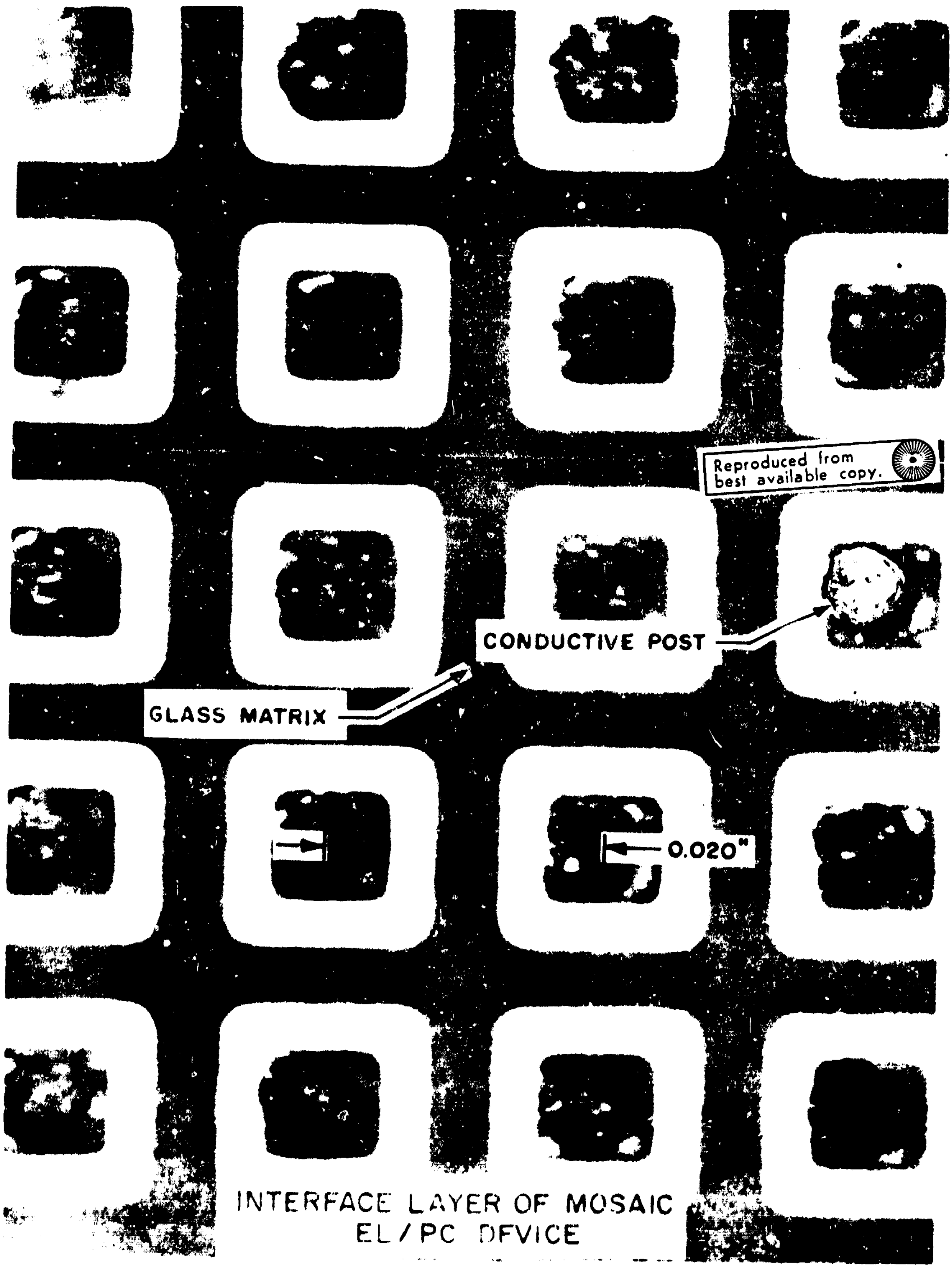

Common Electrode
for the Layer
PC Cell
Individual Cell
Electrodes
0.020"
PC Layer

Figure 1



INTERFACE LAYER OF MOSAIC
EL/PC DEVICE

Schjeldahl Company

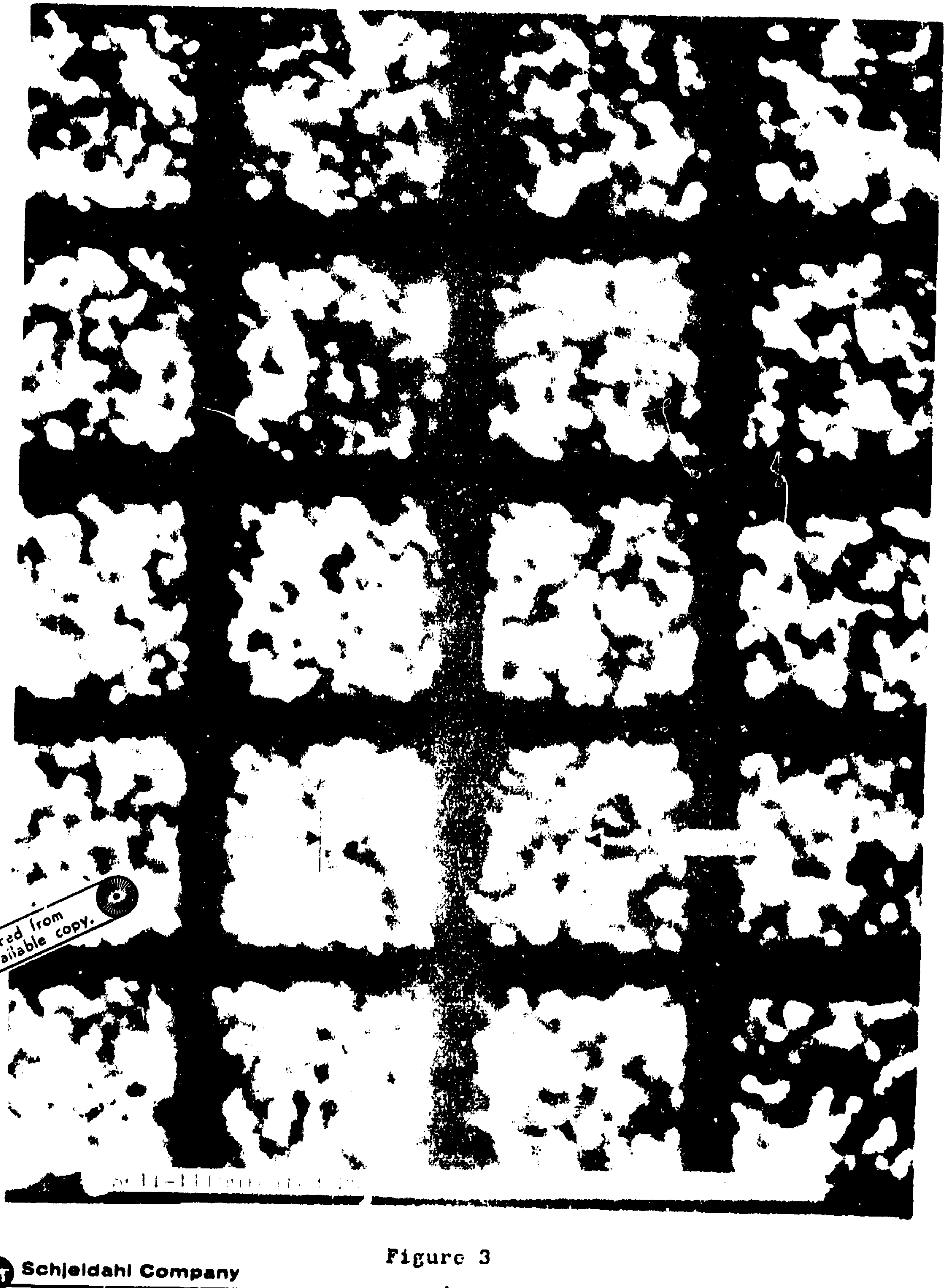
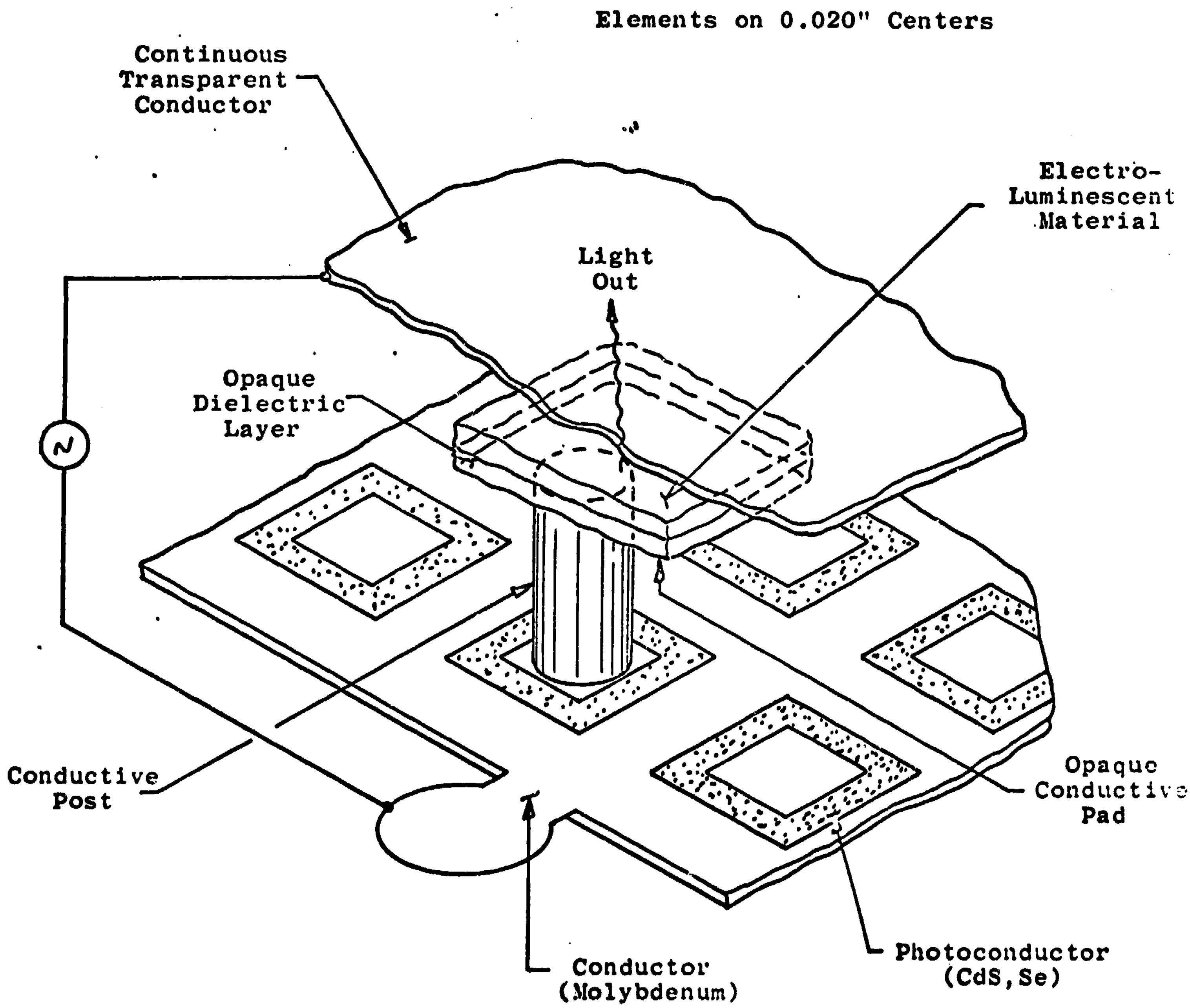
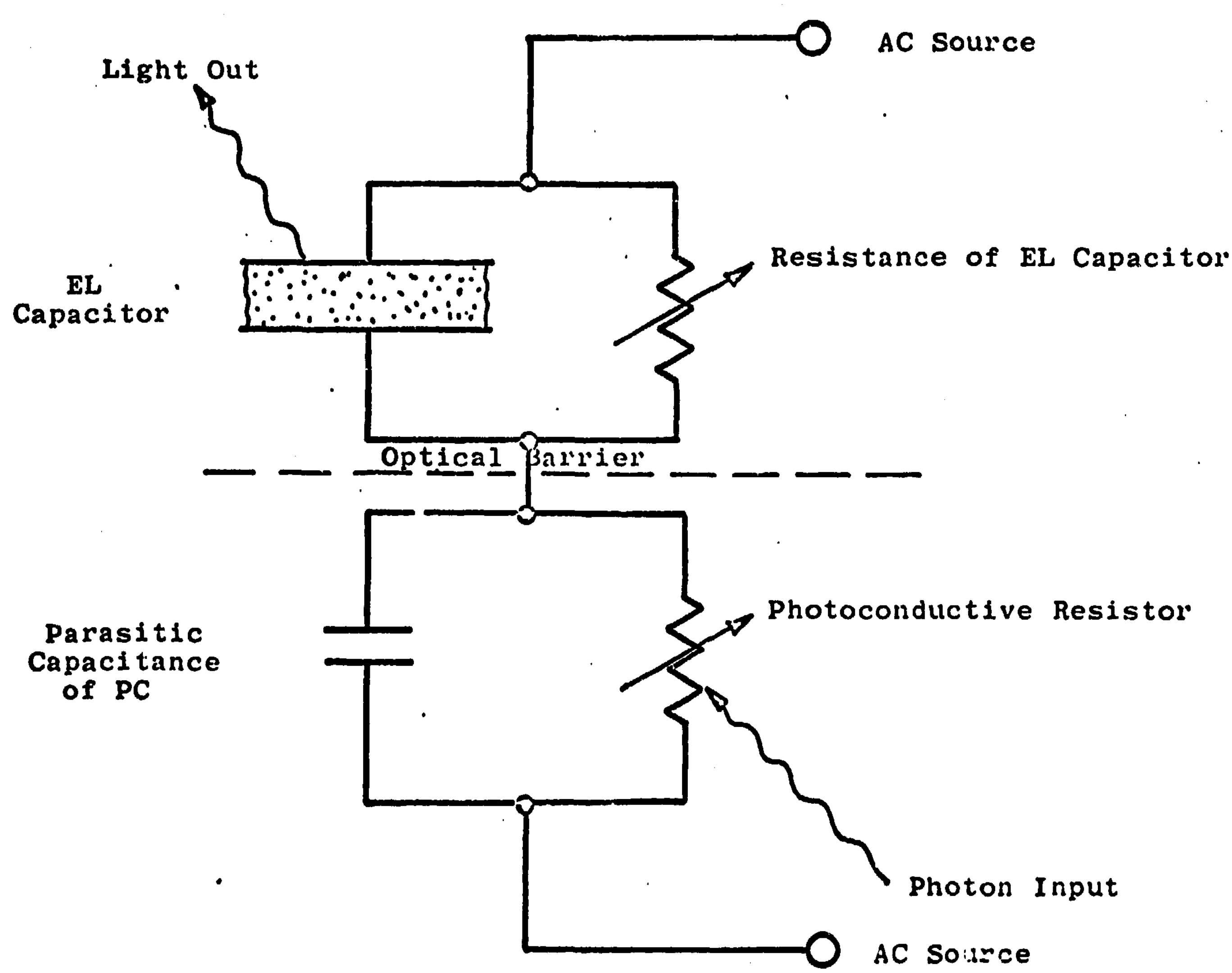


Figure 3



Simple 3D Geometry of Image Conversion Panel

FIGURE 4



Extremely Simplified Schematic of Operation
of
EL/PC Image Conversion Panel

FIGURE 5

1.2 Philosophy of This Program

Under a previous contract (N00017-70-C-0213), it was shown that mosaic EL/PC infrared image converters could be simulated by computer modeling and the operating characteristics of a completed test assembly agreed with the predictions. This type of simulation makes possible many economies in the search for useful combinations of photoconductors and electroluminescent materials.

In this program, we were to continue studies of infrared (IR) photoconductors used with thick film EL and to extend this work to photoconductors sensitive to ultra-violet, visible, and X-ray radiation. Also, we were to further investigate the possibility of using thin film EL(TFEL) in image conversion panels. If the computer simulations indicated that a combination of materials could function properly, then test assemblies were to be fabricated, if possible, and compared with the simulations. In addition, we were to investigate the possibility of placing a visible-to-visible image conversion panel on top of any other type of image conversion panel to boost the conversion gain of the pair.

The work and this report was divided into five tasks:

- Develop Thin Film EL lamp arrays compatible with possible assembly techniques
- Investigate UV sensitive photoconductors to find possible candidates for use in test assemblies
- Investigate X-ray sensitive photoconductors to find possible candidates for use in test assemblies
- Investigate PbS-TFEL combinations and improve the CdSe device fabricated under previous contract.
- Improve CdS,Se visible-to-visible image conversion panels and investigate possibility of cascading with similar panels or any of the image conversion panels above.

2.0 Thin Film EL Fabrication and Testing

2.1 Introduction

Thin film EL (TFEL) has these advantages over thick film EL:

- Higher brightness
- Better brightness maintenance characteristics
- More uniform appearance. It is microscopically uniform in brightness within a cell.

TFEL has these major disadvantages:

- It is much more difficult to fabricate consistent lamps from sample to sample. Many vacuum deposition processes are involved. The heat treatments necessary to form a good lamp limit the possible assembly procedures of an EL/PC device.
- Its brightness is a very steep function of applied voltage which results in very little gray scale range in an EL/PC image conversion panel.
- Its capacitance per unit area is much larger than thick film EL and hence, its impedance per unit area is lower. This requires that PC cells be fabricated with a lower range of impedances than those necessary for thick film EL.

Despite the above shortcomings and difficulties, TFEL is still a desirable light output media because of its high brightness and excellent life if made properly. These characteristics are especially important for aircraft displays.

During this program, we improved upon the performance obtained from TFEL fabricated under the previous contract.

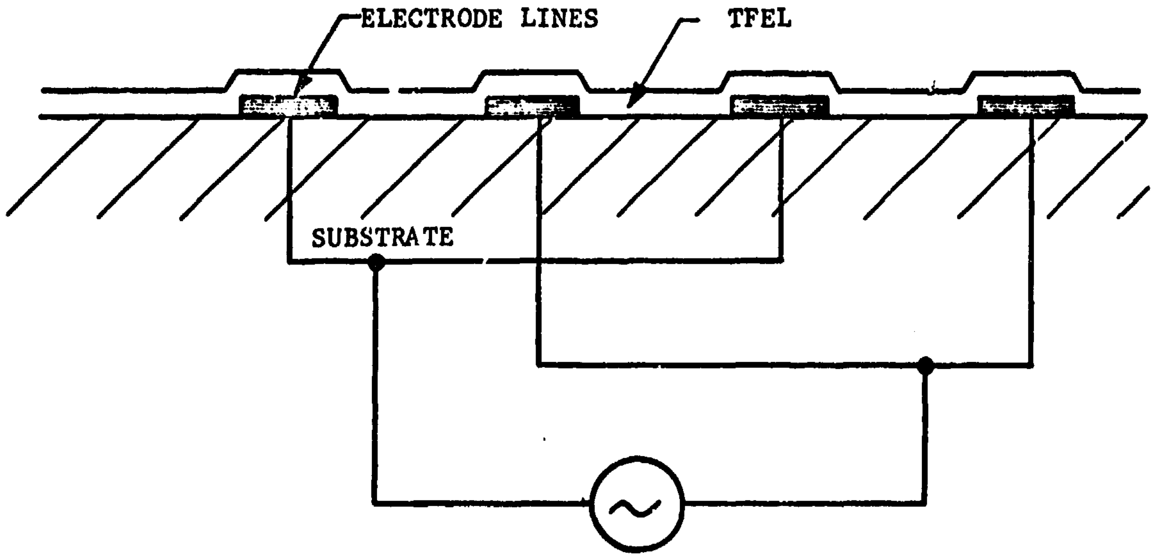
2.2 TFEL Fabrication Techniques and Results

2.2.1 Co-Planar Electrodes

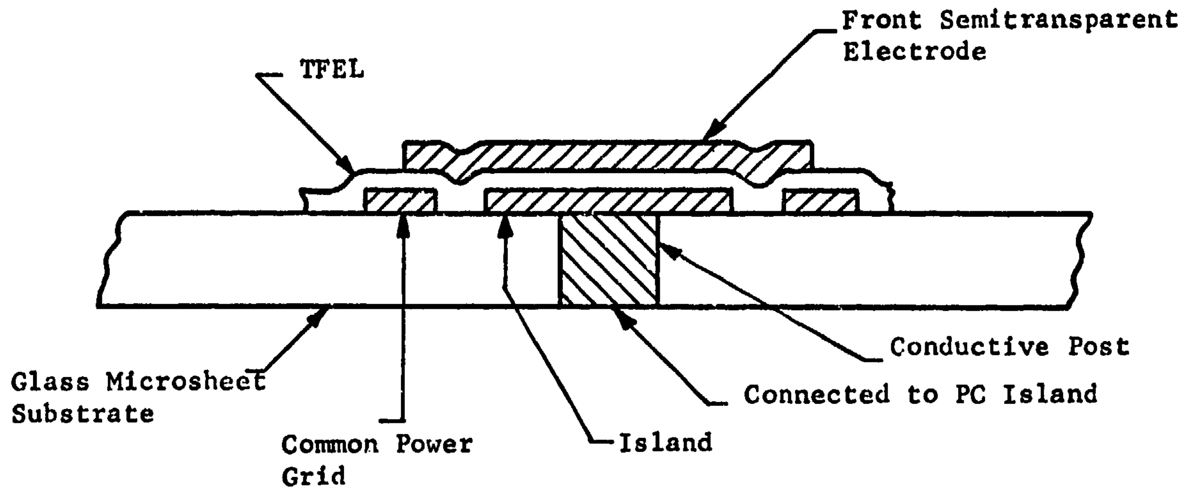
It was originally planned that we try to increase the impedance of the TFEL cells by using a co-planar electroding scheme as shown in Figure 6. Experimental trials indicated that such a configuration held little promise for success because of extreme demands on electrode edge smoothness and electrode spacing of less than 0.001". This electrode spacing is impractical for large area panels.

2.2.2 Series TFEL Lamps

Another impedance raising approach was then tried. This electroding technique is shown in Figure 7. The technique used a "moated" rear electrode for the TFEL cell and a "floating" semitransparent front electrode. If the area of the region common to the power grid and floating electrode and the area common to the "island" and the floating electrode are equal, then the impedance of the TFEL lamp is quadrupled over a simple sandwich electrode structure. The total operating voltage of the TFEL lamp is doubled but the electric fields in the material remain the same as for a simple sandwich cell. We abandoned this approach because the lamp could



CO-PLANAR TFEL ELECTRODES
FIGURE 6



"MOATED" DRIVE ELECTRODES
FOR
TFEL OUTPUT CELL

FIGURE 7

not be fabricated as in Figure 7. Because the TFEL needs high temperature baking, the front semitransparent electrode has to be SnO_2 or InO_2 deposited on a substrate first. The moated rear electrode had to be deposited last and we could not find an etching technique for the metals used (Au, Ni, or Al) that didn't damage the lamps in some unknown way. All lamp samples suffered from voltage breakdown problems.

At this time we decided to concentrate on the simple sandwich cell of TFEL and try harder to adjust the impedance range of the photoconductors.

2.2.3 Sandwich Style TFEL Cells

Concurrent with the unsuccessful attempts at using novel TFEL cell geometries, we were attempting to improve the performance of "simple" sandwich style TFEL cells. Figure 8 is a cross-section through such a cell. The transparent substrates we used were typically borosilicate glass. We tried two types of semitransparent front electrodes: SnO_2 and InO_2. The phosphor was ZnS doped with manganese. The dielectric is GeO_2. The rear electrode is typically Au.

At the beginning of the program, we performed an abbreviated matrix study using:

a) Three types of SnO_2 coated substrates.

b) Three types of GeO_2 evaporation sources.

c) Two types of ZnS:Mn phosphor evaporation sources.

The plan was to abbreviate the matrix by building lamps using all types of processes in (a) above with a standard set of processes from (b) and (c) above. The best (a) process was then used with all types of (b) processes and the same (c) standard. This optimization was carried through each successive layer of the lamp structure. The types of substrates included commercially obtained substrates and SnO_2 and InO_2 coated substrates prepared in our laboratory.

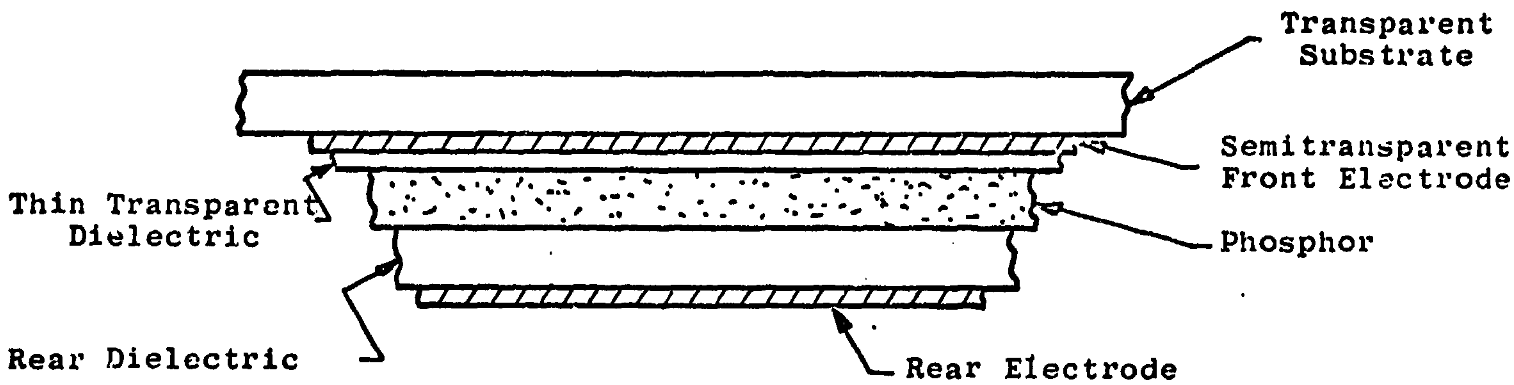
All ZnS:Mn depositions were made in a bell jar vacuum system using an internal chimney deposition system as shown in Figure 9.

The best lamp obtained by this matrix of permutations was fabricated of:

1. Commercially obtained SnO_2 coated glass substrate.

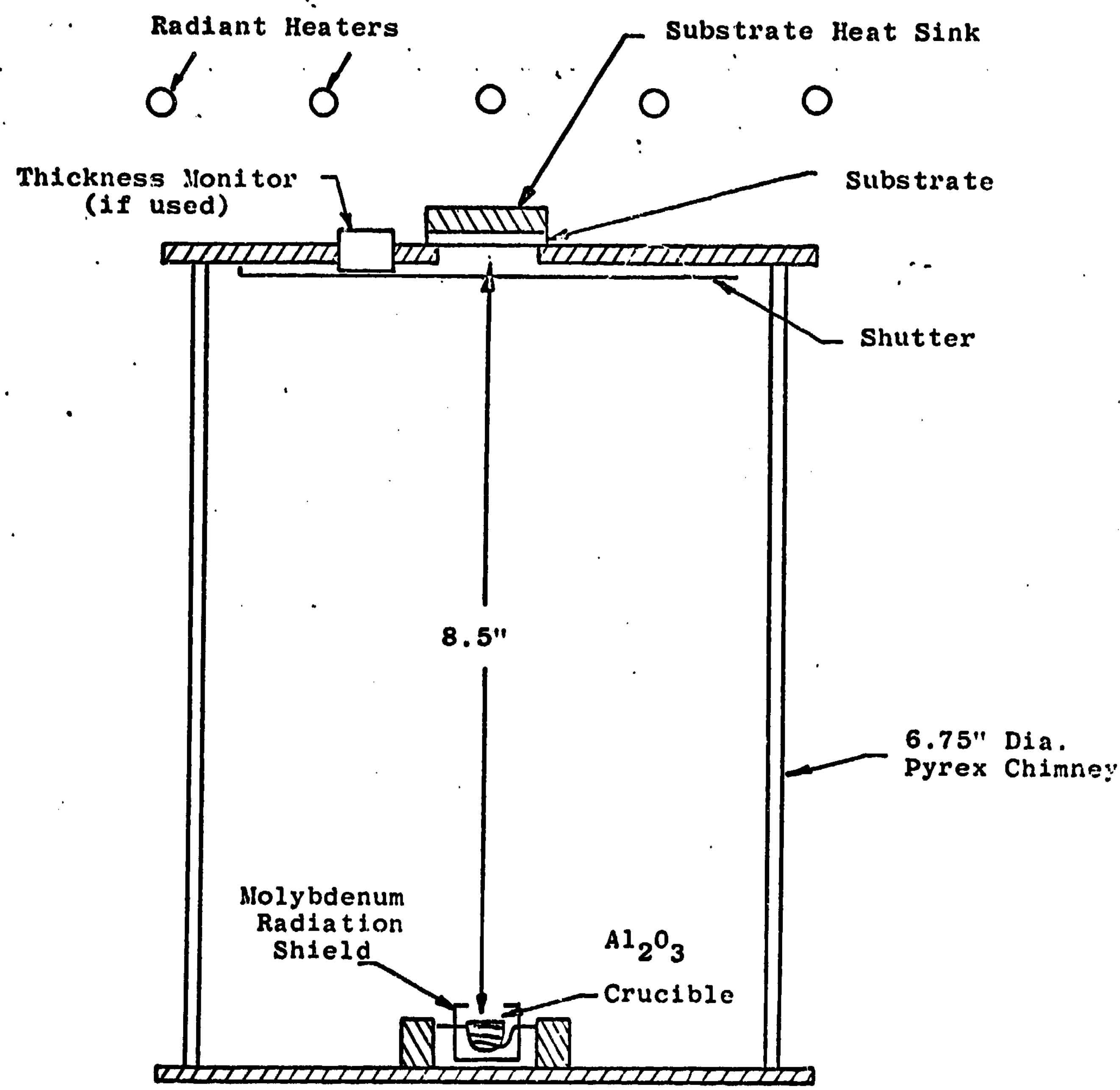
2. 250Å of GeO_2; vacuum baked 2 hrs. at 500°C.

3. 18,000Å of ZnS (shot from charge containing 20% MnS); vacuum baked 2 hrs. at 500°C.



Thin Film EL Lamp

FIGURE 8



The Al_2O_3 Crucible is Heated by a Tungsten Coil. A Close Fitting Plug of ~ ¼" thick Quartz Wool is Placed Over the Deposition Charge and Held in Place by a Simple Refractory Metal Split Ring.

Diagram of ZnS, CdSe, PbS, PbSe Deposition Fixture

FIGURE 9

4. 9,000Å of GeO_2.

5. Karma™ rear electrode.

This lamp would emit 1,000 ft-L when driven at 260 V rms and 5KHz. Lifetimes of this type of lamp were only ~50 hrs. at which time voltage breakdown at small spots would begin to destroy the test cells. Decay was very slight before failure. The voltage breakdown problem plagued us throughout the program.

Figure 10 is a representative sample of the brightness vs. voltage characteristics of the TFEL lamps fabricated in this matrix study. The results are typically that:

1. Increasing thickness of GeO_2 layer shifts the curves to increased operating voltage.

2. Increasing Mn concentration in the phosphor layer (No.3 above) shifts the curve to lower operating voltage and steepens the slope of the curve.

3. Post deposition vacuum baking of the phosphor layer is very important for maximum phosphor brightness and lifetime.

Figure 11 is a comparison of a lamp fabricated in the matrix study with a commercially available TFEL lamp (Sigmatron, Inc., Goleta, California). Our lamp was fabricated as follows:

1. Commercial SnO_2 coated glass substrate

2. 250Å GeO_2, unbaked

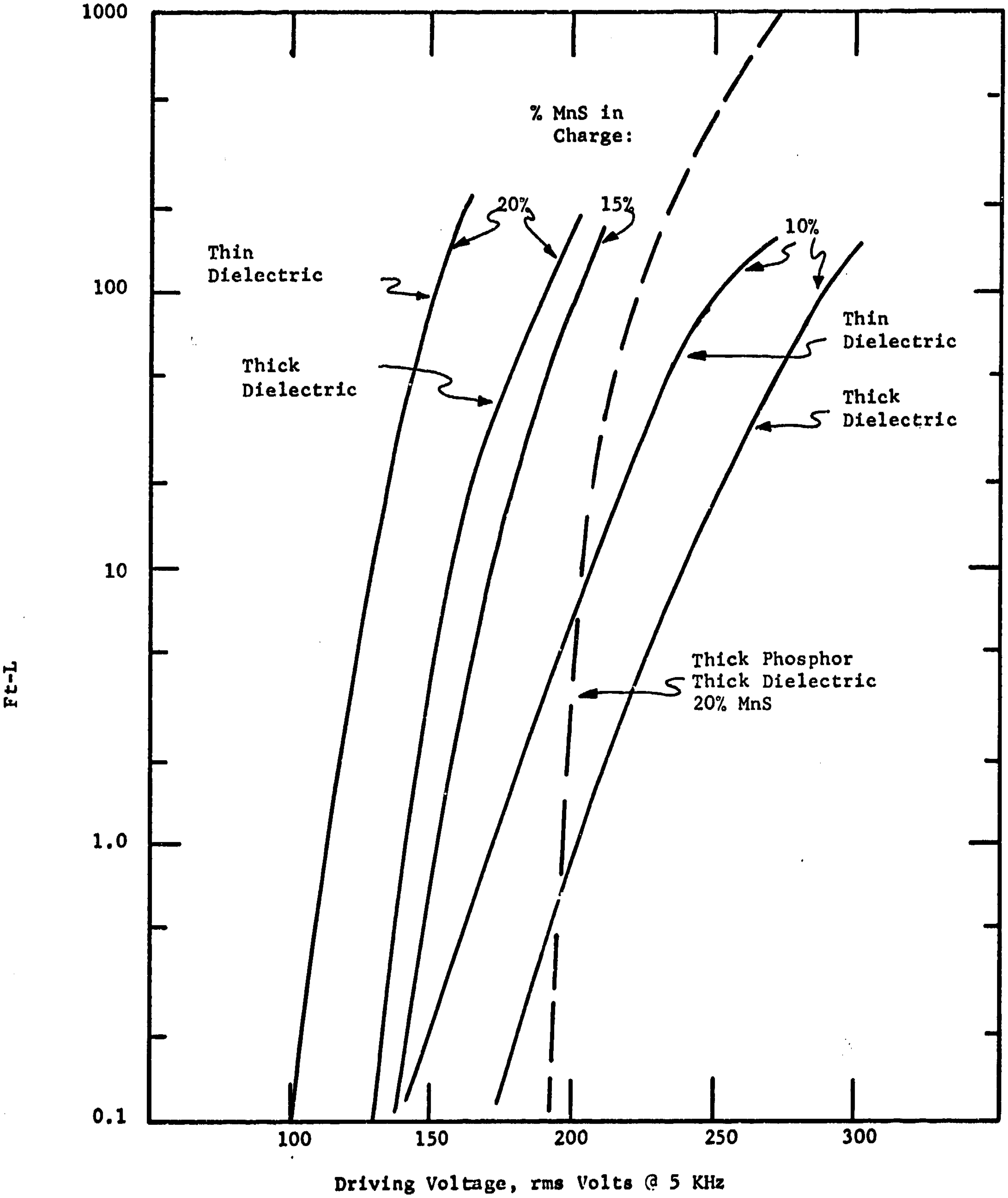
3. 15,000Å ZnS phosphor, shot from charge containing 20% MnS, vacuum baked 2 hrs. at 500°C.

4. 9,000Å GeO_2

5. Au rear electrode

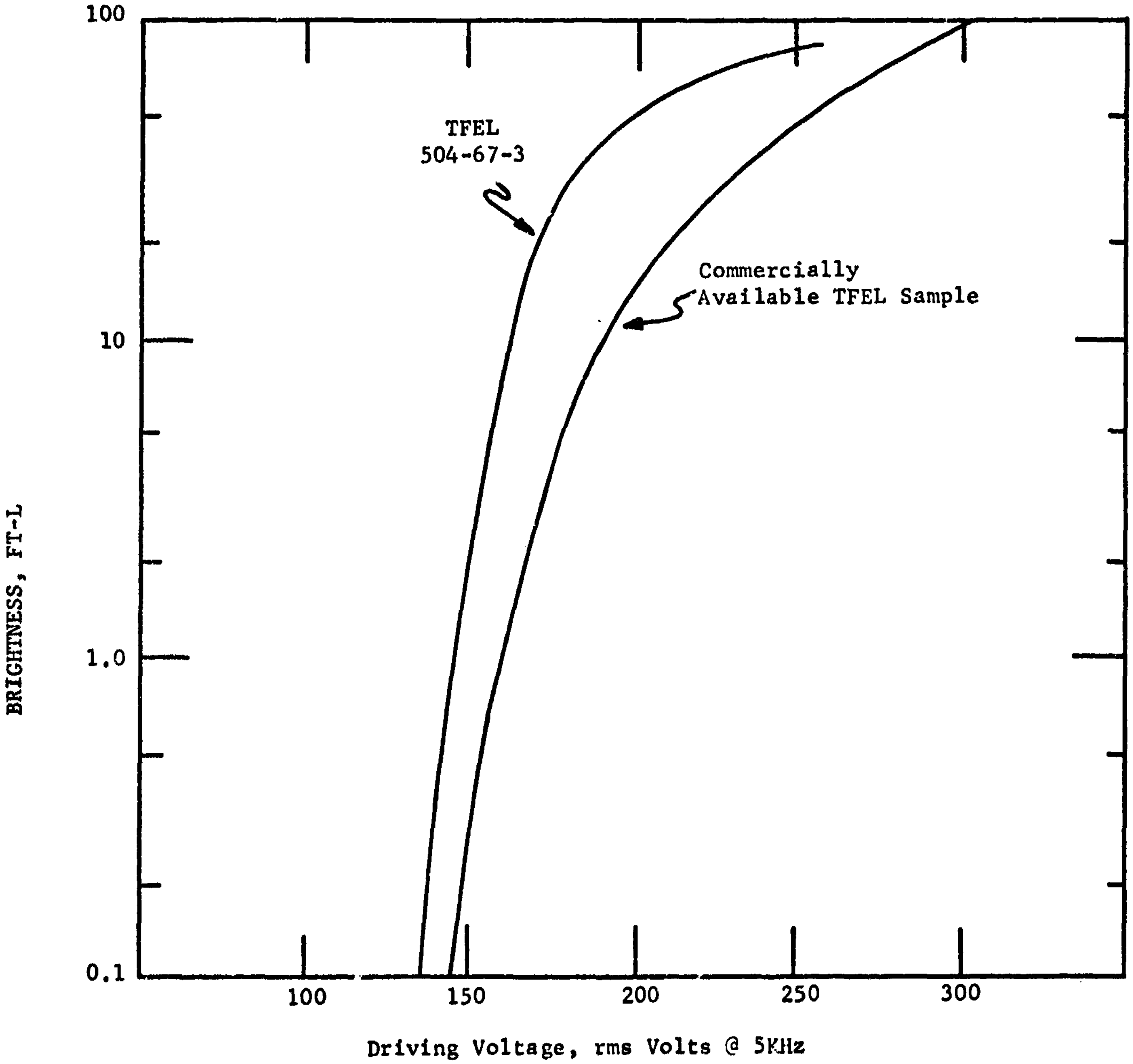
All dielectric and phosphor depositions were made with a substrate temperature of 200°C. The ZnS evaporation crucible has a quartz "wool" plug placed on top of the charge. A thermocouple encapsulated in quartz is used to monitor the temperature of the quartz "wool" plug. For this lamp, the temperature was 1150°C. The lamp operated for 240 hours at near 50 ft-L before voltage breakdown occurred.

The operating frequency was 5 KHz and the voltage was 209 V rms. The voltage was gradually increased to 218 V to compensate for aging. All good lamps exhibited excellent brightness maintenance. But at some time after approximately one hundred hours, they suffered a catastrophic breakdown which obliterated the entire cell.



TRENDS IN B vs V FOR DIFFERENT TFEL CONSTRUCTION PARAMETERS

FIGURE 10



BRIGHTNESS VS. VOLTAGE OF LABORATORY SAMPLE LAMP COMPARED WITH AVAILABLE TFEL LAMPS

FIGURE 11

This catastrophic failure mode of the TFEL lamps which plagued us was traced to almost sub-microscopic pinholes in the phosphor layer. Very small defects in the surface of the finished lamps were observed to be the center of destruction of macroscopic areas that broke down in operation. We were already using a quartz "wool" plug in our phosphor deposition boat. If we increased the thickness of this plug or used a less porous plug, we expected deposition times to become very lengthy. Consequently, we began experimenting with thicker nucleating layers under the phosphor layer. Previously, if a GeO_2 nucleating layer of greater than ~250Å was used, the lamp surface crazed during vacuum baking. We changed the GeO_2 evaporation source from an Al_2O_3 crucible to a Pt resistance heated source of simple folded ribbon geometry. Much better adhesion of GeO_2 to the front electrode was then observed.

The catastrophic failure mode of the TFEL lamps was reduced. The deposition source for the GeO_2 layers and the increased thickness of the phosphor nucleating layer helped.

The best lamp fabricated since using a thicker nucleating layer was manufactured in cross grid matrix style with 0.016" wide InO_2 lines on 0.020" centers for the semitransparent electrode.

The lamp was fabricated of:

1. InO_2 coated substrate (etched into lines).
2. 500Å GeO_2 unbaked, deposited from Pt boat. Charge is fused before opening shutter.
3. 20,000Å of ZnS, shot from a charge containing 20% MnS, vacuum baked two hours at 500°C. Source diffuser plug temperature is 1150°C.
4. 6,000Å of GeO_2 deposited from Pt boat. Charge is fused before opening shutter.
5. Al rear electrode (deposited as lines).

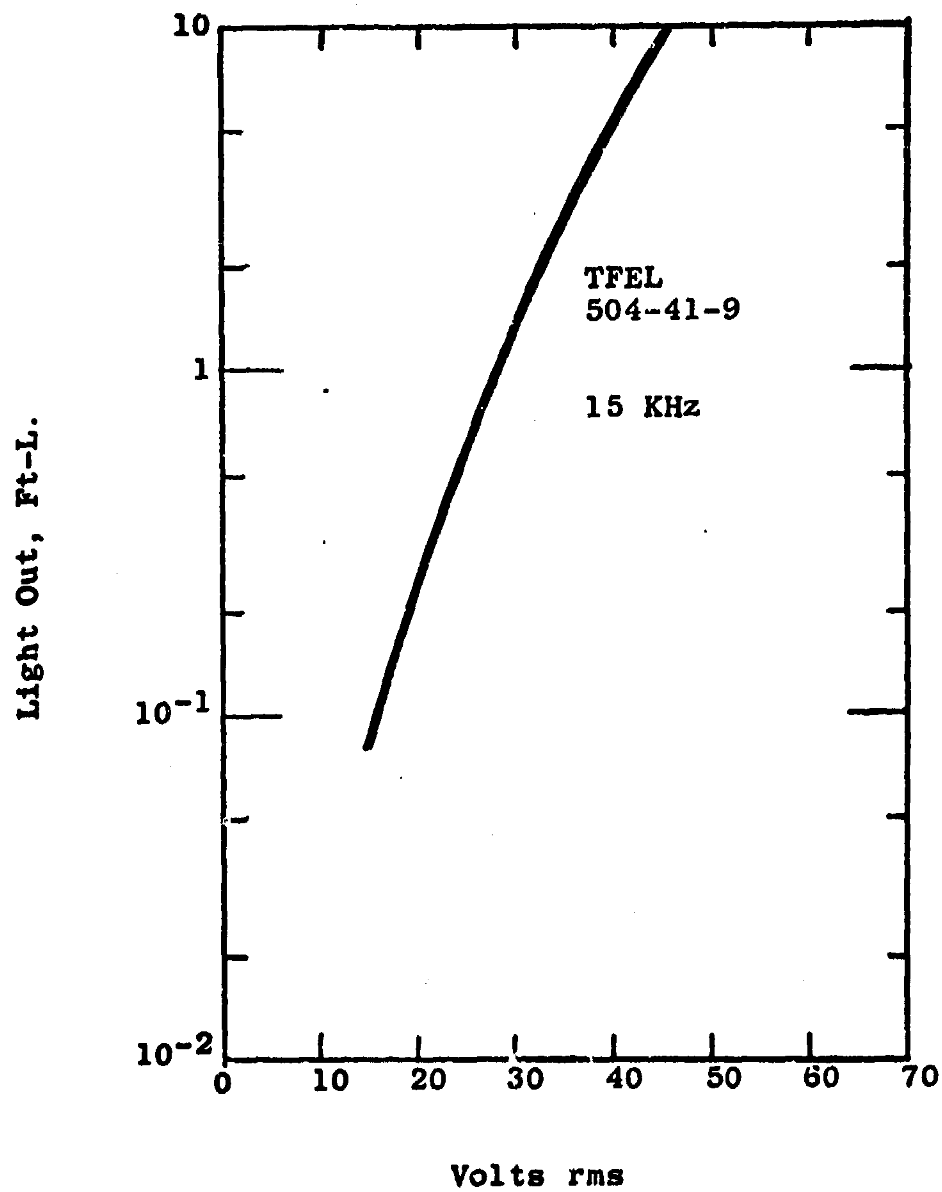
This lamp was operated in a constant brightness mode. It exhibited a fast decay mode after initial turn-on. Its beginning operating parameters were 185 V rms at 5 KHz to emit 50 ft-L. Its "first" half life was ~10 hrs. At this time, the voltage was raised to 192 V rms. Its projected half life at this voltage was ~ 1125 hrs. After 800 hrs. running time, the lamp required 200 V to emit 50 ft-L. Small portions of the lamp did suffer catastrophic failures; final failure occurred at approximately 1200 hours. We feel that this particular phosphor fabrication technique does yield a useful phosphor layer but our substrate preparation procedures need further refining. At this stage of development, the TFEL effort was then directed toward methods of integrating TFEL cells into EL/PC test assemblies.

2.3 Interesting Anomalies of TFEL

While fabricating a test EL/PC assembly, a small portion of the assembly was coated with the following layers:

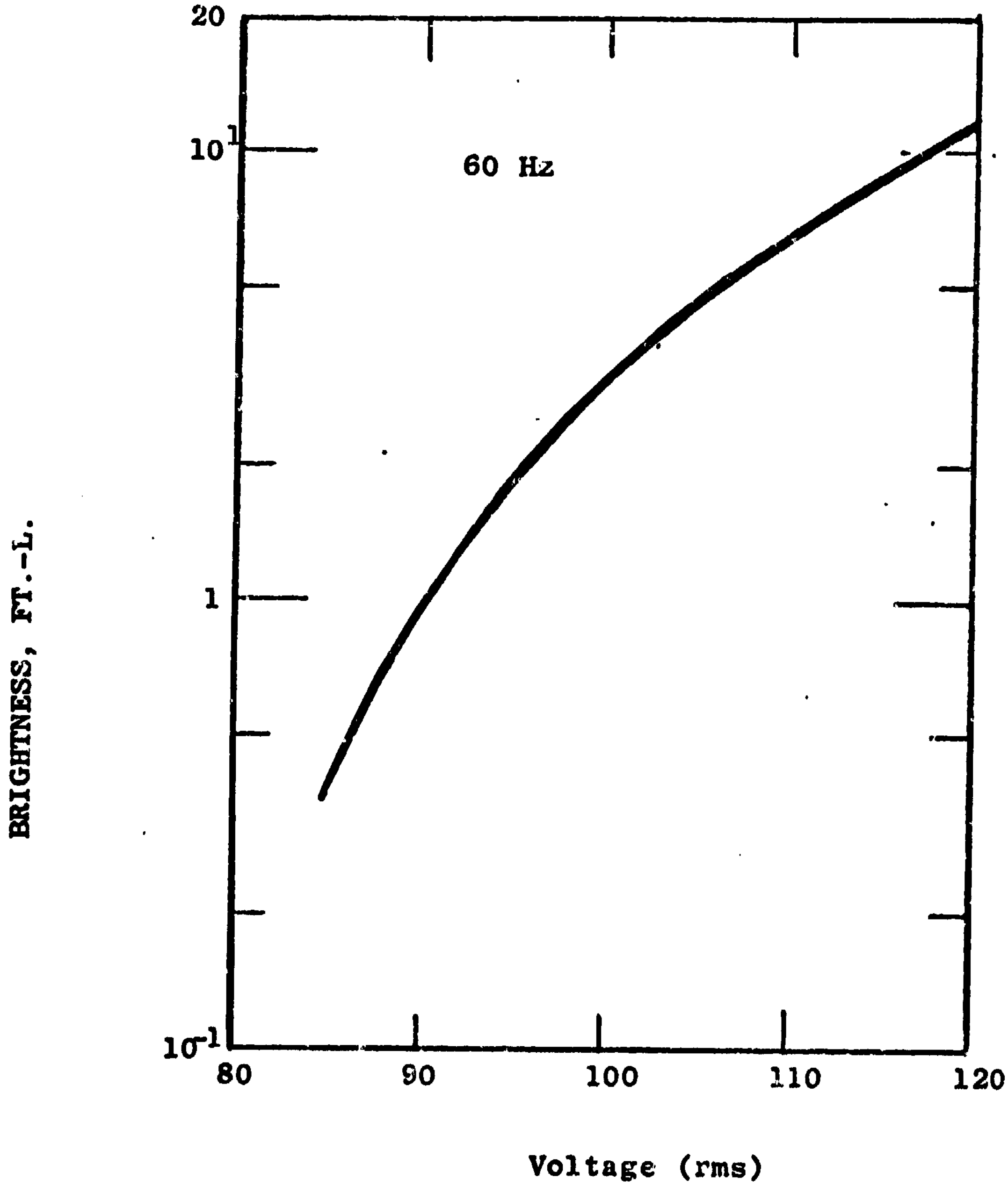
1. Glass substrate
2. Molybdenum base electrode
3. ~ 10,000Å of CdS, Se:Cl
4. 3,000Å GeO_2
5. 16,000Å of ZnS:Mn (shot from a charge containing 15% MnS)
6. 3,000Å GeO_2
7. Semitransparent (~ 40%) Karma™ electrode

This combination of materials produced a very low-voltage TFEL lamp. The operating characteristics of the lamp are shown in Figure 12. The lamp would not emit light under direct current stimulation. As circumstances permitted, we used scrap samples of TFEL lamps to try to determine what caused this behavior. Our best guess as a result of several loosely controlled experiments is that Cl doping from the CdS, Se layer caused the phenomena. As a check, we ran a ZnS:Mn TFEL layer through a photoconductor Cl doping cycle. After depositing the dielectric layer, we obtained a TFEL lamp having operating characteristics as shown in Figure 13. This was the lowest voltage lamp we fabricated (when operated at low frequencies). The lifetime of the lamp was only a few hours.



TFEL Lamp with CdS Layer Included

FIGURE 12



LOW VOLTAGE TFEL OUTPUT BRIGHTNESS

FIGURE 13

3.0 UV-to-Visible Image Conversion Panels

3.1 Introduction

We originally proposed that ultra violet-to-visible mosaic image converters might be feasible if large band gap photoconductor materials, those greater than 3 ev, exist which are compatible with current EL/PC construction techniques and exhibit fast photocurrent rise and decay times. Such a candidate material is ZnO (band gap ~ 3.2 ev). The literature shows it to have a slow photocurrent rise and decay time. However, these reports do not clearly indicate its behavior in thin film form under the large signal voltage biases necessary for mosaic EL/PC image conversion. Thus, materials such as Al_2S_3, ZnO, ZnS, In_2O_3, SnO_2, Sb_2O_3, Bi_2O_3, and/or others, as indicated by brief literature search, were to be prepared in thin film form and doped according to the best information available. Photocurrent under near UV stimulation was to be measured while ac voltages of 50 to 250 volts rms at 400 to 4,000 Hz were applied. These measurements of photocurrent when used in the computer simulation of EL/PC devices would help determine the feasibility of a UV-to-visible image converter.

3.2 Results

The literature search turned up deposition techniques only for ZnO and of course, ZnS. ZnS has a very low conductivity. The few samples of pure ZnS that we prepared with 0.002" electrode spacings and thicknesses of 6,000Å to 20,000Å had resistance values $> 10^9\ \Omega$. We could not detect any photoconductivity when stimulated with intense .336μ radiation.

We then turned to ZnO as it is somewhat better documented as a photoconductor. It seems that most techniques for producing ZnO as a photoconductor are held as proprietary and little has been published on the subject. We first attempted to deposit ZnO by reactive sputtering in a partial atmosphere of O_2. All attempts had very poor adhesion to the substrates. Next we used r-f sputtering and obtained clear, well adhering films. In thicknesses of 6,000Å to 18,000Å the films had a cell resistance (.002" electrode spacing, see Figure 1) of $1.5 \times 10^5\Omega$ to $10^3\Omega$. However, we could detect no photoconductivity under intense UV stimulation. We attempted to Cu dope the films by imbedding the substrates in doped powder and baking the container at 400°C for various lengths of time. The only result was cloudy, peeling films. Again, no photoconductivity was observed but the results are not conclusive since the films were very crazed and cracked.

As one last experiment we checked to see if the ZnS:Mn TFEL lamps would emit light at less than their normal voltage under UV stimulation. No effect other than simple fluorescence was observed.

As a consequence of the above negative results and lacking information as to proper ways to proceed in post deposition treatment of ZnO films, we discontinued effort on this task.

4.0 X-Ray to Visible Image Conversion Panels

4.1 Introduction

Past work on EL/PC mosaic structures showed that uncooled PbS photoconductive ceels appeared to not have a useful dynamic range of resistance for use in a PC-EL enfrared image converter. Very little has been done to investigate its use as an X-ray sensitive photoconductor, and it is judged that carrier lifetime is probably too short for this application.

However, a heterojunction device of PbS and CdS or PbSe and CdSe shown in Figure 14 was proposed as a possible X-ray sensitive photoconductor combination.

A sound theoretical justification for expecting useful performance from such a device couldn't be presented. The photoconductivity mechanisms for PbS are not well understood. However, work performed on a proprietary X-ray dosimeter utilizing thin films of Pb as X-ray to electron converters indicated that such a heterojunction device should be investigated.

4.2 Results

The first problem encountered with the structure of Figure 14 is that we could not prepare PbS with small enough dark conductivity to adequately turn off an EL cell.

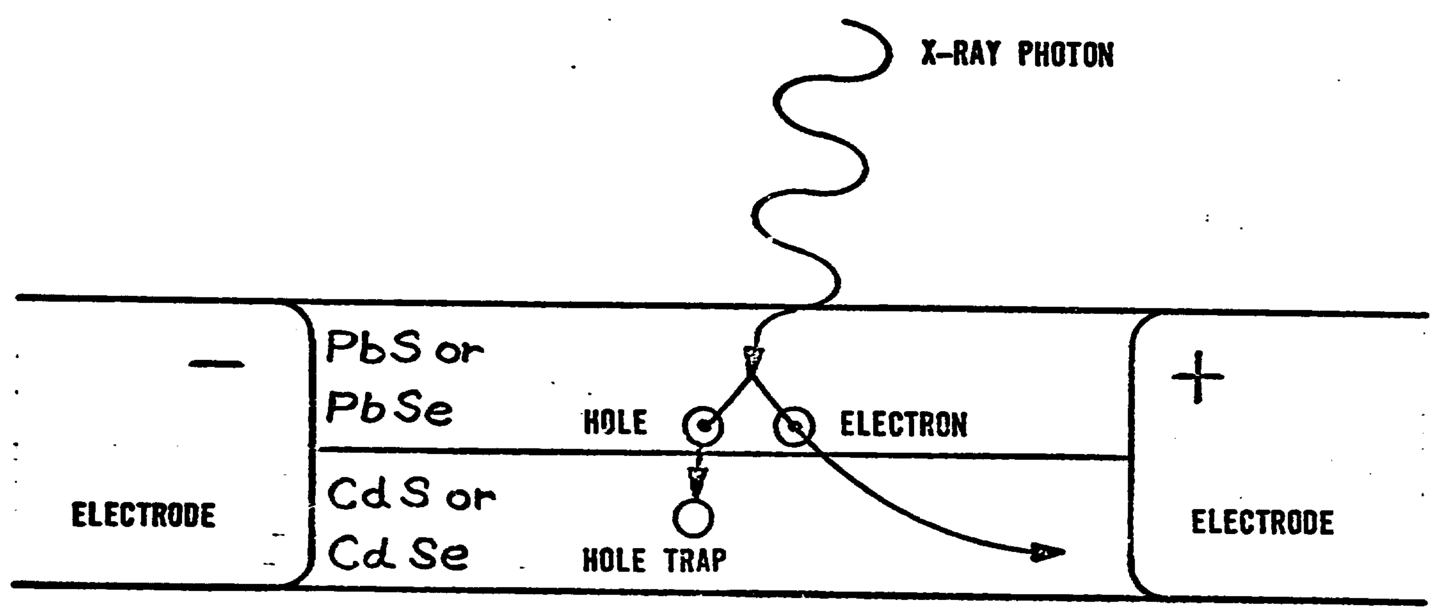
The PbS layer would effectively short out the CdS layer. The only way we could decrease the conductivity of the PbS layer was to decrease the thickness to ~ 1000-2000Å and sinter it in an O_2 atmosphere for several hours. However, films that were this thin were obviously too thin to absorb enough X-ray photons to be useful. The only other thing we could try was to see what happened if the PbS layer was patterned so that it did not contact the electrodes. If a high resistance layer formed at the PbS-CdS junction, the CdS film could retain a smooth enough electric field across its electrode gap to function as a photoconductor. Experimental trials indicated that the opposite effect occurred. It appeared that the PbS-CdS interface became a very conductive region compared to either material. As an increasing voltage was applied to the electrodes, the CdS layer would begin to break down near the electrodes. It acted as if the PbS-CdS interface was a current shunt.

At this point in the program, it was decided to cease effort on this task as proposed.

We checked to see if the operating voltage of a TFEL lamp was reduced by X-ray stimulation. There was no observable effect.

4.3 Recommendations

Using thin film photoconductors to convert X-ray photons into photocurrents of a magnitude suitable for controlling the emission of electroluminescent lamps is most probably not practical.



HETEROJUNCTION CONFIGURATION FOR
CARRIER INJECTION TRANSVERSE TO E FIELD

FIGURE 14

As long ago as eighteen years, moderately successful X-ray-to-visible conversion panels were fabricated of thick film EL and thick film CdS layers. These devices were never practical due to construction problems. Thick film CdS is very difficult to prepare in uniform layers of the necessary ~ 0.010" thickness for adequate X-ray absorption. Also, if the devices are prepared in a "sandwich" structure, which was the only practical process in the past, the shunting capacitance across the PC limits the useful range of the device. However, if TFEL instead of thick film EL could be used, the effective shunting capacitance across the CdS would be reduced significantly. If further work with direct conversion of X-rays is to be pursued, the TFEL and thick film CdS or CdSe sandwich structure should be investigated.

It should be noted that indirect conversion, using a conventional Patterson CB-2 phosphor screen to convert X-rays to visible light and then a visible-to-visible image intensifier panel to amplify the image, has been successfully developed under another contract*. In this way, reductions in radiation levels have been achieved which are quite significant. Optical gains in excess of 100 were achieved on 10" x 10" panels with 0.020" center-to-center cell spacing; image saturation can be obtained with less than 20 mR exposure to 70 KeV X-rays. This then constitutes a performance "yardstick" against which any direct conversion approach must be measured.

---

*U.S. Army Electronics Command, Fort Monmouth, Contract No. DAAB07-71-C-0267.

5.0 Visible-to-Visible Image Conversion Panels

5.1 Introduction

Under this part of the program, we were to develop, if possible, two basic types of visible light amplifier panels. The first type was to be a very sensitive panel. This type was to be sensitive to as small an input light level as possible. The second type was to have as large an output brightness as possible with its sensitivity threshold possibly no better than 10^{-2} to 10^{-1} ft-cd. The high brightness panel was to be considered mostly for use as the second stage of an image conversion system. The first stage of such a system could be whatever type of image converter we developed (IR, UV, X-ray, or Visible Light sensitive). This high brightness second stage would be used as a "brightener" to overcome ambient light problems in viewing an image on the first stage panel by itself. To build such a high brightness panel, a TFEL output is virtually required if we were to have a chance of achieving many tens of ft-Lamberts output brightness.

The first type or sensitive panel would probably have to be one using thick film EL for output. Based on previous experience, thick film EL cells are a much better impedance match for sensitive CdS type photoconductors than are TFEL cells. Also, TFEL cells had not been successfully integrated into an assembly.

As was mentioned in Section 4.3 above, concurrent with this contract we were also working on a contract from Fort Monmouth (DAAB07-71-C-0267) to develop our existing light amplifier technology into the capability for fabricating 10" x 10" image conversion panels using 0.020" EL/PC cells. This excellent research mix involving an assembly technique development program greatly benefited both programs. We used the PC doping results of this program in fabricating 10" x 10" light amplifier panels for the Army and we used the improved assembly techniques in fabricating thick film EL devices in this program.

5.2 Sensitive Light Amplifiers

5.2.1 PC Materials Study

We began with three types of PC deposition material. The first type was CdS. In all doping experiments with Cu and Cl as dopants, the resulting films were sensitive to light levels of 5×10^{-3} ft-cd or greater but response times were very sluggish. Response time for a CdS:Cu,Cl cell to reach 90% of its final conductivity was typically minutes for a stimulation of 5×10^{-3} ft-cd. Also, this material was very history-sensitive. After an hour of light stimulation for testing, the PC cells typically had to be kept in the dark overnight to be able to duplicate the results of the testing.

We also tried using a mixture of 80% CdS and 20% CdSe as a deposition material. When doped with Cu and Cl, films of this material exhibit no long-term "history" effects. However, it was difficult to include enough Cu in the films. The only way we could Cu dope with any success was to imbed the films in a crucible filled with an overdoped (Cu_2S) CdS powder and fire the covered crucible in a N_2 atmosphere at 400°C for times of 15 minutes to 2 hrs. This method would increase the resistivity and sensitivity of the films. But the films are cloudy and have poor uniformity. Subsequent doping with HCl gas further reduced the uniformity but sensitivity was generally increased.

With the poor results of the previous two types of PC, we returned to the material we have used for several years. This is an 80% CdS, 20% CdSe finely divided powder already doped with Cu and Cl and quite photoconductive. Before depositing this material, it must be baked in vacuum at 600°C for at least sixty minutes to drive out the chlorides. The PC films will not adhere to the substrates if this is not done. By using this doped powder, the PC film received adequate Cu doping during formation. Prior to this contract, we had attempted to Cu dope the PC films by evaporating minute amounts of Cu during PC film deposition but the results were always erratic.

Figure 15 is a plot of the PC cell conductivities of a 2" x 2" PC array made with the pre-doped CdS,Se powder. The bars represent the ranges of conductivity observed by measuring 25 cells spaced uniformly about the substrate. The straight line drawn through the plot is the least squares fit to the data used in the simulation programs discussed in the Appendices.

This type of photoconductor can have its impedance values at a stimulation level of 10^{-1} ft-cd varied by almost two orders of magnitude by varying the amount of Cl doping. This feature allowed us to use this same type of photoconductor in assemblies having TFEL output layers.

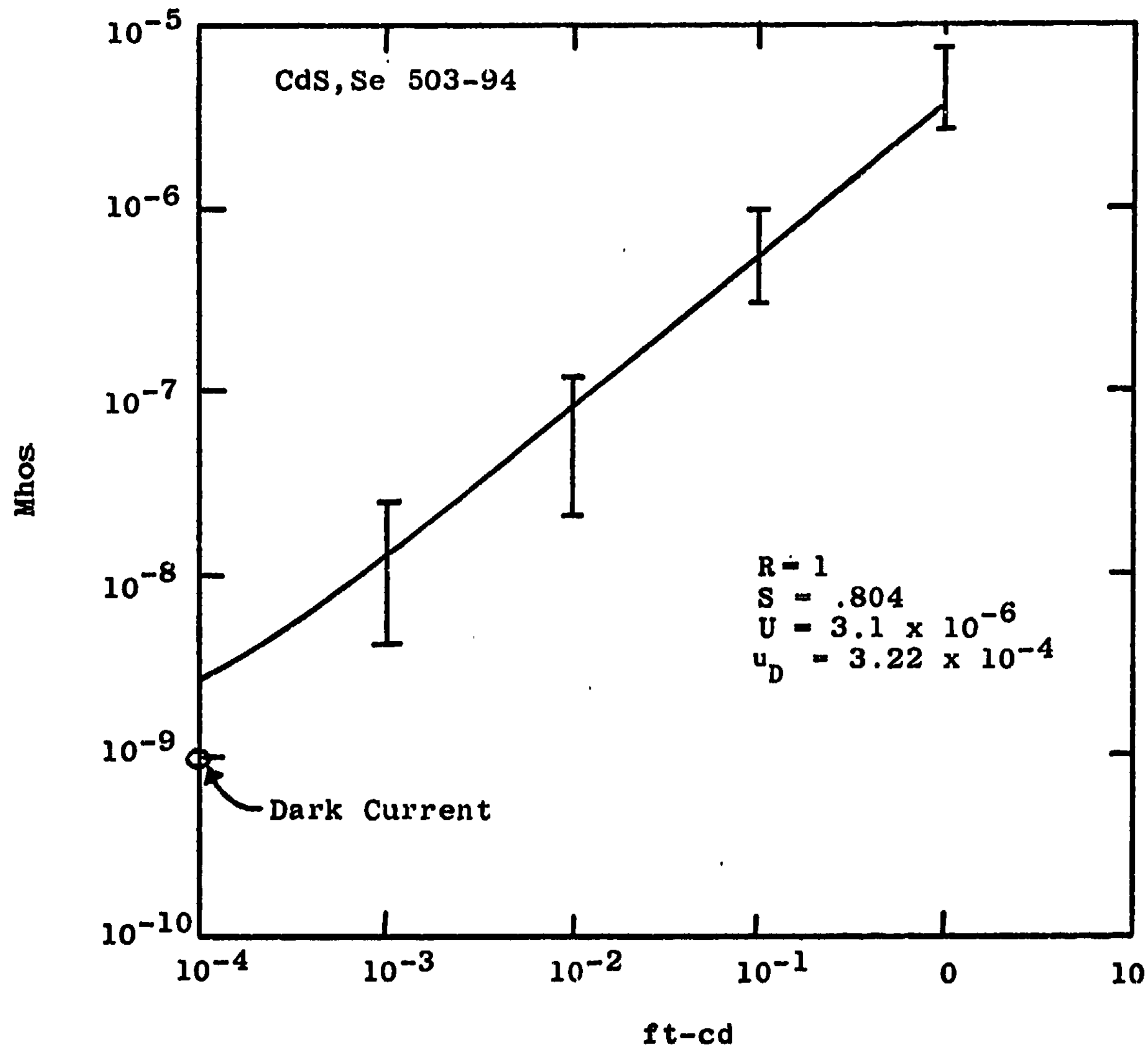
5.3 Assembly Techniques

5.3.1 Thick Film EL Assemblies

Figure 16 shows a cross-sectional view of the structure we use for thick film EL assemblies. This structure is basically the same as we have successfully used for some time. The device is assembled from the PC layer forward. The thick film EL layer is simply sprayed on.

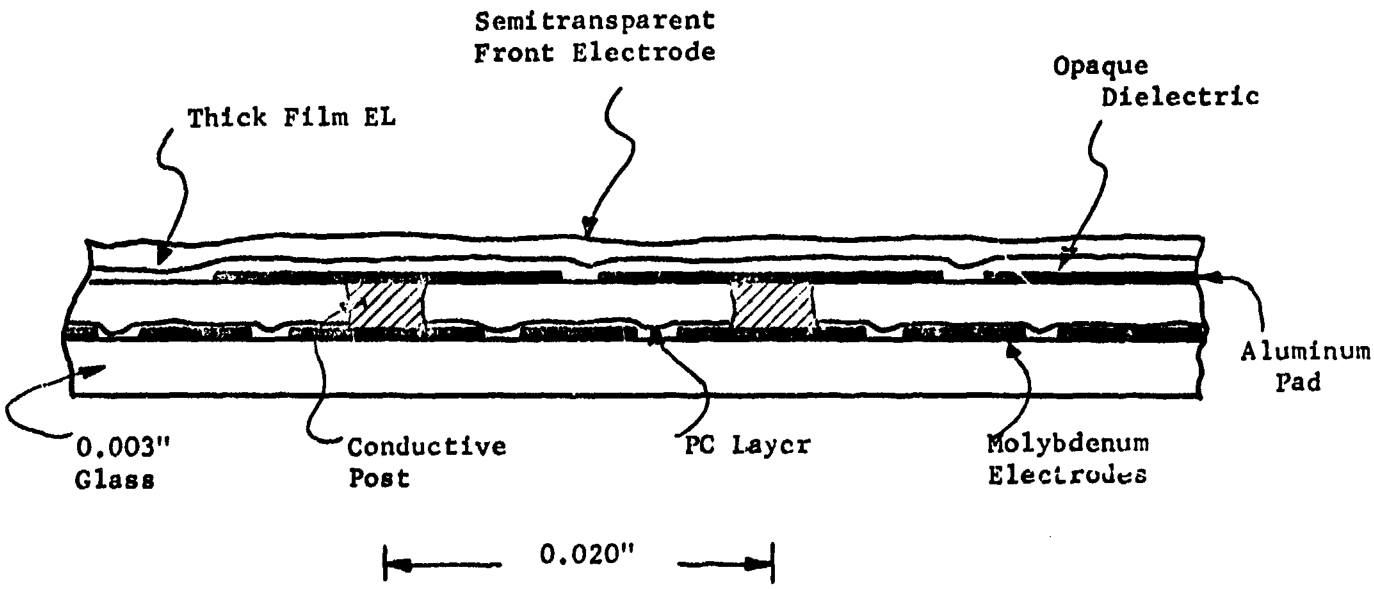
5.3.2 TFEL Assemblies

This proved to be a very difficult task. We were able to dope arrays of CdS,Se photoconductive cells to give us impedance ranges compatible with simple "sandwich" electroded TFEL lamps. We had great difficulty in successfully attaching our standard interconnect layer to the TFEL lamp array. The interconnect layer is a glass-epoxy composite



TYPICAL CONDUCTIVITY OF PC CELLS VS GREEN LIGHT STIMULATION

FIGURE 15



CROSS SECTION OF EL/PC IMAGE CONVERSION PANEL USING THICK FILM EL

FIGURE 16

layer 0.003" thick which contains solid conductive posts on 0.020" center-to-center spacing to connect the center electrode of each PC cell to the rear electrode of each TFEL cell. Our fundamental problem seemed to be that in the initial turn-on of the TFEL lamp array, there are always a number of pinhole defects that must blow out and clear the short circuits at those points. Some of these defects occur in the interface between the TFEL lamp and the conductive post. It appears that these defects enlarge to destroy the entire post-TFEL interface and then the entire TFEL cell breaks down and the effects propagate (probably because of trapped gases and heat) to neighboring cells. Eventually, most of the TFEL lamp array is destroyed.

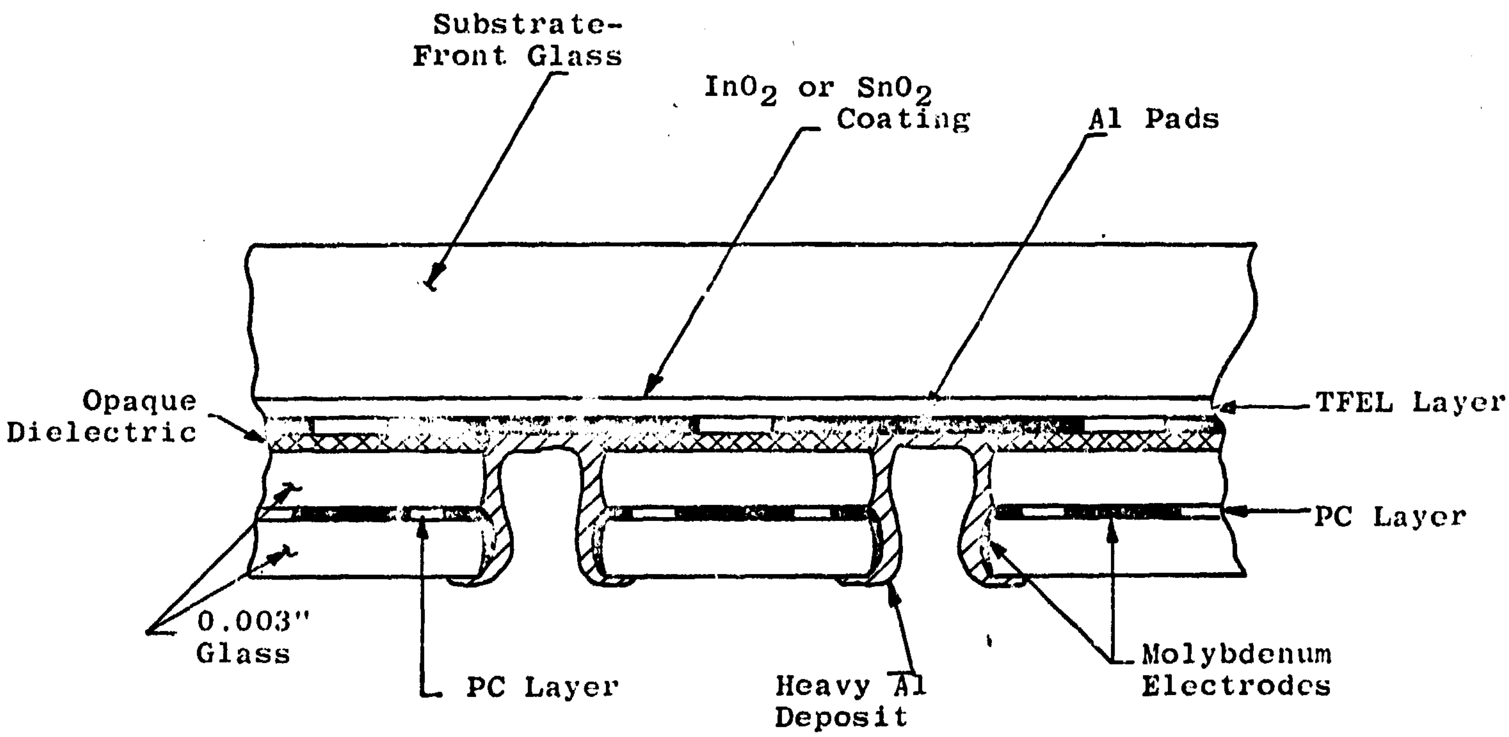
Our next approach to the problem was to omit the interconnect layer. We fabricated the PC cells on a sheet of 0.003" glass which had holes etched through the glass in the center of each center electrode of the PC cell. We bonded this PC substrate to the rear of the TFEL lamp array with the PC itself facing away from the TFEL. The PC substrate then became the interconnect layer. Then thin film through-hole interconnect techniques were used to connect the PC cell electrodes to the TFEL lamp electrodes.

This technique showed promise. For this technique to work, an opaque dielectric layer must be included at the rear of the TFEL layer to prevent light feedback from reaching the PC layer. The best thin film opaque dielectric layer that we made was made of Ge co-deposited with GeO_2. We have achieved 0.1% transparency (in the green) with a film ~ 5,000Å thick. The film has a resistivity of greater than 10^9 ohms per square. The film contained ~ 15% excess Ge. We experienced problems in achieving uniformity of resistivity of the films. The basic technique seems to be that the GeO_2 evaporation must begin first with the Ge evaporation phased in slowly until the desired ratio of rates is achieved. The usual results were that high resistance films peeled off in baking and low resistance films adhered nicely. The problem seems to be in finding the best evaporation rate schedule for getting both adhesion and high resistivity. We could not complete this task before the program was finished. So we fabricated a TFEL light amplifier using a thick film opaque dielectric. This structure is shown in Figure 17. This structure is cumbersome but it verified that the CdS,Se:CuCl photoconductor in thin film form can successfully control TFEL sandwich cells.

5.4 Assembly Test Results

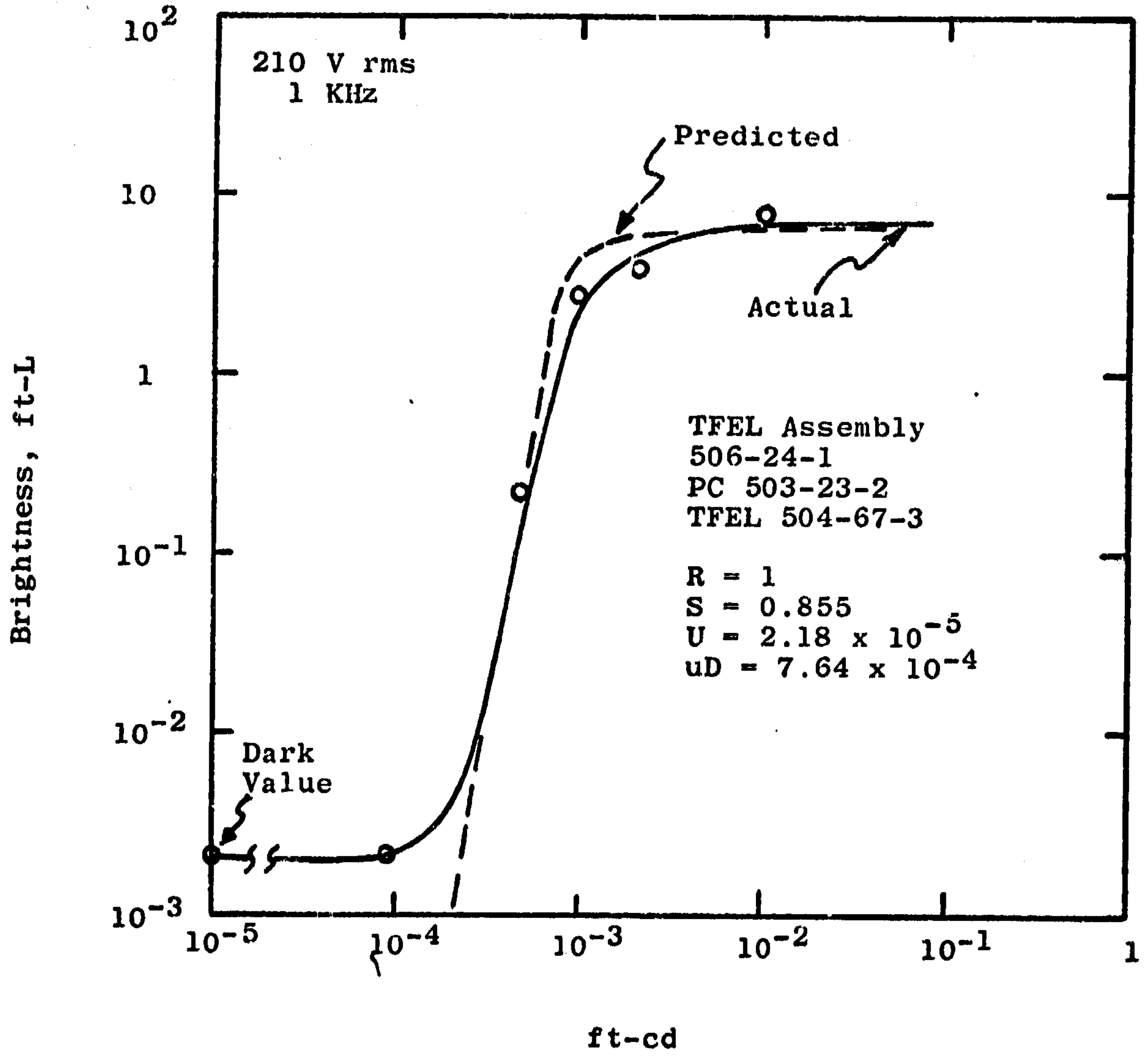
5.4.1 TFEL Assembly

A TFEL assembly built as in Figure 17 had response characteristics as shown in Figure 18. The points plotted are the averaged output of the assembly. Because of the sharp "turn-on threshold" of the device, small variations in TFEL characteristics or PC characteristics cause the vertical portion of the curve to vary over two-thirds of decade of input values. We plotted the prediction vs. the average of several cells since the prediction is an average of PC characteristics measured before assembly. The discrepancy in the dark output for the assembly is most probably due to halation from nearby shorted cells.



INTERCONNECTION TECHNIQUE FOR TFEL/PC STRUCTURE

FIGURE 17



TFEL Visible-to-Visible Image Conversion Panel

FIGURE 18

5.4.2 Thick Film EL Assembly

A thick film EL assembly built as in Figure 16 had response characteristics as shown in Figure 19. This assembly did not fit the computer simulation. Investigating the discrepancy, we discovered that the opaque dielectric layer in the thick film EL layer had been inadvertently sprayed on too thick. This decreased the response of the EL layer and consequently diminished the gain we had expected. This points up the necessity for further development of thin film opaque dielectric layers. The opaque layer should be minimized in thickness as much as possible so that as much as possible of the voltage applied to the EL cell can be across the EL material and not be wasted in the opaque layer.

5.5 Feasibility of Stacking Visible-to-Visible Image Conversion Panels onto Other Panels

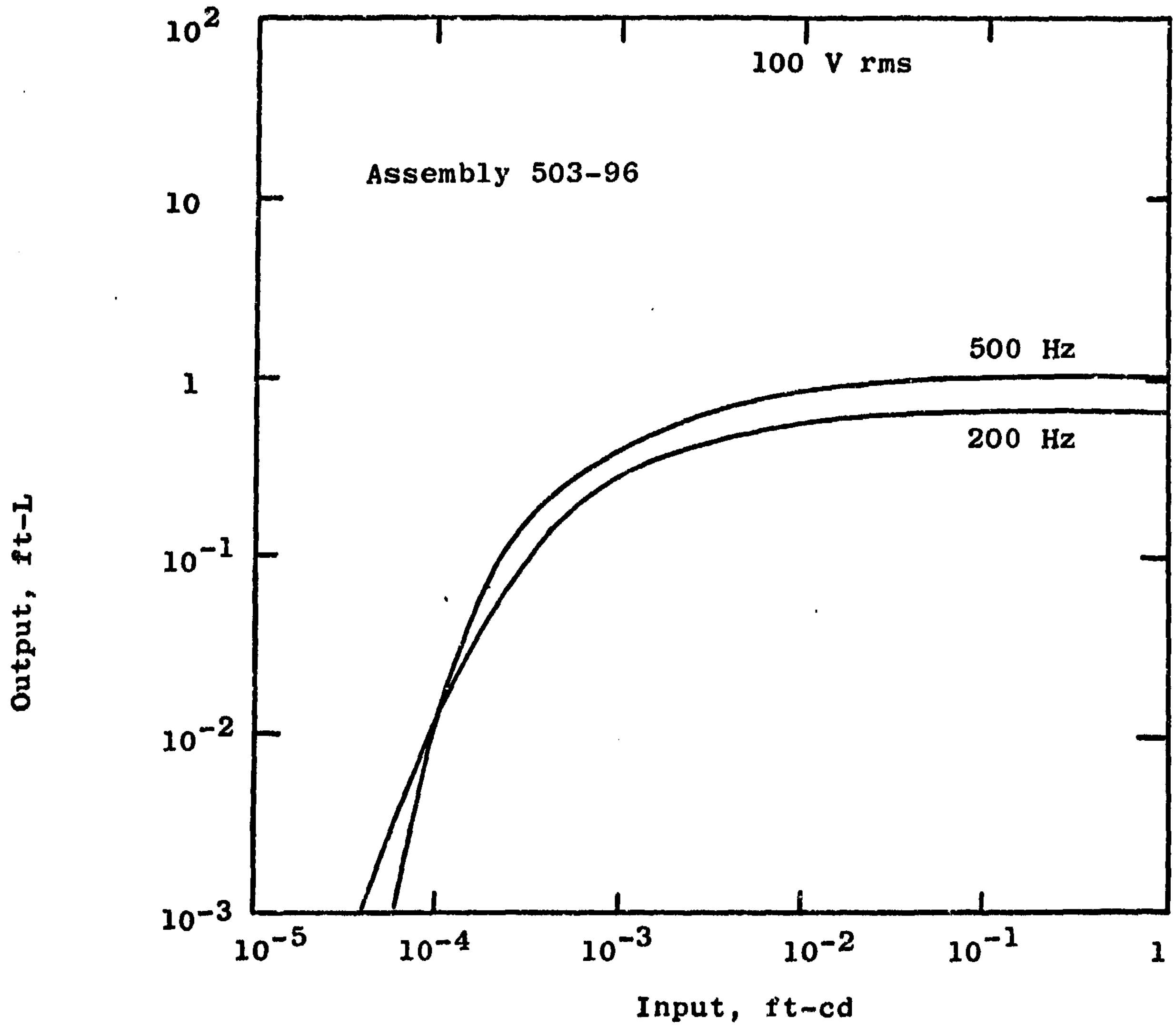
The final assemblies of TFEL and thick film EL image conversion panels were not finished in a form compatible with actual stacking of one onto another because of electroding problems.

Preliminary simulations have been performed using our best CdSe - thick film EL combination from the previous contract and data we have from previous visible-to-visible image converters. The resultant combination would have an output of less than 10^{-3} ft-L for an input of ~ 8×10^{-6} w/cm^2 and an output of ~ [illegible] ft-L for an input of ~ 2×10^{-5} w/cm^2. The usable contrast range is very narrow which makes the device almost a saturating threshold type image converter. This type of performance is due to the fact that both CdSe and CdS PC/EL image converters have a ratio of output/input that increases rapidly to saturation as a function of input. When two of these ratios are multiplied together in a "stacked" device, the resultant ratio yields and input-output curve that resembles a step function. Figure 20 is a plot of the IR input vs. output of a simulated device.

There are two methods to overcome this lack of gray scale range. The first technique is to develop photoconductors which have smaller conductivity change per unit increase in input radiation than the present photoconductors used. Past evidence indicates that some improvement can be made in this area.

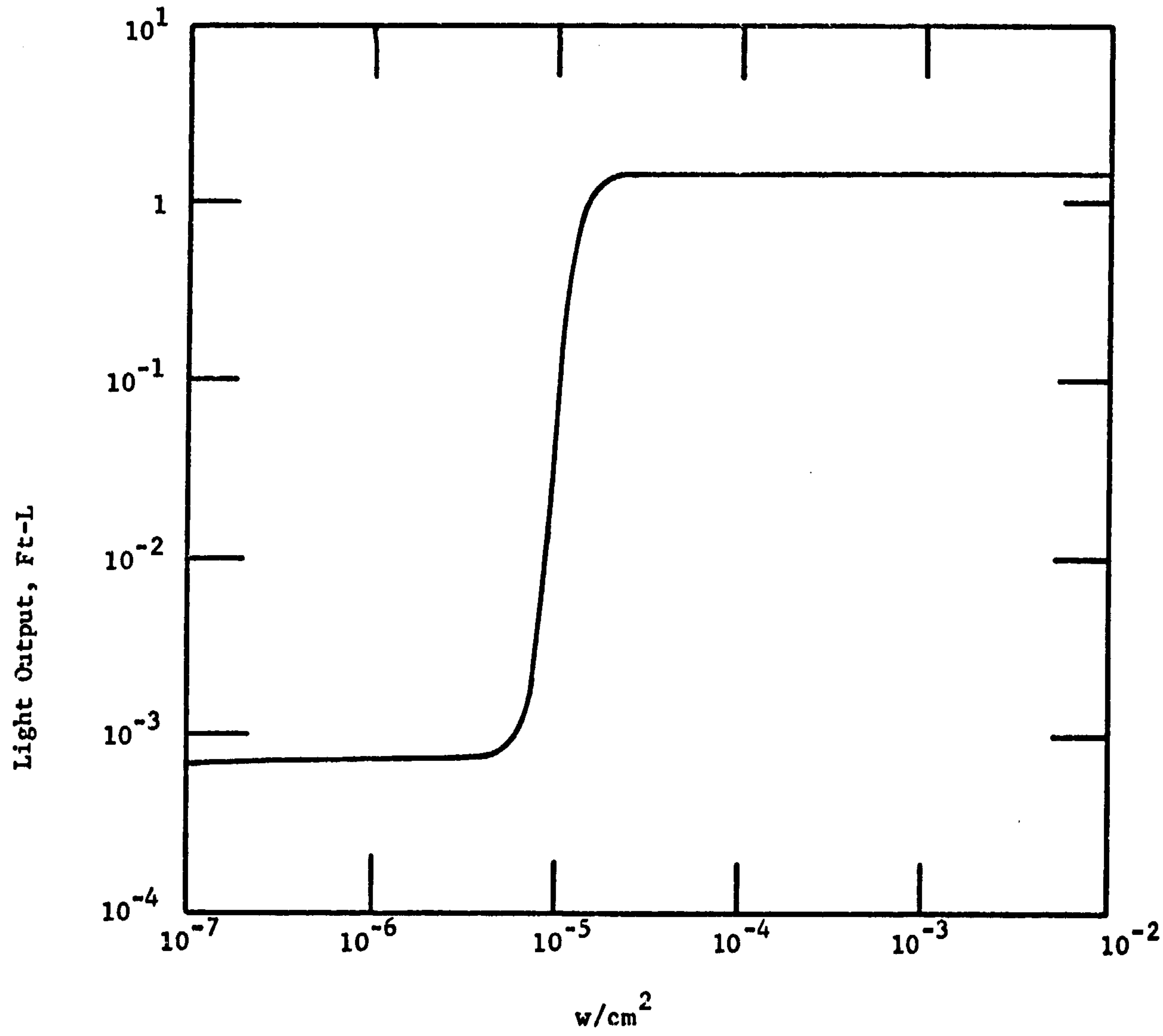
The other technique is to make use of the variation in input-output properties of the EL/PC devices as frequency of voltage is changed. Figures 21 and 22 illustrate how the input-output curves shift with voltage and frequency variation.

We are attempting to determine whether the easily implementable techniques of amplitude modulating and/or frequency modulating the driving voltage of the image converters will effectively expand the gray scale range. The basic idea is to time share the different input-output curves within the limits of the integration time of the eye so that for a fixed input level a non-flickering image is perceived.



PERFORMANCE OF THICK FILM EL VISIBLE-TO-VISIBLE IMAGE CONVERSION PANEL

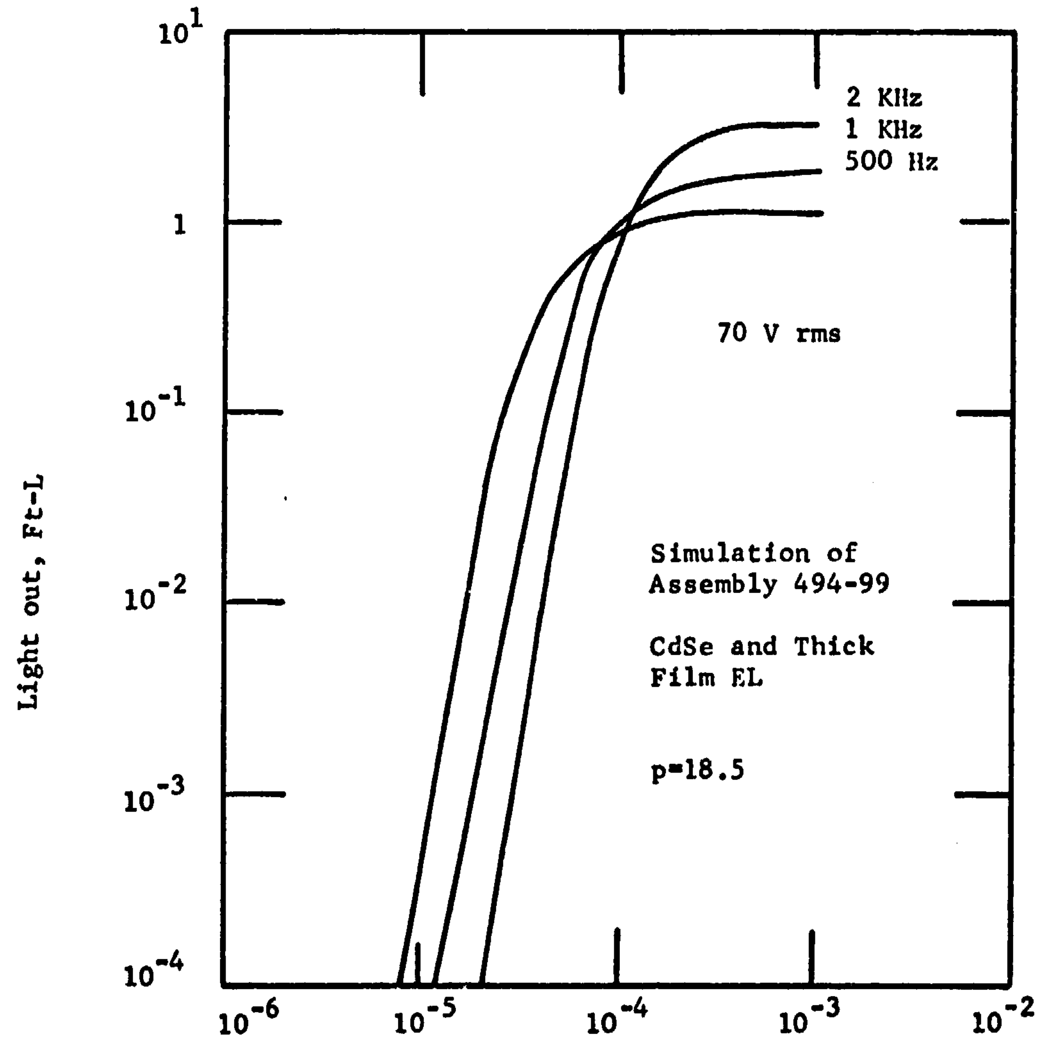
FIGURE 19



(.72μ-3.5μ, 2750°K)

Calculated Overall IR/Visible Performance of Two-Stage Cascaded Image Converter

FIGURE 20

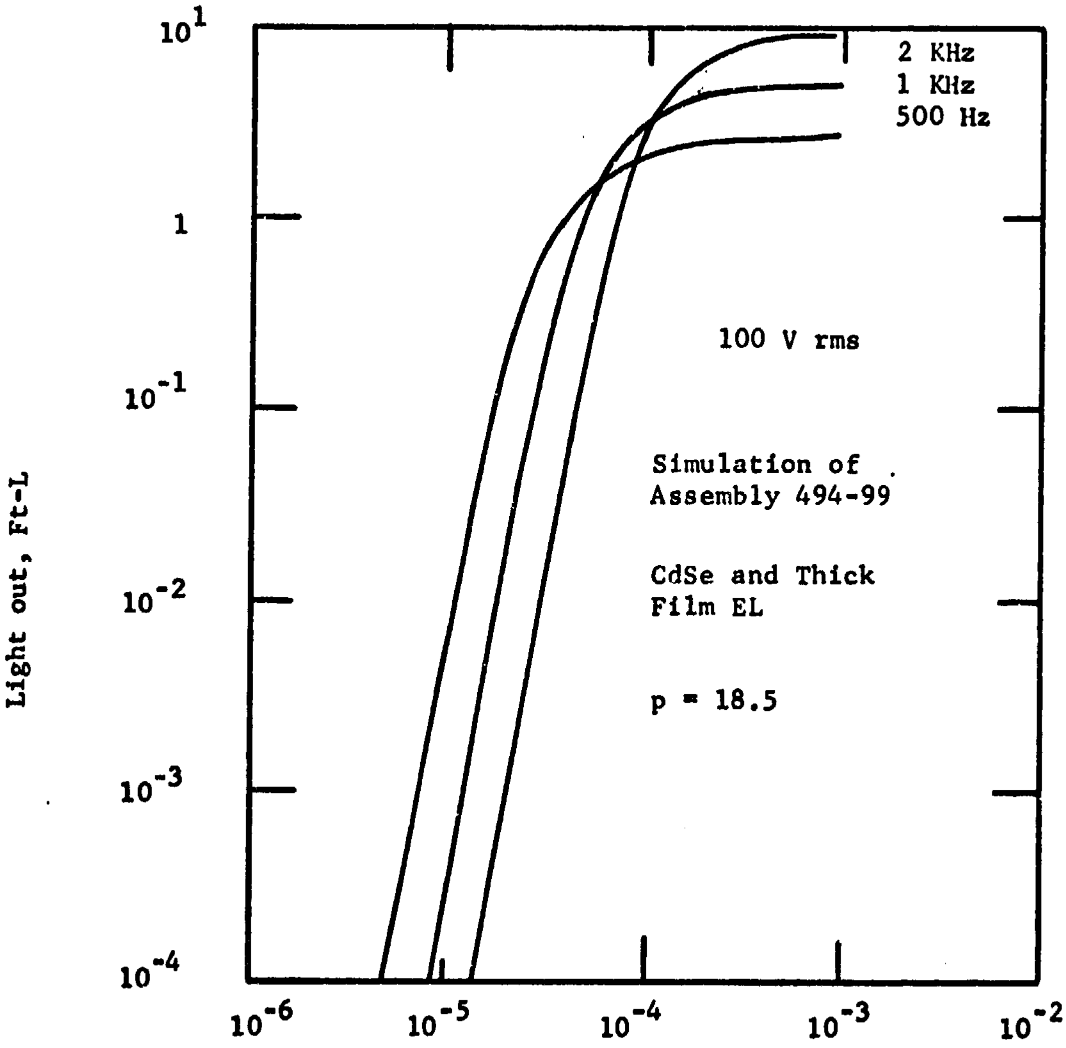


Input Radiation, w/cm^2 (.72μ-3.5μ, 2750°K)

(P is the ratio of El capacitance to shunt capacitance across the photoconductor)

Simulation of EL/PC Panel Operation at 70 V rms

FIGURE 21



Input Radiation, w/cm^2 (.72μ-3.5μ, 2750°K)

(P is the ratio of EL capacitance to shunt capacitance across the photoconductor)

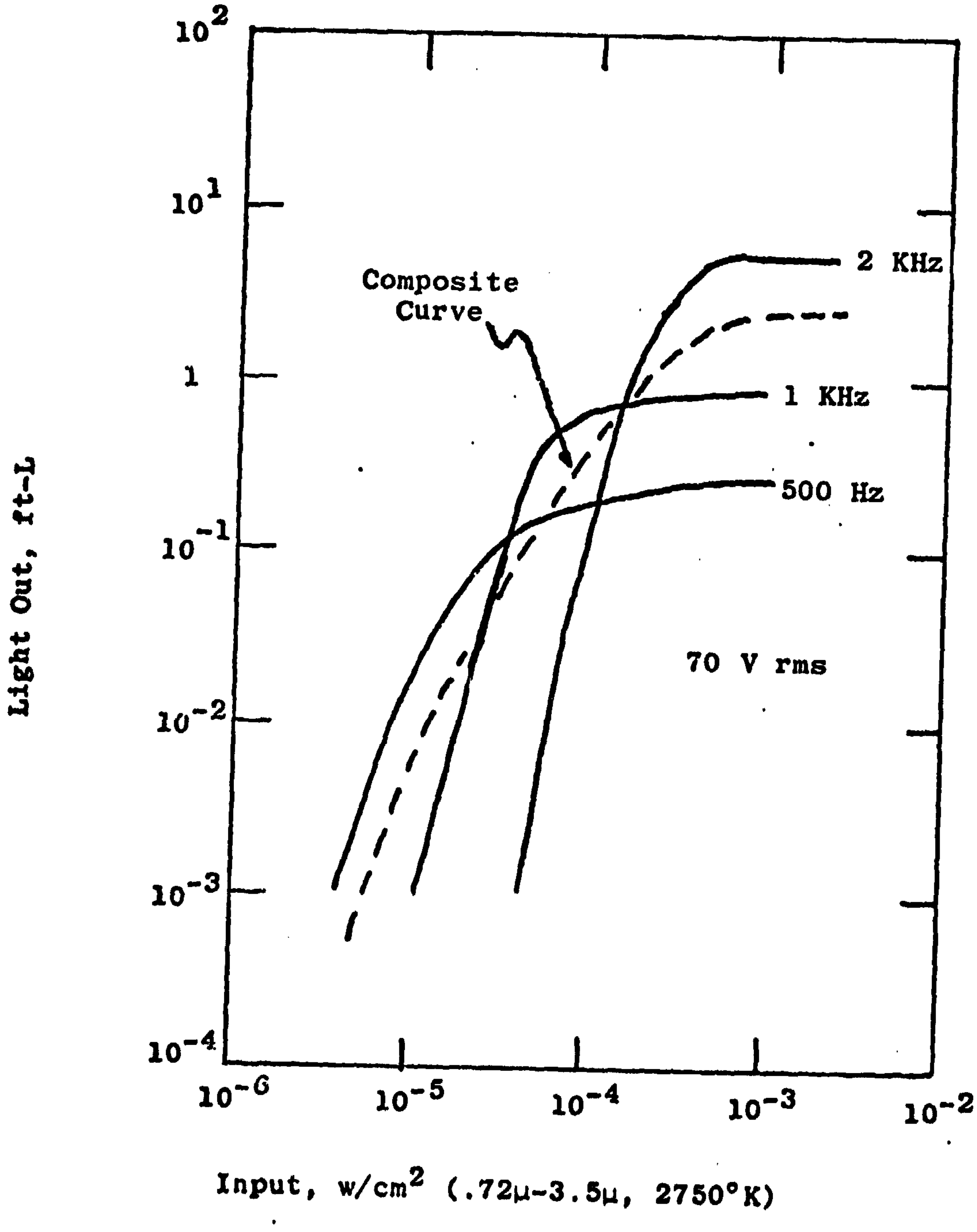
Simulation of EL/PC Panel Operation at 100 V rms

FIGURE 22

Toward this end, the computer simulations developed under the previous contract were "streamlined" and expanded to assist in easier reduction of greater quantities of data. The multi-frequency driving techniques being studied under a concurrent ONR contract have been simulated for an equal mixture of three frequencies and is plotted as the dashed curve in Figure 23. This driving technique has been experimentally verified.

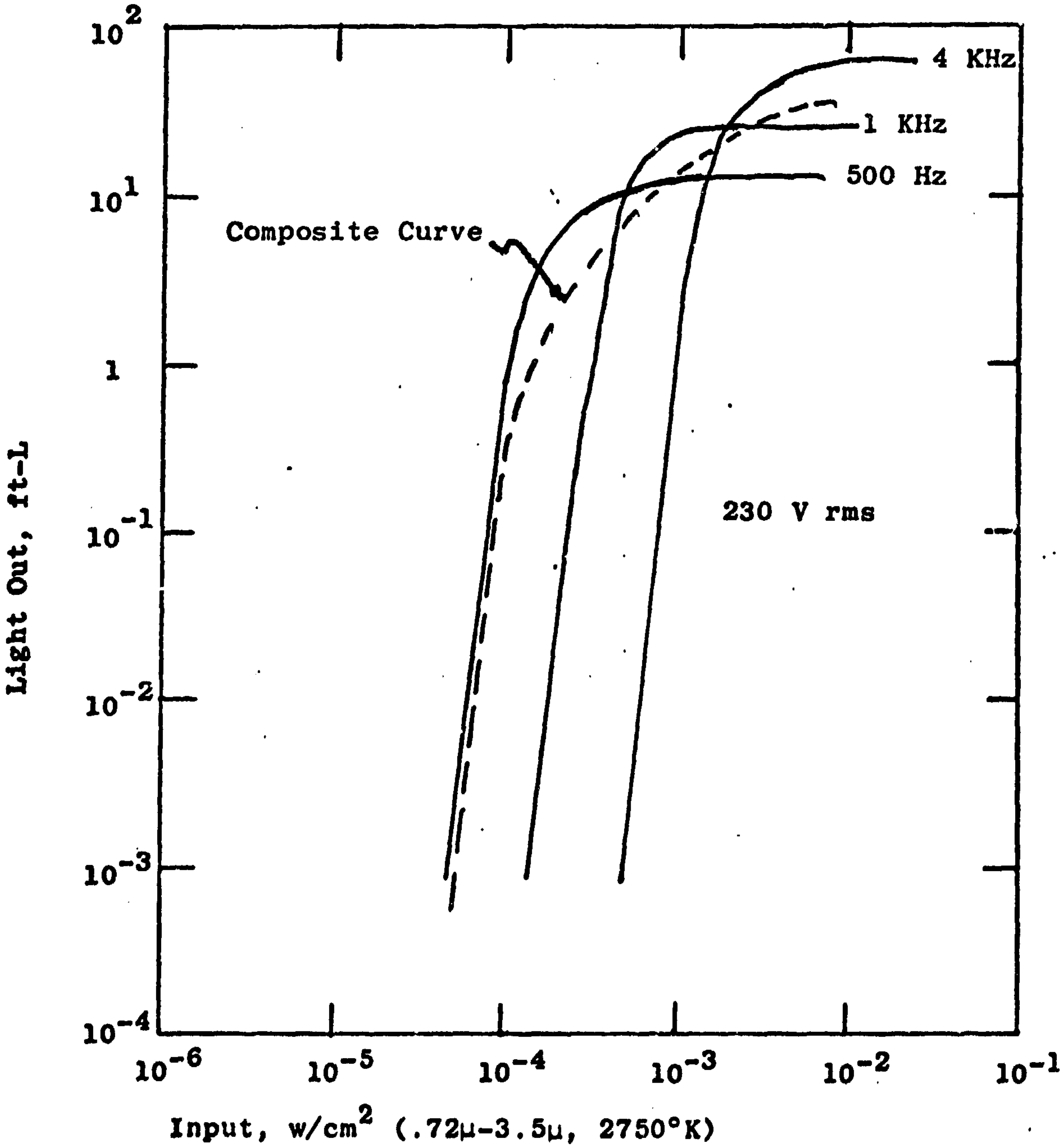
Figure 24 is the same driving technique used with a simulation of the same CdSe as Figure 23 only using TFEL for the output lamps. Again the three frequencies shown were mixed in equal proportions in the composite simulation.

It appears that if the output of the final image conversion panel is to be viewed and analyzed by the human eye, then the slope of the light-in vs. light-out curve of the final panel can be effectively made unity. This will avoid shrinking the response range of a cascaded pair of image conversion panels.



Simulated Operation of CdSe 494-95-8
With Thick Film EL Using 3 Frequency Drive

Figure 23



Simulated Operation of CdSe 494-95-8
With TFEL 494-79-2,5A Using 3 Frequency Drive

Figure 24

6.0 IR-to-Visible Image Conversion Panels

6.1 Introduction

Under this task we were to continue development of the IR sensitive CdSe-thick film EL panels we worked on under the previous contract (N00014-70-C-0213). We were to also extend the work to using TFEL as an output media. Also, we were to investigate the feasibility of placing a visible-to-visible light amplifier panel on top of an IR-to-visible image conversion panel. In this way, rather large conversion gains might be realized for the cascaded pair of panels.

6.2 Results

We finished the last program by using a CdSe PC cell array which was made by depositing pure CdSe onto an etched molybdenum electrode array (see Figure 1) on a substrate of 0.003" thick glass. The CdSe was doped with HCl gas at 400°C for 18 minutes.

Our first attempts at improving upon this technique was to dope the CdSe powder with $CuCl_2$ solution, sinter in vacuum, regrind the powder, and use this powder as deposition material. The Cl would mostly escape during sintering so the deposited films were doped with HCl gas as before. We were never able to get reproducible or uniform films with this process. Small regions of some of the films were extremely sensitive but uniformity was very poor. Vacuum annealing of the CdSe films before Cl doping didn't improve the results.

Next we tried depositing pure CdSe, ~ 10,000Å thick, and then depositing approximately 10Å of Cu on the CdSe films. The 10Å of Cu was deposited by an extrapolation method. First ribbons of Molybdenum with a known thickness of Cu were used as flash evaporation sources and the thickness of the resulting deposit was measured. This measurement gave us a source film to substrate film ratio per unit area of the source ribbon. From this data, we prepared ribbon sources to give us a 10Å Cu deposit on the CdSe. The CdSe films were then baked in vacuum at 400°C for 1 hour to diffuse in the Cu.

Again, the resulting films exhibited very poor uniformity.

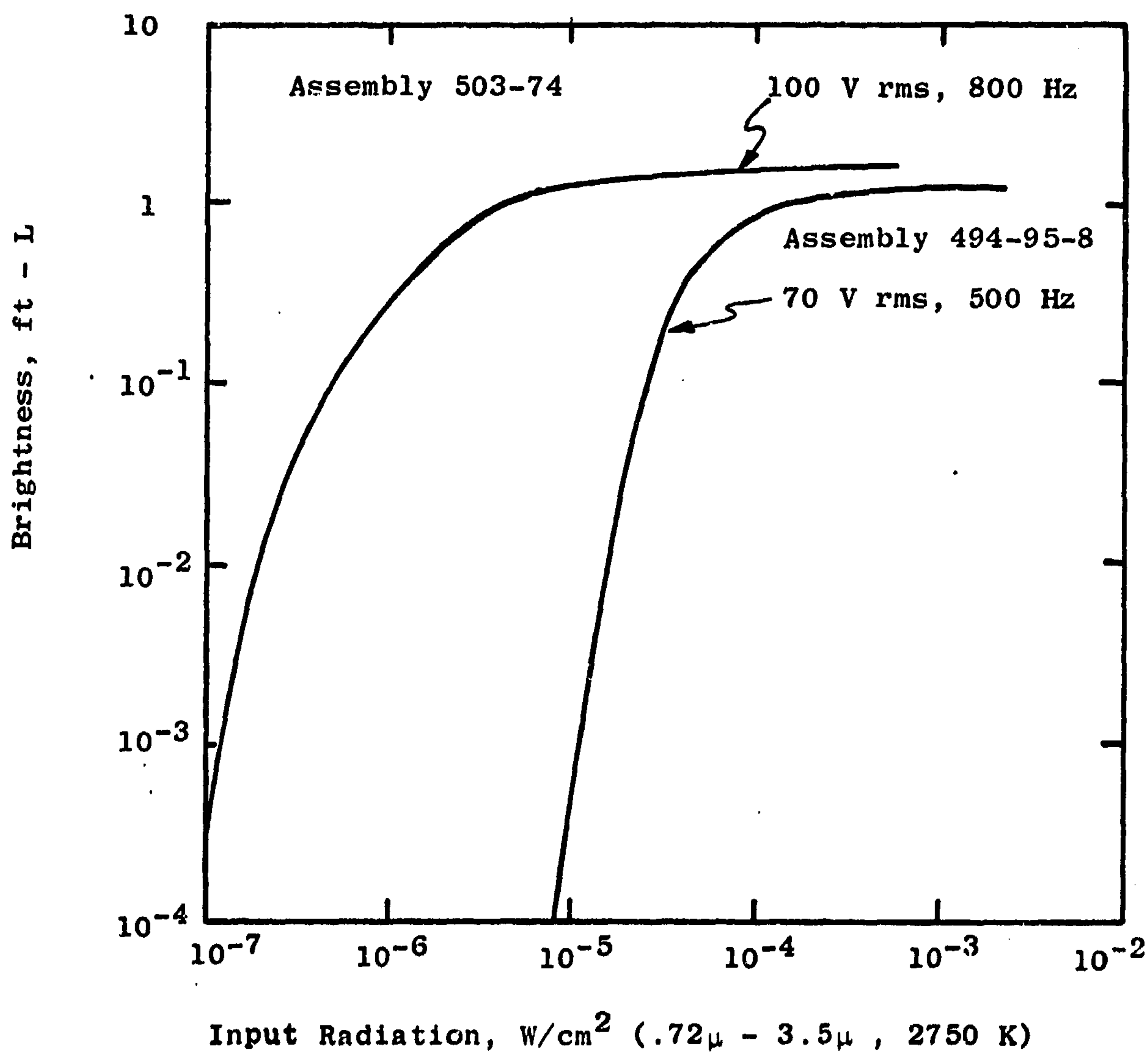
Next, we attempted to improve upon a procedure that was first tried under the previous contract. This procedure was to imbed the CdSe coated substrate in a finely ground powder consisting of 98% CdSe, 1% $CuCl_2$ and 1% NaCl as a flux. This combination of imbedding powder and substrate was then placed in a closed crucible and baked at temperatures equal to or greater than 350°C for various periods of time. All attempts produced films with very non-uniform response. We substituted Cu_2S for the $CuCl_2$ and used various amounts of NaCl and many combinations of baking times and temperatures. No improvement in uniformity was noted. The literature had many excellent descriptions of techniques similar to this being used with good results. However most experimenters reported a large class of different types of recrystallization phenomena seen when using this imbedding technique. We deduced that most previous experimenters had used rather macroscopic electrode sizes and spacings when measuring the response of their resultant films. We have found that we can only use electrode gaps of ~ .0015 to ~ 0.004" in the simple square "moated" electrode pattern (see Figure 1) and achieve proper ranges of cell impedance. The best conclusion we can draw from all the unsuccessful doping-by-imbedding experiments is that this technique is unsatisfactory when using small electrode spacings and buried electrodes.

We then returned to trying by other means to get a CdSe film properly doped with Cu and with Cl as a co-activator. Knowing that using a pre-doped powder for film deposition yielded good results for visible light photoconductors of 80% CdS and 20% CdSe, we again attempted to duplicate this technique using only CdSe doped with Cu and Cl. Initial results from using the pre-doped powder were disappointing. As a point of reference, though, it took more than six man-months of dogged effort to develop a reliable technique for depositing the pre-doped CdS,Se film. The first few pre-doped CdSe films exhibited poor adhesion in patterns very reminiscent of the ones seen in early attempts with the CdS, Se films. However, we did not have 6 man-months of effort left in the program at this time.

At this time, we decided to see just how IR sensitive our green-sensitive CdS, Se films were. A good green-sensitive thick film EL with CdS,Se:CuCl assembly was tested on the IR source and we received a pleasant surprise. It was as sensitive as was predicted for the best cells of CdSe:CuCl that we had occasionally found on some substrates. We had never thought to measure the IR response of the PC for this assembly. Figure 25 shows the response of this assembly to near IR and for comparison, the best assembly that we fabricated under the previous contract.

Following this lucky turn of events, we then tested a TFEL green-sensitive test assembly on the IR source. The results are shown in Figure 26. Again the PC used in this assembly had not been characterized with IR stimulation.

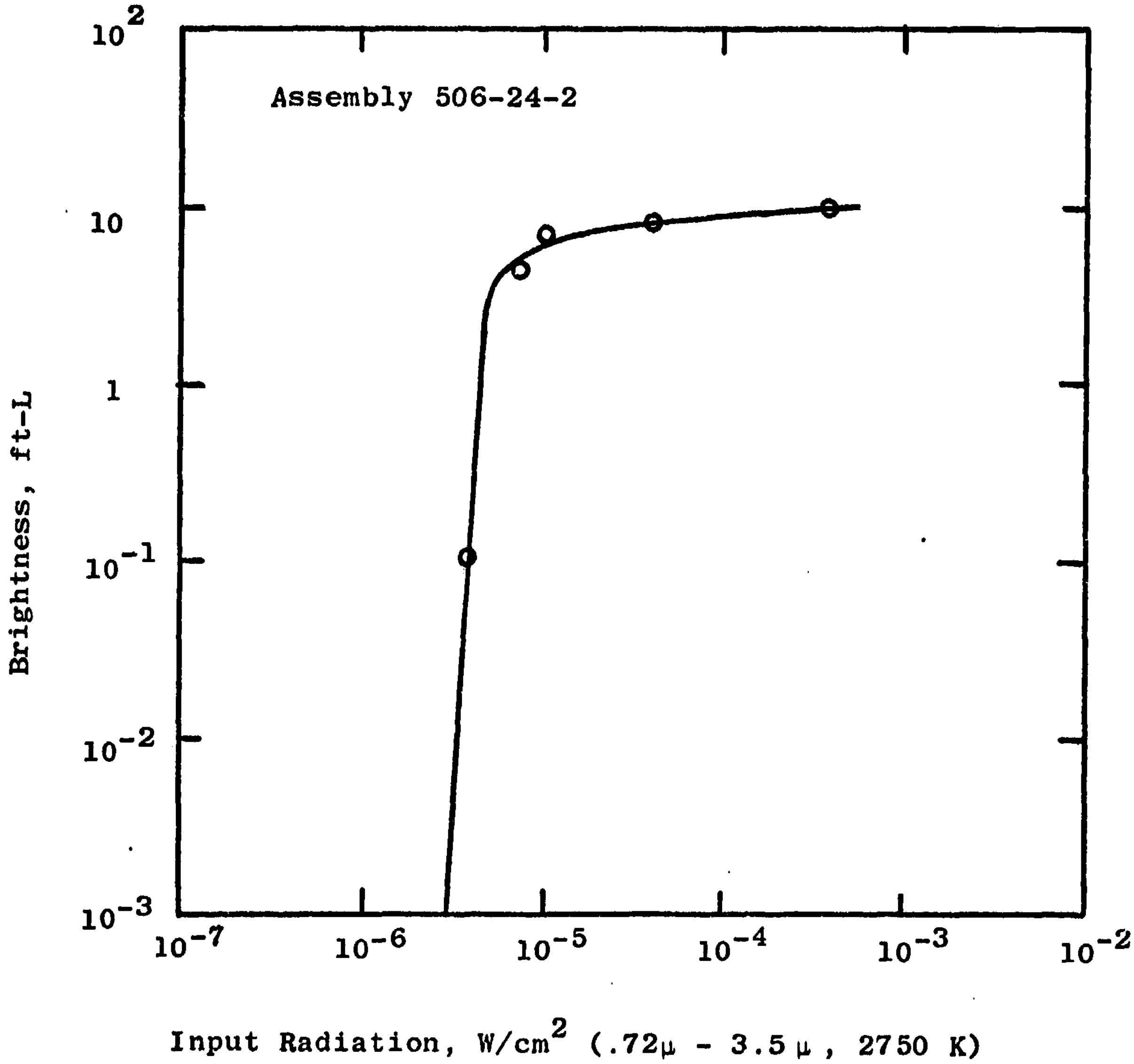
It now appears that the shortest development route to the best IR-to-visible image converter is to modify our CdS, Se:CuCl deposition powder by changing the ratio of CdS to CdSe in small increments until the best IR response is found.



THICK FILM EL/PC IR IMAGE CONVERTERS

PRESENT AND PREVIOUS

FIGURE 25



TFEL IR-TO-VISIBLE IMAGE CONVERTER

FIGURE 26

7.0 General Results, Conclusions, and Recommendations

1) We expanded modeling techniques to facilitate parameterization of materials, to investigate more complex forms of excitation waveforms, and to simulate the cascaded operation of various potential PC/EL candidate systems.

2) TFEL developed to point where can fabricate in useful brightnesses (> 50 F-L) for useful lifetimes (~ 1200 hours); test assemblies have been successfully integrated with photoconductors using these films in mosaic form.

3) Visible: P/C has been developed which, with useful uniformity over large areas, is capable of controlling output for input values around 5×10^{-4} foot-candles. Peak optical gains of the order of 500 have been achieved using thick film EL outputs (Figure 17), and of the order of 3,000 using thin film EL outputs (Figure 18).

4) IR (Figure 25): Response curve moved down 2 orders of magnitude with useful response now available at 10^{-6} w/cm^2.

5) UV: Unsuccessful in obtaining photoconductors with useful characteristics, in terms of impedance and voltage levels required to control series EL mosaic cells, with measurable sensitivity in the UV spectrum.

Recommendations:

Further studies of electroding and interconnecting TFEL would be required before mosaic arrays with the brightness and contrast required for high-ambient displays, such as avionic systems, can be realized with practical geometries and useful yields.

State of the art, in simulation, analysis, design, and fabrication, has developed to the point at which specific applications in IR and visible image amplifiers, image conversion panels, and opto-electronic logic can be evaluated using simulation techniques. In those cases where a simulation shows predicted useful performance, fabrication techniques have been perfected to the point where we can predict the feasibility of realizing a useful structure.

APPENDIX A

IR PROGRAM AND PLOT SUBROUTINE

A1. Introduction

The IR Program is written in FORTRAN IV and is used on a time sharing computer network with a remote teletypewriter terminal. The input files and keyboard inputs and the styles of data output have all been programmed with ease of data handling for the designer in mind. The details of the equations used in the circuit analysis are given in Section A2 below and a detailed description of the program itself is also given. In addition, tables of all the input parameters and a form of useful data sheets for these input parameters are given.

A2. Circuit Analysis and Solution Procedure

Figure A1 shows the form of circuit that this program solves. It is only a series parallel combination of resistors; however, the resistors vary nonlinearly. We treat this circuit as an almost linear circuit. The voltage across the EL cell is given in rms form by the equation:

$$V_2 = V_o \left| \frac{Z_2}{Z_1 + Z_2} \right| \qquad \text{Equation A1}$$

where V_o is the rms applied voltage, Z_1 is the complex impedance of the photoconductor, and Z_2 is the complex impedance of the EL cell. For simplification:

let $S_1 = \omega C_1$ and $S_2 = \omega C_2$

$$\text{then } Z_1 = \frac{1}{G_1 + jS_1} = \frac{G_1 - jS_1}{G_1^2 + S_1^2} = \text{PC Impedance}$$

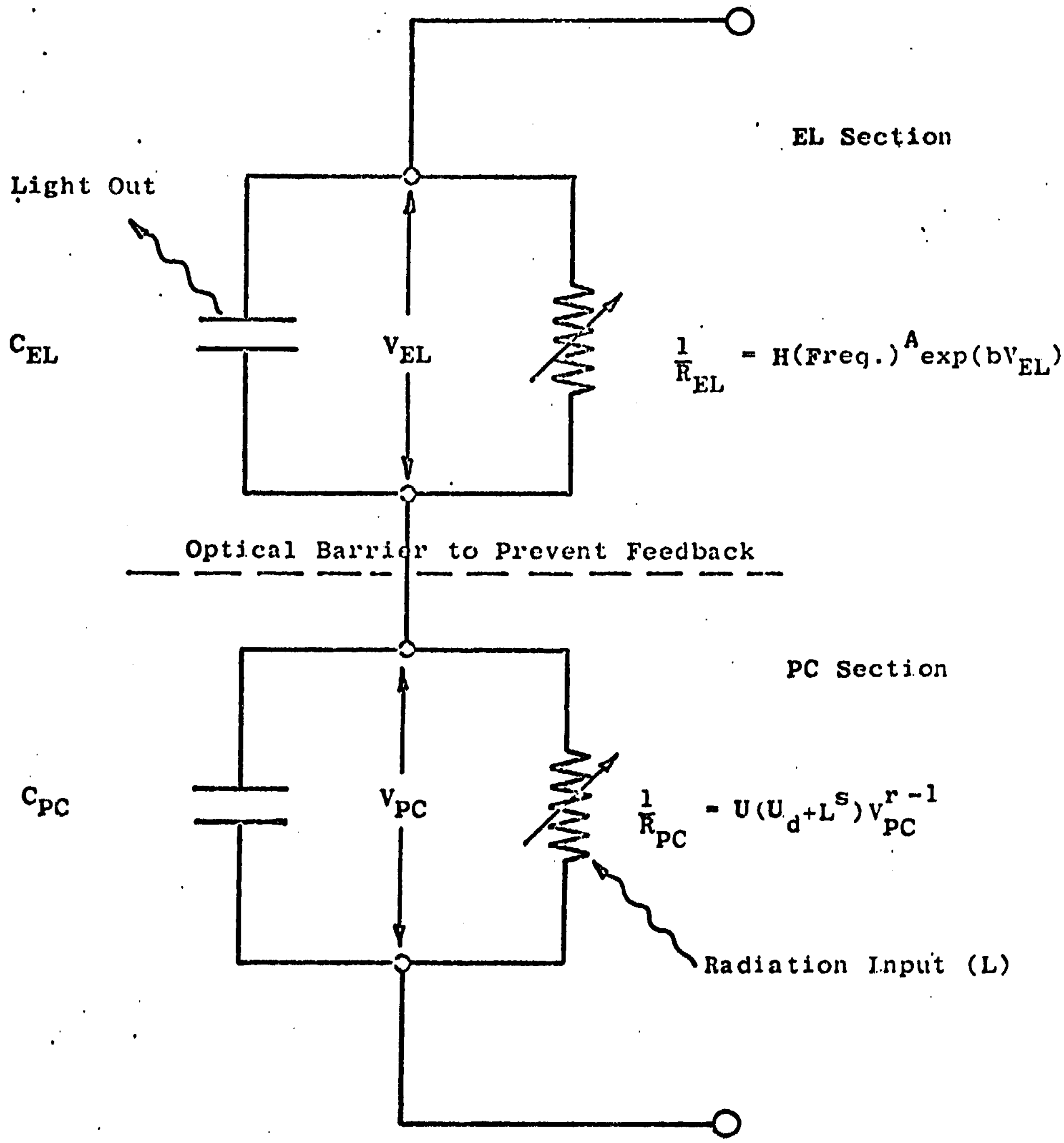
$$Z_2 = \frac{1}{G_2 + jS_2} = \frac{G_2 - jS_2}{G_2^2 + S_1^2} = \text{EL Impedance} \qquad \text{Equation A2}$$

Taking the absolute values, we have:

$$|Z_1|^2 = (G_1^2 + S_1^2)^{-1}$$

$$|Z_2|^2 = (G_2^2 + S_2^2)^{-1} \qquad \text{Equation A3}$$

$$|Z_1 + Z_2|^2 = \frac{(G_1 + G_2)^2 + (S_1 + S_2)^2}{(G_1^2 + S_1^2)(G_2^2 + S_2^2)}$$



Circuit Used in Steady State EL/PC Image Converter Simulation

FIGURE A 1

Putting these values in Equation A1, we have:

$$V_2 = V_o \sqrt{\frac{G_1^2 + S_1^2}{(G_1 + G_2)^2 + (S_1 + S_2)^2}} \qquad \text{Equation A4}$$

To help in simplification in terms later on:

$$\text{let } p = \frac{C_2}{C_1} = \frac{S_2}{S_1}, \text{ note } \frac{pG_1}{\omega C_2} = \frac{G_1}{\omega C_1} \qquad \text{Equation A5}$$

Using this simplification, Equation A1 becomes:

$$V_2 = V_o \sqrt{\frac{\left(\frac{pG_1}{\omega C_2}\right)^2 + 1}{\left(\frac{p(G_1 + G_2)}{\omega C_2}\right)^2 + (1+p)^2}} \qquad \text{Equation A6}$$

Solving similarly for V_1 we have:

$$V_1 = V_o \sqrt{\frac{\left(\frac{pG_2}{\omega C_2}\right)^2 + p^2}{\left(\frac{p(G_1 + G_2)}{\omega C_2}\right)^2 + (1 + p)^2}} \qquad \text{Equation A7}$$

Also, for the ratio of voltages of the EL to the PC element, we have:

$$\frac{V_2}{V_1} = \sqrt{\frac{\left(\frac{pG_1}{\omega C_2}\right)^2 + 1}{\left(\frac{pG_2}{\omega C_2}\right)^2 + p^2}} \qquad \text{Equation A8}$$

The photoconductor conductivity G_1 is usually described by an equation of the form:

$$G_1 = U(U_d + L^s)\ V_1^{r-1} \qquad \text{Equation A9}$$

Where U is a dimensional constant, U_d is a dark conductivity term, L is the input radiation, and s and r are constants. For completeness, the leakage conductivity of the EL is usually found to be best fit by an equation of the form:

$$G_2 = H\ \omega^A\ \exp(b(V_2)) \qquad \text{Equation A10}$$

Where H is a dimensional constant, and A and b are constants. Usually b is very small so in the computations that follow, we neglect the voltage dependence of G_2. Strictly speaking, if one were to have a large b value one should modify the derivation that follows to include this voltage dependance in G_2. The final thing to be calculated is the brightness of the EL. This brightness usually has a functional dependence as given by:

$$B = D\ F^{\alpha}\ \exp\left(-\sqrt{\frac{A}{V_2}} \right) \qquad \text{Equation A11}$$

Where D is a dimensional constant, F is the driving frequency, α and A are constants. Taking Equations A9 and A10 and substituting in equation V_1, we have:

$$G_1 = U(U_d + L^s)(f(G_1))^{r-1} \qquad \text{Equation A12}$$

Where $f(G_1)$ represents the right hand side of Equation A7. In solving this implicit equation, we now need the services of the computer. Equation A11 is of the form:

$$G_1 = f(G_1) \qquad \text{Equation A13}$$

This equation can be solved by Newton's iteration method.

Basically, this method finds the zeros of a function of the type:

$$y = f(x) \qquad \text{Equation A14}$$

By repeatedly doing an iteration of the form:

$$x_{n+1} = x_n - (y_n/y'_n) \qquad \text{Equation A15}$$

To get faster convergence, we used the second order form of this iteration equation as given below:

$$x_{n+1} = x_n - \frac{y(x_n)}{y'(x_n)} \left[1 + \frac{y(x_n)\, y''(x_n)}{(2\, y'(x_n))^2} \right] \qquad \text{Equation A16}$$

After the iteration is complete, the value of G_1 is used in Equation A6 to get the rms voltage applied to the EL cell. The actual equations used in the second order iteration are very long and are contained in the iteration calculation section of the IR Program.

A3. Description of IR Program and Plot Subroutine

IR is written in FORTRAN IV and is used on a time-sharing computer system through a standard teletype terminal. Figure A2 contains a listing of IR. Figure A3 contains a listing of PLOT. The time sharing system it has been used on has excellent file editing capabilities if the file contains line numbers. The first field of numbers on a line are the line numbers. The second field of numbers is the FORTRAN statement number field. The "*" are for comment lines. The program is liberally laced with comments as to the function of flags and switches and the purpose of a group of statements. In the program, the values of input radiation are referred to as "steps". Unless problems with the PC conductivity iteration are encountered, the input radiation as incremented as integers times powers of ten i.e., 1×10^{-6}, 2×10^{-6}, 3×10^{-6},...., 1×10^{-5}, ... If, for example, iteration convergence is not obtained for an input step of 9×10^{-4}, then the input radiation value is "backed up" to 8.1×10^{-4} (8.0×10^{-4} would have been successfully used). If iteration convergence is still not achieved, the input radiation is "backed up" to 8.01×10^{-4}. If convergence is then achieved, the input steps are then 8.02×10^{-4}, ..., 8.09×10^{-4}, 8.1×10^{-4}, ..., 8.9×10^{-4}, 9×10^{-4}. When the program is working in one of these modes, the terms "back up" or "small step" appear in the comment lines.

A feature which might be overlooked upon first glance at the program or the block diagram is that whatever form of data output is chosen, the program computes a value of light output for zero radiation input for every voltage and frequency. This computation is done at the beginning of every input light loop.

The linearized circuit equations discussed in the previous section are utilized in the program under the comment "iteration calculations" and at line 1260 and line 1300.

Table AI lists all the parameters for the data files, the file numbers, and gives a brief description of the parameters.

If desired, the resultant data may be written into a data file defined at program execution time.

Figure A4 is a block diagram of the IR program. This is not a flow chart. It is meant to be used as a guide to finding one's way through the program in addition to providing a brief overview of the operation of the program.

Figure A5 is a data sheet that has been useful to the computer operator when using the program and it contans the format specifications used in the files.

The subroutine PLOT plots logarithmically the light output versus the radiation input. The abscissa is not internally scaled and accepts only the fifty-five "normal step" values generated in IR. The ordinate scale is controlled by the variable LP which allows a vertical scale on the teletypewriter of six orders of magnitude. After the plot, 3 lines of data identification will be printed if they were included in the data files. This subroutine is used with several other programs that are described later.

IR PRØGRAM

```
      * IMAGE INTENSIFIER, G=U*(UD+T**S)*(V1**(R-1.0))
    * CHØØSE TYPE ØF ØUTPUT; KKK=1, DATA TABLE
    *                        KKK=2, PLØT ØNLY
    *                        KKK=3, DATA TABLE AND PLØT
         DIMENSIØN P(5),V(5),FR(5)
         DIMENSIØN TT(19,5),BB(19,5)
         CØMMØN TT,BB,LP
         DIMENSIØN GVØL(55)
           DIMENSIØN DV(3),AV(3),VEA(3),ALF(3)
         CALL DEFINE(1,3HEL,)
         CALL DEFINE(2,3HPC,)
         CALL DEFINE(3,6HKNØBS,)
          CALL DEFINE(4,6HBRITE )
         KILLD=0
         KKK=2
         READ (2,1) R, S, U, UD
         IF(IEØF(2).NE.1) READ (2,552)
     552 FØRMAT('                                  ')
          READ(1,2) C
         READ (1,901) AALF, DD, AA
         IF(IEØF(1).NE.1) READ(1,551)
     551 FØRMAT('                                  ')
         READ (3,4) (V(J), J=1,5)
         READ(3,4) (FR(K), K=1,5)
          READ(4,106) (VEA(I),I=1,3)
          READ(4,106) (DV(I),I=1,3)
          READ(4,106) (AV(I),I=1,3)
          READ(4,106) (ALF(I),I=1,3)
         IF(IEØF(4).NE.1) READ(4,550)
     550 FØRMAT('                                  ')
         WRITE(9,811)
     811 FØRMAT(/'CREATE A DATA FILE?  0=NØ, 1=YES'/)
         READ(9,812) KD
     812 FØRMAT(I1)
         IF(KD.EQ.1) WRITE (9,813)
     813 FØRMAT(/'SUPPRESS ØTHER ØUTPUT? 0=NØ, 1=YES'/)
         IF(KD.EQ.1) READ(9,812) KILLD
         IF(KILLD.EQ.1) GØ TØ 701
          WRITE(9,107)
         READ(9,999) KKK
     705 FØRMAT(I10)
     701 WRITE(9,997)
         READ(9,996) CSHUNT
         CSHUNT=CSHUNT*1.0E-12
         WRITE(9,5)
         READ(9,996) TBEGIN
         LP=ALØG10(TBEGIN)
         IF(KD.EQ.1) WRITE(5,792) LP
     792 FØRMAT(I2)
         WRITE (9,101) R,S,U,UD
          WRITE(9,102) C
         WRITE(9,902) AALF, DD, AA
         P(1)=C/CSHUNT
          WRITE(9,3) P(1)
         WRITE (9,104)  V
         WRITE (9,105) FR
```

Figure A2
Page 1 of IR Program

```
     WRITE(9,517) DV
     WRITE(9,518) AV
     WRITE(9,519) VEA
     WRITE(9,520) ALF
*  NVT=2  PUT G VALUES INTØ GVØL(L) ARRAY
*  NVT=1  USE GVØL(L) ARRAY FØR G IN IMPEDANCE CALC.
    IF(ABS(R-1.).LE..1) NVT=2
*  'NCK' SAVES LAST 'L' INDEX ØF INPUT LIGHT
*   LØØP IN CASE ØF SATURATIØN BREAKØUT
    NCK=0
*  'NVTCK' USED AS SWITCH TØ STATEMENT 581 IN CASE
*  ØF ITERATIØN BLØWUP WHEN COMPUTING GVØL(L) VALUES
*  USING ØTHER THAN FIRST FREQ. VALUE
     NVTCK=1
*  SET 'IVE' TØ FIRST SECTIØN ØF B VS V EL CURVE
     IVE=1
     I=1
*  VØLTAGE VALUES DØ LØØP
    DØ 88 J=1,5
    IF (V(J)-0.0) 99, 99, 10
10 CØNTINUE
*  PUT NØN-ZERØ VALUES IN INPUT,OUTPUT LIGHT MATRICES
     DØ 516 LM=1,19
     DØ 515 LLM=1,5
     TT(LM,LLM)=1.E-7
 515 BB(LM,LLM)=1.E-7
 516 CØNTINUE
*  FREQUENCY VALUES DØ LØØP
    DØ 77 K=1,5
*  SET LIGHT LØØP TERMINAL PARAMETER
    IDK=1
    IF(FR(K)-0.0)89,89,6
  6 CØNTINUE
    IF(KILLD.EQ.1) GØ TØ 815
    WRITE (9,7) P(I), V(J), FR(K)
815 CØNTINUE
301 CØNTINUE
* PRINT CØLUMN HEADINGS
    IF(KILLD.EQ.1) GØ TØ 922
    IF(IDK.EQ.1) GØ TØ 921
    GØ TØ (921,922,921), KKK
921 WRITE(9,12)
922 CØNTINUE
* SET FIRST LIGHT VALUE
    T=TBEGIN
    IF(IDK.EQ.1) T=0.
*  SET VALUES FØR LØG. INPUT LIGHT VALUE GENERATØR
    LT=ALØG10(TBEGIN*.99)
    ILT=0
* SET MAIN PRINT COUNTER
    N=0
* SET VPC AND V1 FØR ENTERING LIGHT LØØP
    VPC=V(J)/4.0
    V1=V(J)-VPC
*  SET SUBSCRIPTS FØR FIRST INPUT,ØUTPUT MATRIX VALUES
    II=0
```

Figure A2
Page 2 of IR Program

```
      KK=0
*     INPUT LIGHT LØØP
      DØ 15 L=1,IDK
* INPUT LIGHT LØG STEP GENERATØR
      ILT=ILT+1
      GØ TØ (53,53,53,53,53,53,53,53,53,52),ILT
   52 LT=LT+1
      ILT=1
   53 CØNTINUE
*
*     SET ITERATIØN BLØWUP CØUNTER
      MM=1
*     ADVANCE NØRMAL LARGE LIGHT STEP PRINT CØUNTER
     N=N+1
*     SET SMALL STEP PRINT CØUNTER
      MMM=1
* REENTER FRØM SUCCESSFUL SMALL STEP CALC.
   51 CØNTINUE
*     SET ITERATIØN CØUNTER
      M=0
*     ENTER ITERATIØN LØØP ØN SMALL LIGHT STEP
   87 CØNTINUE
      IF (L-1) 23, 23, 22
   22 VPC=V(J)-VE
      V1=VE
   23 CØNTINUE
*     CHECK VØLTAGE DEPENDENCE ØF CØNDUCTIVITY
      IF(ABS(R-1.).GT..1) GØ TØ 863
      GØ TØ (867,863),NVT
  867 IF(L.GT.NCK) GØ TØ 863
      G=GVØL(L)
      GØ TØ 864
  863 G=U*(UD+T**S)*(VPC**(R-1.))
  864 CØNTINUE
*     NØRMAL ITERATIØN REENTRY
    8 CØNTINUE
* CØMPUTE IMPEDANCE ØF PC
      Y1=P(I)*G/(6.28*FR(K)*C)
*     ADVANCE ITERATIØN CØUNTER
      M=M+1
* CØMPUTE 1/R ØF EL
      Y2G=DD*(FR(K)**AALF)*EXP(AA*(V(J)-V1))
* CØMPUTE PØWER FACTØR
      PF=1./SQRT((((6.28*FR(K)*C)/Y2G)**2)+1.)
*
*     ITERATIØN CALCULATIØNS
      Y2=P(I)*PF/SQRT(1.-PF*PF)
      Y=Y1+Y2
      Z=(1.+P(I))*(1.+P(I))
      V1=V(J)*SQRT((Y2*Y2+P(I)*P(I))/(Y*Y+Z))
      G1=U*(UD+T**S)*(V1**(R-1.))
      DIFG=(R-1.)*P(I)*G1/(6.28*FR(K)*C*(Y*Y+Z))
      DDIFG=(((DIFG*P(I)/6.28*FR(K)*C*Y))+(2.*(-DIFG)*P(I)*Y*
     + (DIFG))/(6.28*FR(K)*C*(Y*Y+Z))))/(1.+(DIFG/G1))
      GD=(G1-G)/(-DIFG-1.)
      G2=G-(GD)*(1.+((GD)*DDIFG)/(2.*(-DIFG-1.)))
```

Figure A2
Page 3 of IR Program

```
 *  CONVERGENCE TEST
ESC=ABS((G2-G)/G2)
     GØ TØ (511,512,513), MM
511 IF(ESC-0.01) 20, 20, 13
512 IF(ESC-0.02) 20, 20, 13
513 IF(ESC-0.05) 20, 20, 13
 *  VALUE FØR NEXT ITERATION
 13 G=G2
     IF (M-500) 66, 66, 44
 66 GØ TØ 8
 * END ØF ITERATIØN, NØ CØNVERGENCE
 *  TRY ADVANCING LIGHT INPUT BY 1/10 PREVIØUS STEP
 44 GØ TØ (43,131,132),MM
* FIRST BACKUP, MM=1
 43 T=T-((10.0**LT)*0.9)
     M=0
     MM=2
     MMM=2
     NVT=2
     GØ TØ 87
* SECØND BACKUP, MM=2
131 T=T-((10.0**LT)*0.09)
     M=0
     MM=3
    NNN=MMM
     MMM=2
     GØ TØ 37
 *  ITERATIØN HAS CØNVERGED
 20 CØNTINUE
* CØMPUTE ØUTPUT VARIABLES
Y3=P(I)*G2/(6.28*FR(K)*C)
VE=V(J)*SQRT((Y3*Y3+1.0)/((Y3+Y2)*(Y3+Y2)+Z))
     DØ 181 IT=1,3
     IF(VE-VEA(IT) ) 182,181,181
182 IVE=IT
     GØ TØ 183
181 CØNTINUE
183 CØNTINUE
 400 DVLØG=ALØG(DV(IVE))
      FLØG=ALF(IVE)*(ALØG(FR(K)))
      ELØG=SQRT(AV(IVE)/VE)
      BLØG=DVLØG+FLØG-ELØG
    IF(BLØG.LT.-23.026) BLØG=-23.026
      B=EXP(BLØG)
* SMALL STEP PRINT CHECK
     GØ TØ (393,396,395,396,395,396,395,396,395,394), MMM
396 WRITE(9,11) T, B, VE, G2
395 CØNTINUE
     GØ TØ (393,397,398), MM
398 T=T+((10.0**LT)*0.01)
     GØ TØ 399
397 T=T+((10.0**LT)*0.1)
399 MMM=MMM+1
     M=0
     GØ TØ 87
394 GØ TØ (571,572,573),MM
```

Figure A2
Page 4 of IR Program

```
573 T=T+((10.**LT)*.01)
    MMM=NNN
     MM=2
     GØ TØ 571
572 T=T+((10.**LT)*.1)
     MMM=1
     MM=1
     GØ TØ (571,581),NVTCK
581 NVT=1
571 GØ TØ 51
* END ØF SMALL STEP CALC.
* MAIN STEP PRINT CHECK
393 CØNTINUE
     IF(IDK.EQ.1)GØ TØ 951
    IF(ABS(R-1.).GT..1) GØ TØ 862
    GØ TØ (866,869),NVT
866 IF(L.LE.NCK) GØ TØ 862
869 GVØL(L)=G2
862 GØ TØ (96,96,15,15,96,15,15,15,98),N
 96 CØNTINUE
    GØ TØ (693,930,930), KKK
930 CØNTINUE
    II=II+1
    JJ=K
    KK=KK+1
    LL=K
    TT(II,JJ)=T
    BB(KK,LL)=B
     IF(KD.EQ.1) WRITE(5,810) B,T,V(J),FR(K)
810 FØRMAT(4E12.4)
    IF(II-19) 693,692,692
 692 II=0
    KK=0
693 CØNTINUE
    GØ TØ (951,950,951), KKK
951 CØNTINUE
    IF(KILLD.EQ.1) GØ TØ 814
    WRITE(9,11) T, B, VE, G2
814 CØNTINUE
    IF(IDK.EQ.1) GØ TØ 300
950 CØNTINUE
* BREAKØUT ØF LIGHT LØØP IF ØUTPUT IS SATURATED
    IF (L-1) 232, 232, 231
231 IF ((VE/V(J))-0.995) 232, 111, 111
232 CØNTINUE
 98 IF (N-9) 612, 611, 611
611 N=0
612 CØNTINUE
* END ØF LIGHT STEP LØØP
 15 T=T+(10.0**LT)
    IDK=1
    NCK=55
    GØ TØ 111
 *  CHANGE LIGHT LØØP TØ FULL RANGE
300 IDK=55
    GØ TØ 301
```

FIGURE A2
Page 5 of IR Program

```
*  ESCAPE FROM LIGHT LOOP ( SATURATED OUTPUT )
111 CONTINUE
   NVT=1
    NVTCK=2
    IF(NCK.EQ.55) GO TO 63
    NCK=L
 63 CONTINUE
    GO TO 77
*  NO ITERATION CONVERGENCE FOR THIS FREQ.,VOLTAGE
132 WRITE(9,33) ESC
* END OF FREQ DO LOOP
77 CONTINUE
 89 CONTINUE
    GO TO (940,941,941), KKK
941 CONTINUE
*  CALL PLOTTING SUBR.
    IF(KILLD.EQ.1) GO TO 940
    CALL LOGPL
    WRITE(9,552)
    WRITE(9,55.)
    WRITE(9,550)
940 CONTINUE
   NVT=2
   NCK=0
    NVTCK=1
* END OF VOLT DO LOOP
 88 CONTINUE
99 CONTINUE
*
*  FORMAT STATEMENTS
517 FORMAT('DV = ',3(1PE8.2,2X))
 12 FORMAT('WATTS/CM2',2X,'LIGHT OUT',4X,'V EL',6X,'PCOND')
 11 FORMAT(1P4E10.2)
  1 FORMAT(4E15.2)
101 FORMAT(//4H  R=,1PE10.2,4H  S=,E10.2,4H  U=,1PE10.2,
   + 4H UD=,1PE10.2)
  2 FORMAT(E15.6)
102 FORMAT('  C=',1PE10.2)
901 FORMAT(3E15.6)
902 FORMAT(5HAALF=,1PE9.2,4H DD=,1PE10.2,4H AA=,E10.2)
  3 FORMAT('CAP RATIO=',1PE8.2)
518 FORMAT('AV = ',3(1PE8.2,2X))
  4 FORMAT(5F10.1)
104 FORMAT (10H V APPL=  ,5F10.1)
  5 FORMAT('BEGINNING INPUT RAD.'/)
105 FORMAT(10H  FREQ=   ,5F10.1)
  7 FORMAT(10HCAP RATIO=,F6.1,10H   V APPL=,F6.1,
   + 8H   FREQ=,F7.1)
33 FORMAT(3HESC,1PE20.8)
106 FORMAT(3E16.2)
107 FORMAT('TYPE "2" IF PLOT IS DESIRED'/
  +  'TYPE "1" IF ONLY DATA IS DESIRED'/
  +  'TYPE "3" IF BOTH DATA AND PLOT ARE DESIRED'//)
997 FORMAT('TYPE PC SHUNT CAPACITANCE IN PF'//)
996 FORMAT(E16.2)
999 FORMAT(I1)
```

FIGURE A2
Page 6 of IR Program

IR PRØGRAM

```
 6660 519 FØRMAT('VEA = ',3(1PE8.2,2X))
 6680 520 FØRMAT('ALF=  ',3(1PE8.2,2X)/)
 6780     STØP
 6800     END
```

FIGURE A2
Page 7 of IR Program

PLOT SUBROUTINE

```
      SUBRØUTINE LØGPL
      INTEGER X,PLØT,BLANK,DØT
      DIMENSION LINE(61), XX(19,5), YY(19,5),Y(5),PLØT(5)
      CØMMØN XX,YY,LP
* CHØØSE PLOTTING SYMBØLS
      DATA BLANK/1H /,DØT/1H*/,X/1HX/
      DATA PLØT/1H1,1H2,1H3,1H4,1H5/
* LABEL THE PLØT
      WRITE (9,201)
  201 FØRMAT(///20H   LIGHT ØUT, FT L   )
  207 WRITE(9,600)
  600 FØRMAT('10-4',5X,'10-3',6X,'10-2',6X,'10-1',7X,
     + '1',8X,'10+1',6X,'10+2')
* PRINT LEFT BØRDER
   99 CØNTINUE
      DØ 101 N=1,61
      LINE(N)=DØT
  101 CØNTINUE
  602 DØ 605 I=1,7
      LIN=1+10*(I-1)
      LINE(LIN)=X
  605 CØNTINUE
  603 WRITE(9,102) LINE, LP
  102 FØRMAT (61A1,'1.0E',I2)
* BLANK THE LINE
      DØ 103 I=1,61
      LINE(I)=BLANK
  103 CØNTINUE
* WE ØNLY PLØT 1,2,5,10,ETC ØN X-AXIS;2=2,5=4,10=6
* CØMPUTE YY PØINTS
      DØ 105 K=1,19
      DØ 104 L=1,5
      IF(YY(K,L).LT.1.E-7) YY(K,L)=1.E-7
      Y(L)=ALØG10(YY(K,L))
  222 YY(K,L)=Y(L)*10.+41.
  104 CØNTINUE
  105 CØNTINUE
* X AXIS STEP LØØP
      DØ 107 I=1,19
* MAKE SURE LINE(N) IS BLANK
      DØ 120 NN=1,61
      LINE(NN)=BLANK
  120 CØNTINUE
* LØAD IN PLØTTING SYMBØLS IN CØRRECT PØSITIØN
      ICHECK=0
      DØ 106 J=1,5
      N=YY(I,J)
      IF (N-0) 106, 106, 108
  108 IF (N-61) 109, 109, 106
  109 LINE(N)=PLØT(J)
      ICHECK=ICHECK+1
  106 CØNTINUE
      LINE(1)=DØT
* SELECT HØRIZ. PØSITIØN
      GØ TØ (107,111,112,114,111,112,114,111,112,114,111,112,
     + 114,111,112,114,111,112,114), I
```

FIGURE A3
PAGE 1 of PLOT PROGRAM

PLØT SUBRØUTINE

```
* PLØT 2
111 IF(ICHECK-0) 400, 400, 411
400 WRITE(9,402) LINE(1)
402 FØRMAT(1H./1A1)
    GØ TØ 107
411 IC=61
    DØ 70 IV=1,61
    IF(LINE(IC).NE.BLANK) GØ TØ 80
    IC=IC-1
 70 CØNTINUE
 80 CØNTINUE
503 WRITE(9,403) (LINE(NNN), NNN=1,IC)
    GØ TØ 107
403 FØRMAT(1H./61A1)
* PLØT 5
112 IF(ICHECK-0) 400, 400, 412
412 IC=61
    DØ 82 IV=1,61
    IF(LINE(IC).NE.BLANK) GØ TØ 84
    IC=IC-1
 82 CØNTINUE
 84 CØNTINUE
    WRITE(9,404) (LINE(NNN),NNN=1,IC)
404 FØRMAT(1H./61A1)
    GØ TØ 107
* PLØT 1, 10, ETC.
114 LINE(1)=X
    LINE(61)=X
    LP=LP+1
    IF (I-19) 443, 445, 445
443 CØNTINUE
    IF(ICHECK-0) 400, 400, 444
* RIGHT BØRDER DECADE MARKERS
445 DØ 714 IDUM=1,7
    LIN=1+10*(IDUM-1)
    LINE(LIN)=X
714 CØNTINUE
713 WRITE(9,301) LINE,LP
301 FØRMAT(1H./61A1,'1.0E',I2)
    GØ TØ 107
444 CØNTINUE
511 WRITE (9,405) LINE,LP
405 FØRMAT(1H./61A1,'1.0E',I2)
107 CØNTINUE
    LP=LP-6
    RETURN
    END
```

FIGURE A3
PAGE 2 OF PLOT PROGRAM

TABLE AI

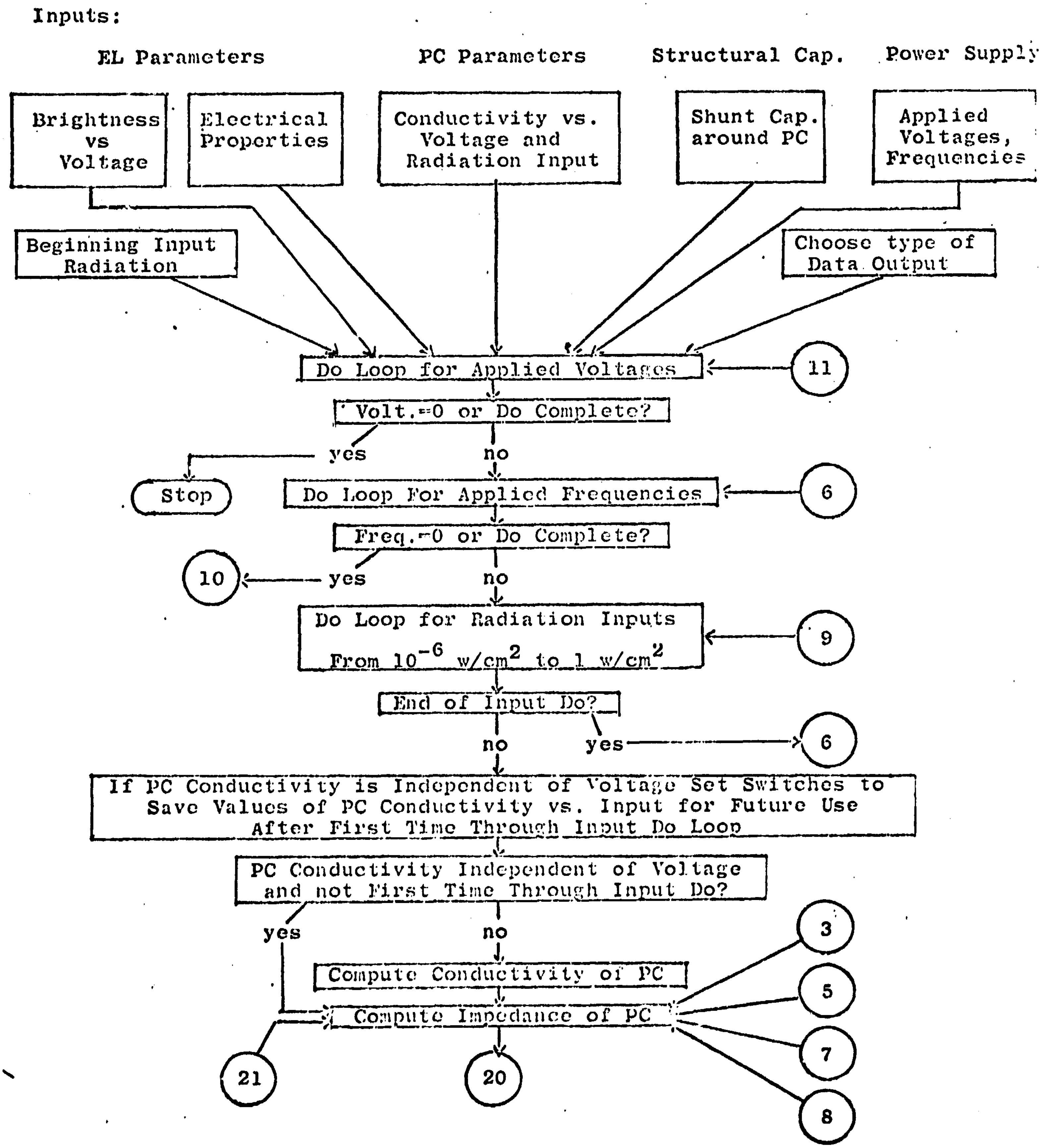
Input Parameters for IR Program

File Name	Input Device	Variable	Comments
EL	1	C	Capacitance of EL/cell
		AALF	Frequency dependence of EL leakage conductivity. $G_{EL} \propto$ (Freq.) AALF
		DD	Dimensional constant (H) for EL leakage conductivity (EL conductivity is in mhos)
		AA	Coefficient (b) of voltage dependence of EL leakage conductivity. $G_{EL} \propto$ Exp(AA*(Voltage))
		(Optional)	30 character line for data identification
PC	2	R	Exponent of voltage dependence of PC conductivity. $G_{PC} \propto (\text{Volt})^{R-1}$
		S	Exponent of input energy dependence of PC conductivity. $G_{PC} \propto (L)^S$
		U	Dimensional constant for PC conductivity (PC conductivity in mhos)
		UD	Dark current constant (U_d) for PC conductivity
		(Optional)	30 character line for data identification
KNOBS	3	V(I)	Array of up to 5 r.m.s. applied voltages [in Volts]
		FR(I)	Array of up to 5 applied frequencies [in Hz]

TABLE AI

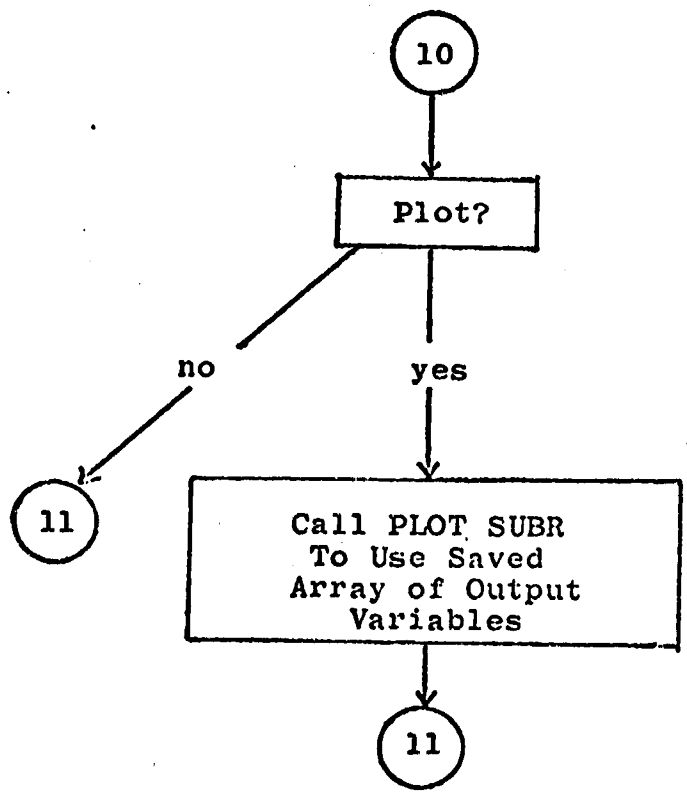
Input Parameters for IR Program (cont.)

File Name	Input Device	Variable	Comments
BRITE	4	VEA(I)	If brightness of EL vs. voltage fits the equation $B \propto \exp(-\sqrt{\frac{A}{Volt}})$ only over limited ranges one can fit this equation to the experimental curve over 3 ranges of voltage. VEA(I) are the upper voltage limits of each approximation.
		DV(I)	Array of up to 3 dimensional constants to fit an EL brightness vs. voltage curve (Brightness in Ft-L).
		AV(I)	Array of up to 3 exponential constants to fit the equation, $B \propto \mathrm{Exp}(-\sqrt{\frac{AV(I)}{Volt}})$ to an EL brightness vs. voltage plot over the full range of possible applied voltages.
		ALF(I)	Array of up to 3 exponential constants of EL brightness. $B \propto (\mathrm{Freq.})^{ALF(I)}$ derived from fitting of an EL brightness vs. voltage curve.
		(Optional)	30 character line for data identification.
Keyboard Inputs		CSHUNT	Shunting capacitance around the PC due to structure of device [in pf]. (E16.2)
		TBEGIN	Smallest input radiation value for the simulation. (E16.2)



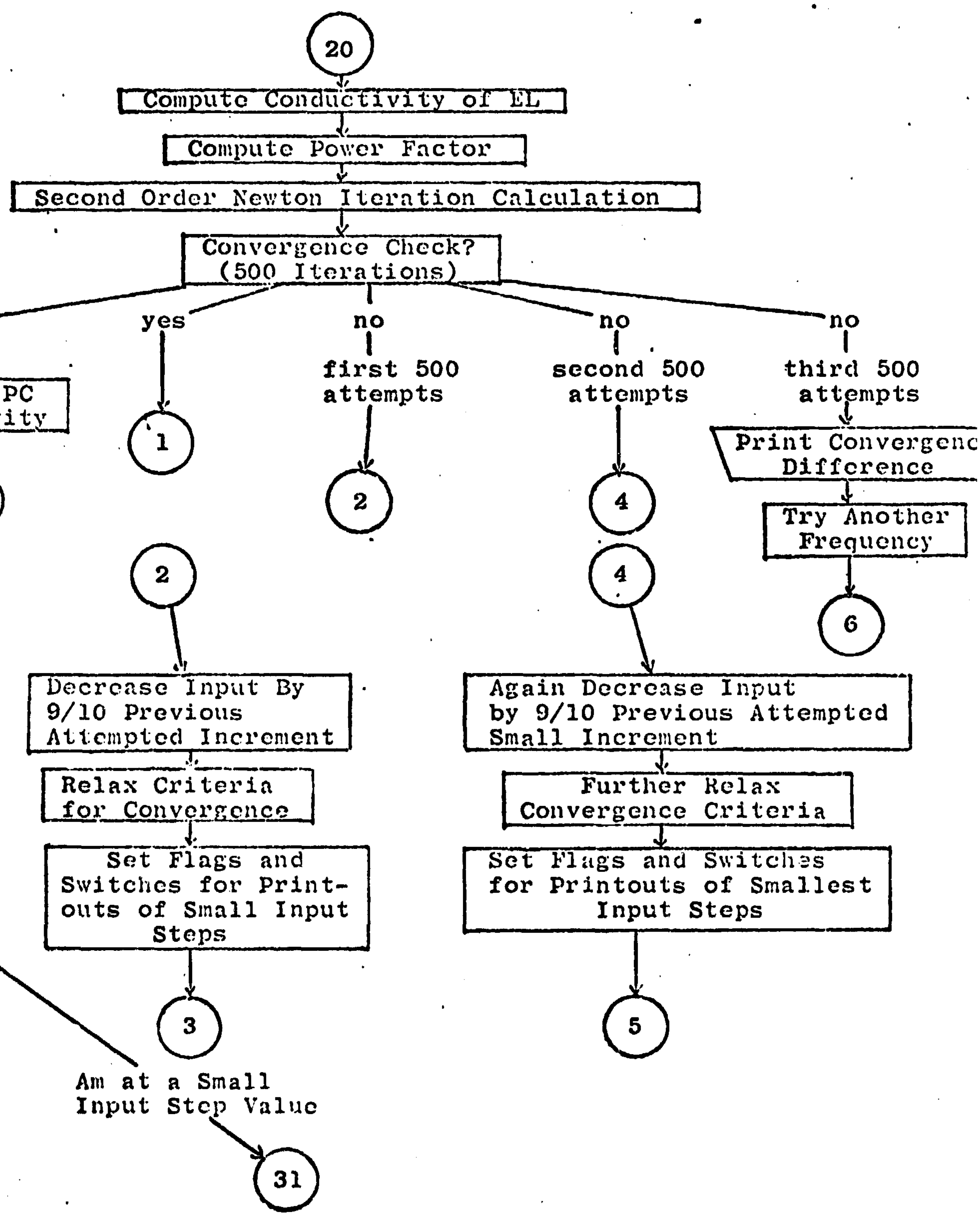
BLOCK DIAGRAM OF IR PROGRAM

FIGURE A4



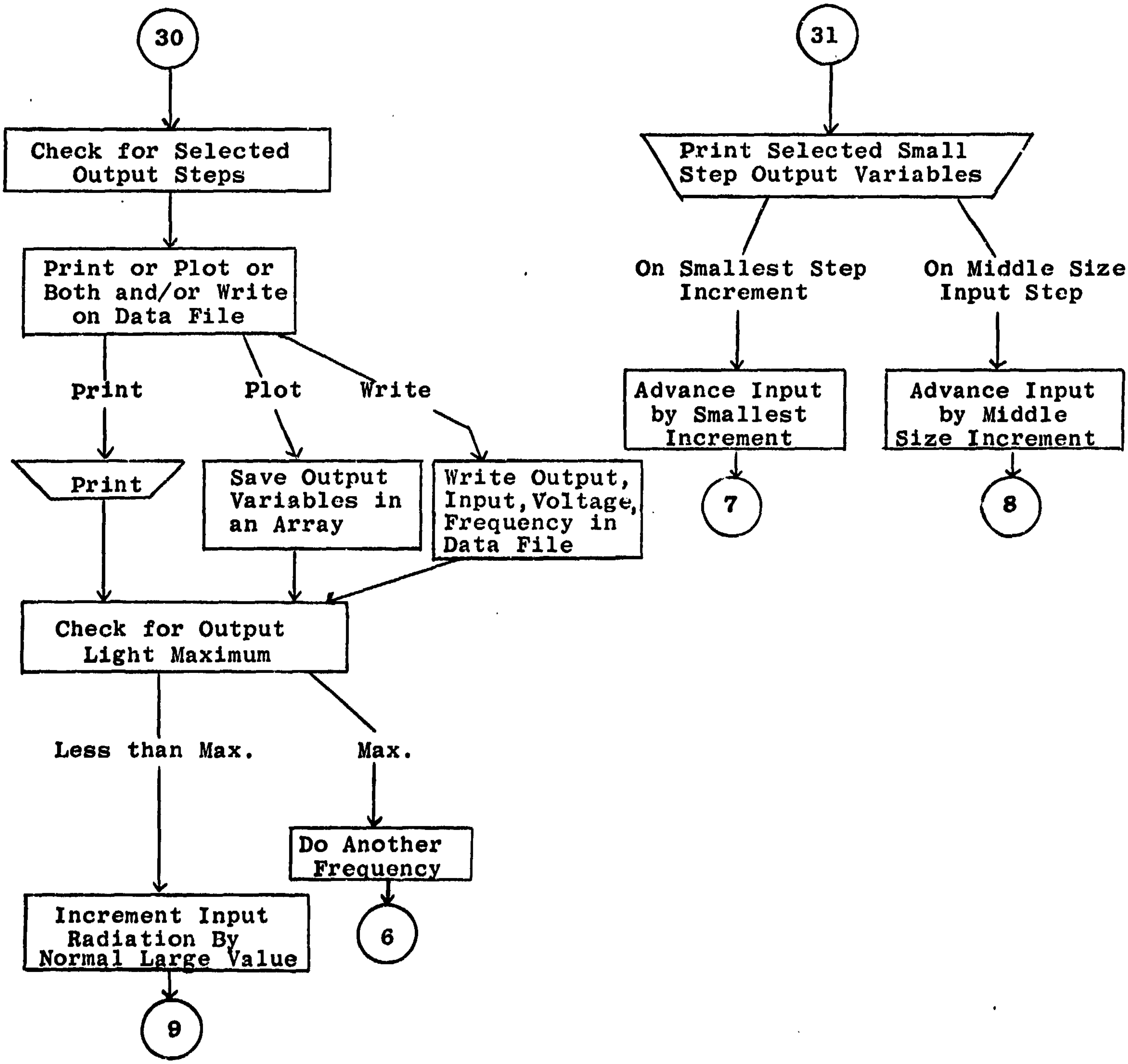
BLOCK DIAGRAM OF IR PROGRAM

FIGURE A4



BLOCK DIAGRAM OF IR PROGRAM

FIGURE A4



BLOCK DIAGRAM OF IR PROGRAM

FIGURE A4

INPUT DATA FORMAT FOR IR DATE:

EQUATIONS:

$$B = DV(I) * F^{ALF(I)} \exp -\sqrt{\frac{AV(I)}{VE}}$$

$$Y2G(\text{Leakage}) = DD*FR(k)^{AALF} \exp(AA*V(J)-V1))$$

$$G1(g) = U*(UD + T^{S})*(V1^{R-1})$$

DATA BLOCKS:

NAME	DEVICE	DATA
EL	1:	C________ (E15.6)
		AALF______ DD______ AA______ (E15.6)
		(Optional: 30 character line for labeling)
PC	2:	R______ S______ U______ UD______ (E15.2)
		(Optional: 30 character line for labeling)
KNOBS	3:	V(I)______ ______ ______ ______ ______(F10.1)
		FR(I)______ ______ ______ ______ ______(F10.1)
BRITE	4:	VEA(I) ______ ______ ______ (E16.2)
		DV(I) ______ ______ ______ (E16.2)
		AV(I) ______ ______ ______ (E16.2)
		ALF(I) ______ ______ ______ (E16.2)
		(Optional: 30 character line for labeling)

Test Data:

FIGURE A5

APPENDIX B

IMINT PROGRAM AND RUNGE SUBROUTINE

B1. Introduction

The IMINT Program treats essentially the same circuit as the IR Program with one important difference. The difference is that the conductance of the photoconductor is allowed to vary exponentially with time in response to step functions light input. A schematic diagram of the circuit treated is shown in Figure B1.

B2. Circuit Analysis and Solution Procedure

To solve this circuit we do not use any linear approximations. Instead, we write the equations for the total current through the combined circuit in a form:

$$I = C_{EL} \frac{d(V_{EL})}{dt} + V_{EL} \frac{1}{R_{EL}}$$

Equation B1

$$I = C_{PC} \frac{d(V_{PC})}{dt} + V_{PC} \frac{1}{R_{PC}}$$

Equation B2

The conductivity of the EL cell is written again as it was for the IR Program and is expressed below:

$$\frac{1}{R_{EL}} = H\, F^{A} \exp(K(V_{EL}))$$

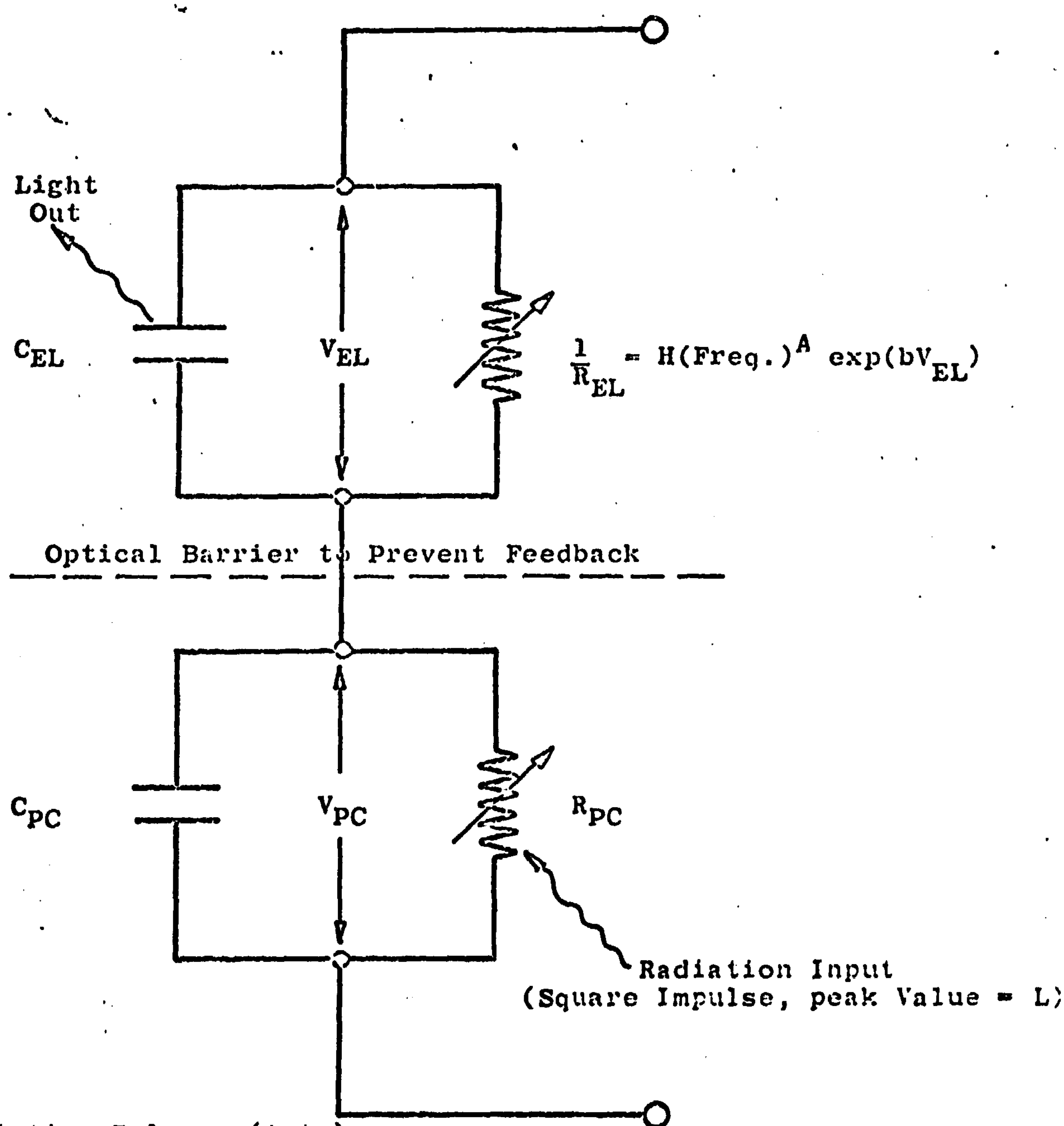
Equation B3

where H is a dimensional constant, F is the frequency, and A and K are constants. The photoconductor conductivity is again expressed in the same form as before, but modified with an exponential time term.

In the equation below, the upper exponential term is for the duration of the light pulse. The lower time term is for the decay time of the photoconductor after the input radiation pulse has ceased.

$$\frac{1}{R_{PC}} = U(U_d + L^{s})\, V_{PC}^{r-1} \begin{Bmatrix} 1 - \exp(-\lambda_1(t-t_1)), & \text{if } t_1<t<t_2 \\ \exp(-\lambda_2(t-t_2)), & \text{if } t_2<t \end{Bmatrix}$$

Equation B4



Before Radiation Pulse: $(t<t_1)$

$$\frac{1}{R_{PC}} = (U)(U_d)(V_{PC})$$

During Radiation Pulse: $(t_1<t<t_2)$

$$\frac{1}{R_{PC}} = U(U_d + L^s)(V_{PC})^{r-1}[1-\exp(-\lambda_1(t-t_1))]$$

After Radiation Pulse: $(t_2<t)$

$$\frac{1}{R_{PC}} = U(U_d + L^s)(V_{PC})^{r-1}[\exp(-\lambda_2(t-t_2))]$$

Circuit Used in Simulation of EL/PC Image Converter Response to Transient Stimulation

FIGURE B1

In this equation, U is dimensional constant, U_d is a dark conductivity term, L is peak input radiation, s and r are constants, λ_1 is a rise time constant, λ_2 is a decay time constant, t_1 is the beginning of the light pulse, and t_2 is the end of the light pulse. The applied voltage is assumed to be of the form:

$$V_{app} = V_m \sin(\omega t-\delta_o) \qquad \text{Equation B5}$$

Where δ_o is chosen so that the beginning voltage on the EL for the simulation is zero. This gives us for the voltage on the photoconductor the following term:

$$V_{PC} = [V_m \sin(\omega t-\delta_o)]-V_{EL} \qquad \text{Equation B6}$$

Putting Equation B6 into the combined Equation B1 and B2, we have Equation B7.

$$(C_{EL} + C_{PC}) \frac{d}{dt} V_{EL} = -V_{EL}[HF^A \exp(K(V_{EL}))]$$

$$+C_{PC}[V_m\omega \cos(\omega t-\delta_o)]$$

$$+ [U(U_d + L^s)] \; [V_m \sin(\omega t-\delta_o) - V_{EL}]^r \left\{ \frac{1-\exp(\lambda_1(t-t_1))}{\exp(-\lambda_2(t-t_2))} \right\}$$

Equation B7

This equation is of the functional form:

$$\frac{dy}{dt} = f(y,t) \qquad \text{Equation B8}$$

This equation is a first order equation which is easily integrable by several numerical techniques. We have used one of the simplest techniques which is the Runge-Kutta method. The present IMINT Program is not ideally suited for the simulation of thin film EL light output because it has no provision yet for the inclusion of multiple curve fits to the TFEL brightness versus voltage curve.

B3. Description of IMINT Program and Runge Subroutine

IMINT is written in FORTRAN IV and is used on a time sharing computer system through a standard teletype terminal. Figure B2 contains a listing of IMINT. The time sharing system it has been used on has excellent file editing capabilities if the file contains line numbers. The first field of numbers on a line are the line numbers. The second field of numbers is the FORTRAN statement number field. The "*" are for comment lines. The program is liberally laced with comments as to the function of flags and switches and the purpose of a group of statements. A complete listing of the input parameters for the program along with the device number called for in the program are shown in Table BI. Table BII contains the input parameters which are entered at the keyboard at program execution time along with comments as to the nature of the parameters. The IMINT Program integrates Equation B4 in the section above by means of a subroutine called RUNGE. The program is basically a simple integration program except for two parts. The first of these parts is the determination of the phase difference between the applied voltage and the voltage on the EL. This phase difference (δ_o) is determined such that the voltage on the EL at the beginning of the simulated voltage cycle is passing through zero in the positive direction. The program finds this phase angle from an initial guess by the designer by means of an iteration technique and computing the rate of change of the convergence difference between two cycles run with different phase angles and computing a new phase angle based on this rate of change of convergence with respect to phase angle. Once the program has determined a δ_o so that the voltage on the EL returns to zero in one period of the applied frequency, the program then integrates from the end of this one cycle (with no input radiation during this cycle) forward in time for as many cycles as the designer choses.

The second part of the program differs from a simple integration routine because of the time varying nature of the radiation input. This time varying nature is handled by introducing the exponential rise of decay functions as shown in Equation B4 of the section above at the appropriate time in the integration.

Figure B3 is a block diagram of the IMINT Program. This is not a flow chart. It is meant to be used as a guide for finding one's way through the program in addition to providing a brief overview of the operation of the program. Table BIII and Table BIV are data sheets that have been useful to the computer operator when using the program and contain the format specifications used in the files.

The subroutine RUNGE is a simple form of the Runge-Kutta technique for integrating first order differential equations. The flags, switches, and variables in the subroutine are described in the comment statements at the beginning of the subroutine listing. A listing of RUNGE is contained in Figure B4.

As yet, we do not have a useful plotting subroutine to plot the output of the IMINT Program. At present, the output is the time, voltage on the EL, EL current, and derivitive of the voltage on the EL. The data must then be plotted by hand. From the plot, one can find peak AC voltages applied to the EL as a function of time and use this in a simple calculation with EL brightness formulas that are appropriate for thick film or thin film EL to get the brightness output.

IMINT PROGRAM

```
      * IMAGE INTENSIFIER PROGRAM
      * OFFICE OF NAVAL RESEARCH PROGRAM
      *
      *
        DIMENSION Y(10),DY(10)
        CALL DEFINE(1,6HIIDAT )
       READ(1,10)CEL,CPC,FREQ,A,H,AK
        READ(1,10) VM,U,UD,S,PASMX,VEL
        READ(1,26) T,GLAM1,GLAM2
        READ(1,11) N
        WRITE(9,12)
     12 FORMAT('EL,ELP,PHSE,DPHSE'/)
        READ(9,25) EL,ELP,PHSE,DPHSE
        WRITE(9,13)
     13 FORMAT('TF,DPRT,DT,VDED'/)
        READ(9,25) TF,DPRT,DT,VDED
        WRITE(9,14)
     14 FORMAT('R,T1,T2'/)
        READ(9,26) R,T1,T2
        WRITE(9,16)
     16 FORMAT('CYCMX'/)
        READ(9,15) CYCMX
       WRITE(9,17)
    17 FORMAT('CONVCR'/)
       READ(9,15) CONVCR
      *
    10 FORMAT(6E12.5)
    11 FORMAT(I4)
    15 FORMAT(E12.5)
    25 FORMAT(4E12.5)
    26 FORMAT(3E12.5)
     *
*   INITIALIZATION OF FLAGS AND SWITCHES
*
*     "MG" IS INPUT STATE INDICATOR.  MG=1 IS BEFORE PULSE
*       MG=2 IS DURING PULSE, MG=3 IS AFTER PULSE
      MG=1
*     "CYC" IS VOLTAGE CYCLE COUNTER
      CYC=1.
      L=1
      IG=1
      PI=3.14159
*     "APPSW" IS 0 FOR FIRST INTEGRATION OF FIRST CYCLE
      APPSW=0.
*     "TPRT" IS TIME TO PRINT OUTPUT VARIABLES
      TPRT=T
*     "DTF" IS PERIOD OF DRIVING FREQ.
      DTF=TF-T
      M=1
*     "NCON=1" IS SWITCH TO CONVERGENCE CHECK
*     "NCON=2" IS SWITCH AROUND CONVERGENCE CHECK AFTER
*        INTEGRATING SECOND TIME WITH PHSE=PHSE+DPHSE
*     "NCON=3" IS SWITCH COMPLETELY AROUND CONVERGENCE
*        CHECKS AND PHASE ANGLE CORRECTIONS
      NCON=1
*     "ISAVE" IS FLAG TO SAVE 'VEL','T','TPRT'
```

Figure B2
Page 1 of IMINT Program

IMINT PROGRAM

```
      ISAVE=1
*
      WRITE(9,31)
   31 FORMAT(1X,'CEL',9X,'CPC',9X,'FREQ',8X,'VM')
      WRITE(9,30) CEL,CPC,FREQ,VM
      WRITE(9,32)
   32 FORMAT(1X,'H',11X,'A',11X,'AK',10X,'VEL')
      WRITE(9,30) H,A,AK,VEL
      WRITE(9,33)
   33 FORMAT(1X,'U',11X,'UD',10X,'S',11X,'R')
      WRITE(9,30) U,UD,S,R
      WRITE(9,34)
   34 FORMAT(1X,'PHSE',8X,'DPHSE',7X,'TF',10X,'DT')
      WRITE(9,30) PHSE,DPHSE,TF,DT
      WRITE(9,35)
   35 FORMAT(1X,'GLAM1',7X,'GLAM2',7X,'EL',10X,'ELP')
      WRITE(9,30) GLAM1,GLAM2,EL,ELP
      WRITE(9,36)
   36 FORMAT(1X,'T1',10X,'T2')
      WRITE(9,30) T1,T2
*
   30 FORMAT(1P4E12.5)
      OMEGA=2*PI*FREQ
      DPHSE=DPHSE*PI/180.
      PHSE=PHSE*PI/180.
      VEL5=CPC*OMEGA*VM
      VEL7=R*(OMEGA/(2.*PI))**A
*
   40 GO TO (45,46),ISAVE
   45 A1=T
    A2=VEL
      A3=TPRT
      ISAVE=2
      GO TO 48
   46 T=A1
      VEL=A2
      TPRT=A3
*
   48 PPH=PHSE*180./PI
      WRITE(9,840) PPH
  840 FORMAT(/'PHASE ANGLE = ',F10.3)
      WRITE(9,49)
   49 FORMAT(/4X,'TIME',8X,'VEL',6X,'CURR',6X,'VELD'/)
*      INTEGRATION REENTRY
   50 VEL1=VEL5*COS(OMEGA*T+PHSE)
      VEL4=VM*SIN(OMEGA*T+PHSE)-VEL
      GO TO (54,55,56),MG
   55 VEL6=(1.-EXP(-(T-T1)/GLAM1))*VEL8
      GO TO 58
   56 VEL6=(EXP(-(T-T2)/GLAM2))*VEL8
      GO TO 58
   54 VEL6=U*(UD+EL**S)
   58 CONTINUE
      VEL2=VEL4-VEL6*ABS(VEL4)**R
      VEL3=-VEL*VEL7*EXP(AK*VEL)
*
```

Figure B2
Page 2 of IMINT Program

```
*  BASIC DIFFERENTIAL EQUATION
   VELD=(VEL1+VEL2+VEL3)/(CEL+CPC)
 *
   GO TO (60,100),M
60 IF(T.LT.(TPRT-1.E-7)) GO TO 80
 *
   CURR=(CEL*VELD)+(VEL)*(FREQ**A)*H*EXP(AK*VEL)
   WRITE(9,70) T,VEL,CURR,VELD
 *
70 FORMAT(1P2E12.5,E9.2,E12.5)
   TPRT=TPRT+DPRT
 *
80 CONTINUE
   GO TO (81,82,83),MG
81 IF(T.LT.(T1-1.E-7)) GO TO 83
   EL=ELP
   MG=2
   VEL8=U*(UD+EL**S)
   GO TO 50
82 IF(T.LT.(T2-1.E-7)) GO TO 83
   MG=3
   EL=0.
   VEL8=U*(UD+EL**S)
   GO TO 50
83 CONTINUE
 *
  IF(T.GE.(TF-1.E-7)) GO TO 200
   M=2
100 CONTINUE
   DY(1)=VELD
   Y(1)=VEL
*
   CALL RUNGE(L,IG,Y,DY,DT,M,T,N)
*
   VEL=Y(1)
  GO TO 50
200 CONTINUE
   GO TO (210,240,300),NCON
*   TEST FOR CONVERGENCE
210 VDE=VEL
   VDEAI=-VDE
   IF(ABS(ABS(VDEAI)-ABS(VDED))-CONVCR) 300,300,230
*
*  DERIVE NEW PHASE ANGLE FOR SECOND CONVERGENCE ATTEMPT
230 IF(APPSW.EQ.1.) GO TO 250
   APPSW=1.
   PASS=1.
   PSAVE=PHSE
   PHSE=PHSE+DPHSE
   NCON=2
  GO TO 40
240 DELVDE=VEL-VDE
   PVDE=DELVDE/DPHSE
  GO TO 270
 *
*  DERIVE NEW PHASE ANGLE BASED ON PREVIOUS TRIES
```

Figure B2
Page 3 of IMINT Program

IMINT PROGRAM

```
250 IF(PASS.EQ.PASMX) GO TO 400
    PASS=PASS+1.
270 CORR=VDEAI/PVDE
    PHSE=PSAVE+CORR
    PSAVE=PHSE
    NCON=1
   GO TO 40
  *
300 CONTINUE
   IF(CYC.EQ.CYCMX) GO TO 400
    IF(CYC.EQ.1.) NCON=3
    CYC=CYC+1.
    TF=TF+DTF
    ISAVE=1
    TPRT=T
    APPSW=0.
   GO TO 40
  *
400 STOP
    END
```

Figure B2
Page 4 of IMINT Program

TABLE BI

Input Parameters for IMINT Program from Data File

File Name: IIDAT Device Number: 1

Parameter Name	Comments
CEL	Capacitance/Cell of EL [in farads].
CPC	Shunt Capacitance around PC cell [in farads].
FREQ	Applied power supply frequency to the device [in Hz].
A	Exponent of frequency dependence of EL leakage conductivity according to: $G_{EL} \propto (Freq.)^A$.
H	Dimensional constant of leakage conductivity of EL [EL leakage in mhos].
AK	Exponential coefficient of voltage dependence of leakage conductivity of EL according to: $G_{EL} \propto Exp(AK*Volt.)$, Note: Volt. is absolute value of peak applied voltage.
VM	Maximum peak applied voltage to the device.
U	Dimensional constant of PC conductivity [PC conductivity in mhos].
UD	Dark conductivity term (U_d) of PC conductivity.
S	Exponent of steady state dependence of PC conductivity upon input radiation.
PASMX	Upper limit on number of searches for convergence of first voltage cycle.
VEL	Voltage across EL cell at time = T.
T	Time at which simulation begins [in seconds].
GLAM1	PC conductivity rise time constant used in form: $G_{PC} \propto 1 - Exp(-\frac{T-T1}{GLAM1})$. (Times in seconds)

TABLE BI

Input Parameters for IMINT Program from Data File (Cont.)

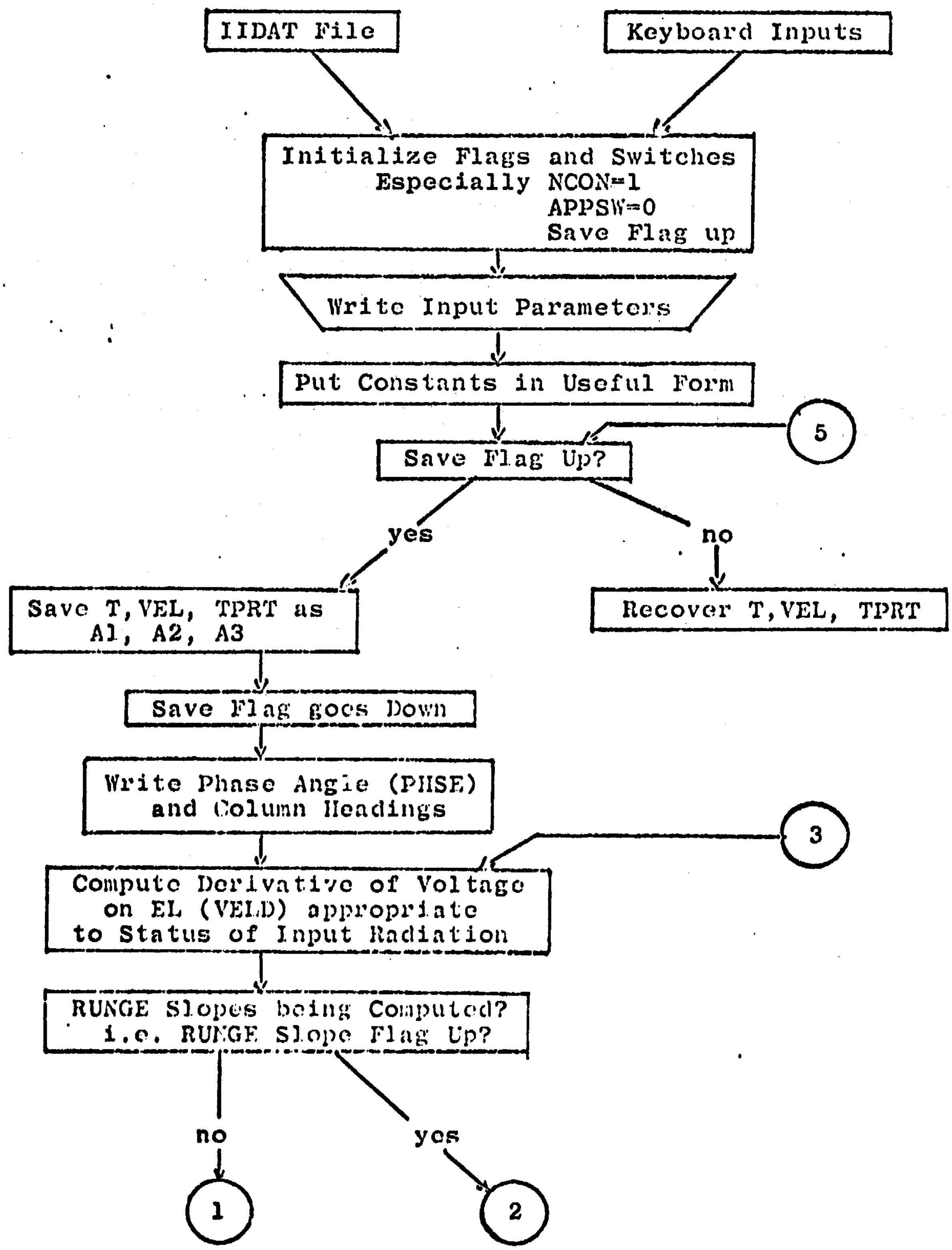
File Name: IIDAT Device Number: 1

Parameter Name	Comments
GLAM2	PC conductivity decay time constant used in form: $G_{PC} \propto \mathrm{Exp}(-\frac{T-T2}{GLAM2})$. [Times in seconds]
N	Number of simultaneous first order differential equations to be integrated by RUNGE subroutine. In IMINT, N = 1.

TABLE BII

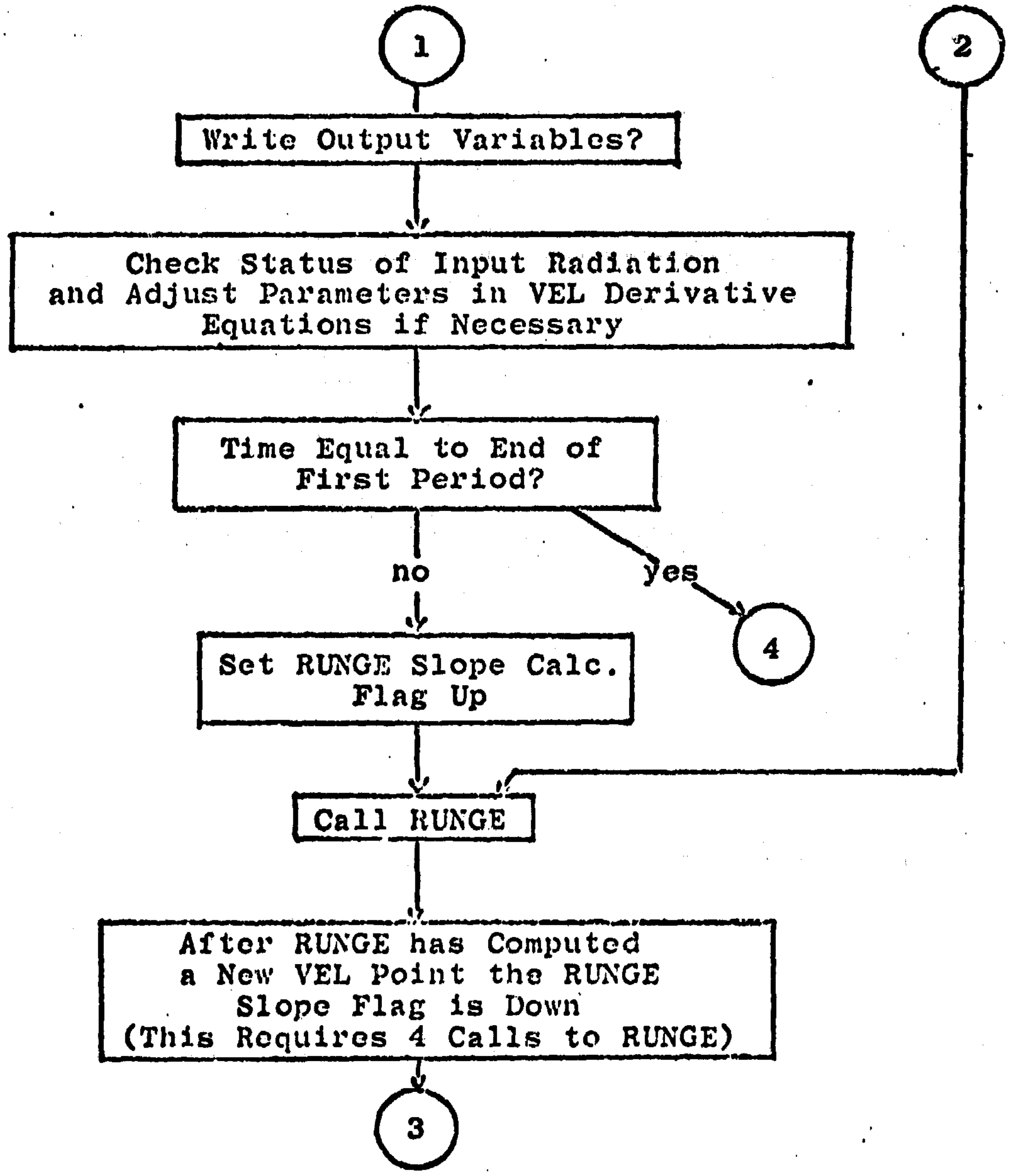
Input Parameters for IMINT Program Entered at Program Execution Time

Parameter Name	Comments
EL	Input radiation before input pulse [in units consistent with PC conductivity equation].
ELP	Peak value of square pulse input radiation [same units as EL above].
PHSE	Initial guess at voltage phase angle for first steady-state cycle [in degrees].
DPHSE	Increment for adjusting PHSE after integration of first steady-state cycle [in degrees].
TF	Time at which voltage on EL repeats its value at T. (TF-T) is period of the driving frequency [in seconds].
DPRT	Time increment between printouts [in seconds].
DT	Time increment used per integration step [in seconds].
VDED	Desired value of voltage on EL after integration of first steady-state voltage cycle (usually equal to VEL).
R	Exponent of input radiation dependence of PC conductivity: $G_{PC} \propto (L)^R$ (Note R = r-1 in equations).
T1	Start time of input radiation pulse [in seconds].
T2	Stop time of input radiation pulse [in seconds].
CCMX	Maximum number of EL voltage cycles computed.
CONVCR	Difference allowed between EL voltage computed at end of first voltage cycle and the desired voltage value (VDED) [in volts].



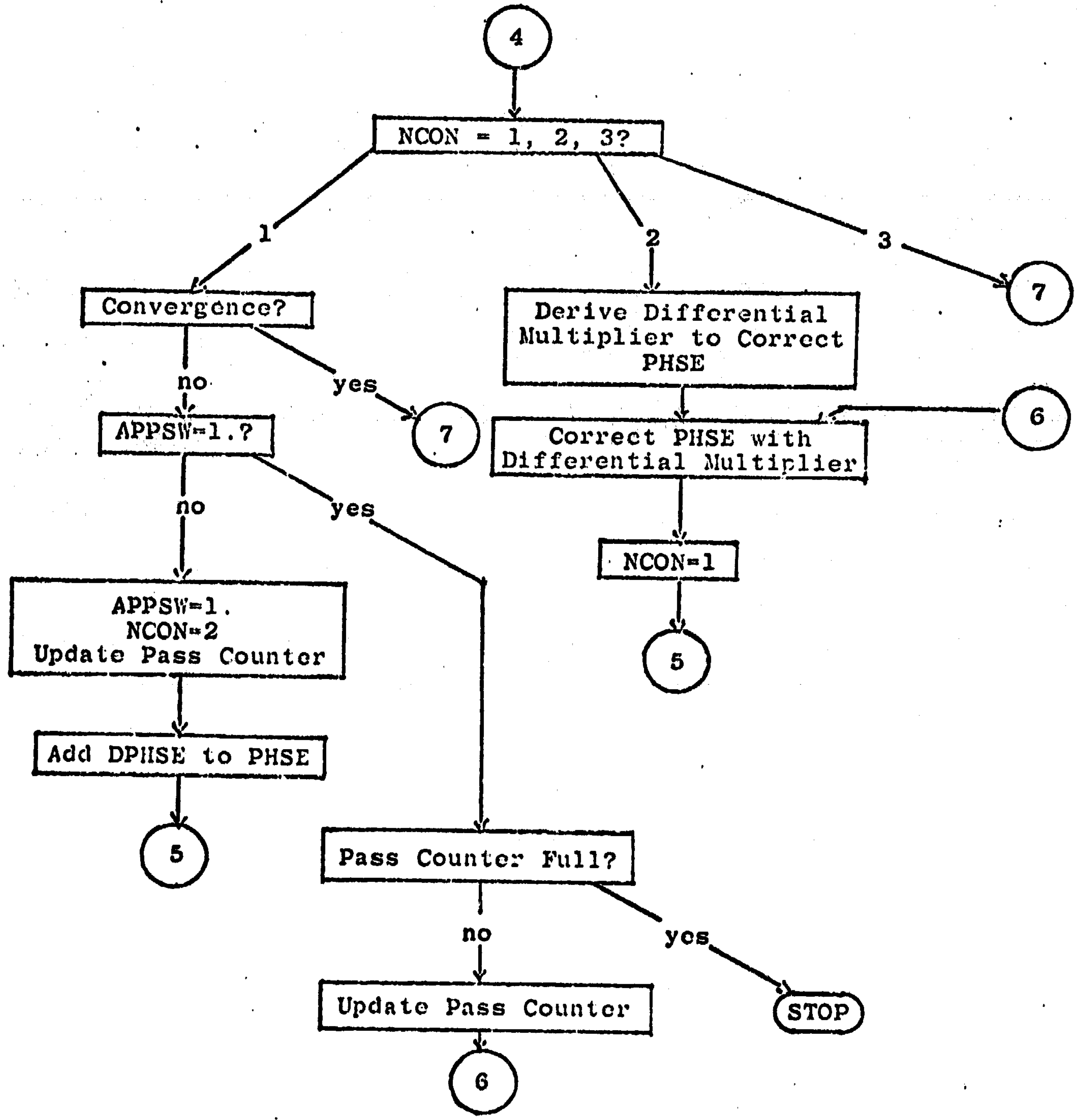
BLOCK DIAGRAM OF IMINT PROGRAM

FIGURE B3



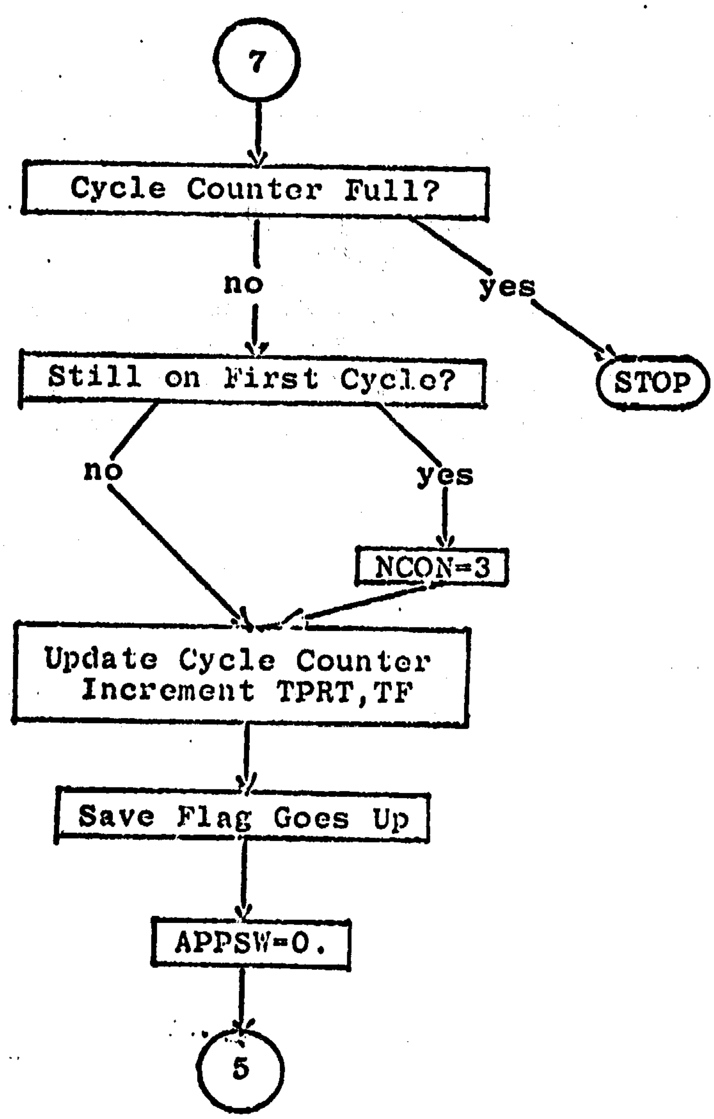
BLOCK DIAGRAM OF IMINT PROGRAM

FIGURE B3



BLOCK DIAGRAM OF IMINT PROGRAM

FIGURE B3



BLOCK DIAGRAM OF IMINT PROGRAM

FIGURE B3

IIDAT DATA FILE INPUTS FORMAT FOR IMINT DATE:

CEL	CPL	FREQ	A (EL Leakage Constants)	H (EL Leakage Constants)	AK (EL Leakage Constants)	
______	______	______	______	______	______	(6E12.5)

VM	U (PC Constants)	UD (PC Constants)	S (PC Constants)	PASMX	VEL	
______	______	______	______	______	______	(6E12.5)

T	GLAM1	GLAM2	
______	______	______	(3E12.5)

N	
______	(I4)

COMMENTS:

TEST DATA:

TABLE BIII

TTY Inputs for IMINT   DATE:

EL	ELP	PHSE	DPHSE	
________	________	________	________	(4E12.5)

TF	DPRT	DT	VDED	
________	________	________	________	(4E12.5)

R	T1	T2	
________	________	________	(3E12.5)

CCMX	
________	(E12.5)

CONVCR	
________	(E12.5)

COMMENTS:

TEST DATA:

TABLE BIV

RUNGE SUBROUTINE

```
      SUBROUTINE RUNGE(L,IG,Y,DY,DT,M,T,N)
 *  N=NUMBER OF DIFFERENTIAL EQUATIONS (MAX. OF 10)
 *   IG=1 INDICATES IF CALL IS FOR FIRST RUNGE SLOPE
 *        CALC. IN THE SUBROUTINE
 *   T=INDEPENDENT VARIABLE
 *   DT=INTEGRATION INCREMENT ØF IND. VARIABLE
 *   Y=DEPENDENT VARIABLE
 *   DY=DERIVATIVE ØF Y
 *   L=2 IS SWITCH AROUND "IG" CHECK AT STATEMENT 100 (ON
 *        FIRST CALL TO RUNGE SLOPES)
 *   M=2 INDICATES TØ MAIN PRØGRAM THAT RUNGE SLØPES ARE
 *        BEING COMPUTED
      DIMENSION DY(10),Y(10),F(80)
 90 GØ TØ (100,110),L
 100 GO TO(101,110),IG
 101 J=1
      L=2
      DØ 106 K=1,N
      K3=N+K
 106 F(K3)=Y(K)
       GØ TØ 90
 110 DØ 140 K=1,N
      K1=K
      K2=K+5*N
      K3=K2+N
      K4=K+N
      GO TØ(111,112,113,114),J
 111 F(K1)=DY(K)*DT
      Y(K)=F(K4)+.5*F(K1)
      GØ TØ 140
 112 F(K2)=DY(K)*DT
     GØ TO 124
 113 F(K3)=DY(K)*DT
     GØ TØ 134
 114 Y(K)=F(K4)+(F(K1)+2.*(F(K2)+F(K3))+DY(K)*DT)/6.
      GØ TØ 140
 124 Y(K)=.5*F(K2)
      Y(K)=Y(K)+F(K4)
      GØ TO 140
 134 Y(K)=F(K4)+F(K3)
 140 CONTINUE
      GØ TØ(170,180,170,180),J
 170 T=T+.5*DT
 180 J=J+1
      IF(J-4)404,404,299
  299 IG=1
       M=1
      GØ TO 406
 404 IG=2
 405 L=1
 406 RETURN
      END
```

Figure B4
RUNGE Subroutine

APPENDIX C

UTILITY PROGRAMS

C1. Introduction

Several smaller programs were developed to aid in the analysis of proposed devices. The first group of programs are used as aids in extracting useful parameters of the light-emitting materials and the photoconductive materials. This group includes the GFIT, ELFIT, ELDG, and PLDATA programs and the SLPLOT subroutine.

The GFIT program fits a non-voltage dependent equation to resistance vs. input radiation measurements of photoconductor cells. The ELFIT program fits the electroluminescent brightness vs. frequency and voltage measurements to an equation over three consecutive ranges of applied voltage. The ELDG program creates pairs of brightness vs. voltage data from an equation. The data is put in a file for plotting with the PLDATA program. The PLDATA program takes data from a file, modifies it for use in the SLPLOT subroutine, and calls the subroutine. The SLPLOT subroutine generates a four-cycle semi-logarithmic plot of a maximum of five curves of fifty points each.

The second group of utility programs simulate unusual ways of driving image conversion panels and the stacking or cascading of image conversion panels. The AM and FM programs use data files generated by the IR program to simulate the time averaged light output from image conversion panels driven by very simple amplitude or frequency modulated voltage waveforms. The MASSA program condenses the data files generated by the IR program for use in the AM or FM programs. The CASCAD program uses data files of input

RUNGE SUBROUTINE

```
      SUBROUTINE RUNGE(L,IG,Y,DY,DT,M,T,N)
*  N=NUMBER OF DIFFERENTIAL EQUATIONS (MAX. OF 10)
*  IG=1 INDICATES IF CALL IS FØR FIRST RUNGE SLOPE
*       CALC. IN THE SUBROUTINE
*  T=INDEPENDENT VARIABLE
*  DT=INTEGRATION INCREMENT ØF IND. VARIABLE
*  Y=DEPENDENT VARIABLE
*  DY=DERIVATIVE ØF Y
*  L=2 IS SWITCH AROUND "IG" CHECK AT STATEMENT 100 (ON
*       FIRST CALL TO RUNGE SLOPES)
*  M=2 INDICATES TØ MAIN PRØGRAM THAT RUNGE SLØPES ARE
*       BEING CØMPUTED
      DIMENSION DY(10),Y(10),F(60)
   90 GØ TØ (100,110),L
  100 GO TO(101,110),IG
  101 J=1
      L=2
      DØ 106 K=1,N
      K3=N+K
  106 F(K3)=Y(K)
      GØ TØ 90
  110 DØ 140 K=1,N
      K1=K
      K2=K+5*N
      K3=K2+N
      K4=K+N
      GØ TØ(111,112,113,114),J
  111 F(K1)=DY(K)*DT
      Y(K)=F(K4)+.5*F(K1)
      GØ TØ 140
  112 F(K2)=DY(K)*DT
      GØ TØ 124
  113 F(K3)=DY(K)*DT
      GØ TØ 134
  114 Y(K)=F(K4)+(F(K1)+2.*(F(K2)+F(K3))+DY(K)*DT)/6.
      GØ TØ 140
  124 Y(K)=.5*F(K2)
      Y(K)=Y(K)+F(K4)
      GØ TØ 140
  134 Y(K)=F(K4)+F(K3)
  140 CØNTINUE
      GØ TØ(170,180,170,180),J
  170 T=T+.5*DT
  180 J=J+1
      IF(J-4)404,404,299
  299 IG=1
      M=1
      GØ TØ 406
  404 IG=2
  405 L=1
  406 RETURN
      END
```

Figure B4
RUNGE Subroutine

vs. output of simulated image conversion panels to compute the light output of a cascaded pair of panels. The MASSA2 program is used after the MASSA program to condense IR2 data output for use in CASCAD. In addition, the AM or FM programs can be used to effectively sort IR output data before use in CASCAD.

C2. GFIT Program

This program fits an equation of the form:

$$g \equiv \text{conductivity} = u(u_d + T^S)$$

where u and u_d are constants, T is input radiation, and S is a constant, to resistance vs. input radiation data obtained by measuring individual PC cells under stimulation. The fit is obtained by assuming that for $T \geq 10^{-3}$, $g \simeq u \cdot u_d T^S$. The natural logarithm of both sides is taken and the resulting equation is fitted by means of the least-squares method to the test data. This determines S and U. After this fit, the simple average of the dark current data is used for the product $u \cdot u_d$ and u_d is computed.

The program uses data from a stored data file containing the input radiation and resulting cell resistances. The file is called for at program execution time. A zero input radiation value signifies the end of the data file and reads in the average (computed manually) dark resistance of the cells.

Table CI summarizes the necessary data inputs and formats for the program. Figure C1 is a listing of the GFIT program.

GFIT PRØGRAM

```
*   CØNDUCTIVITY EQUATIØN FIT
*   G=U*(UD+T**S)
    DIMENSIØN T(75),G(75),TL(75),GL(75)
    DATA S1,S2,S3,S4/ 4*0./
    DØ 20 I=1,75
    READ(1,2) T(I),G(I)
    G(I)=1./G(I)
  2 FØRMAT(2E16.4)
    IE=I-1
    IF(T(I).LE.0.) GØ TØ 30
 20 CØNTINUE
 30 DØ 40 J=1,IE
   GL(J)=ALØG(G(J))
    TL(J)=ALØG(T(J))
 40 CØNTINUE
    DØ 50 K=1,IE
    S1=S1+GL(K)*TL(K)
    S2=S2+(TL(K))**2
    S3=S3+GL(K)
    S4=S4+TL(K)
 50 CØNTINUE
    FN=IE
    S=(((S3*S4)/FN)-S1)/(((S4**2)/FN)-S2)
    BL=(S3-S*S4)/FN
  4 FØRMAT(1P3E10.2)
    U=EXP(BL)
    UD=G(IE+1)/U
    WRITE(9,3)
  3 FØRMAT(2X,'LIGHT IN',2X,'G MEAS.',2X,'G CALC.'/)
    II=IE+1
    DØ 60 L=1,II
    GG=U*(UD+T(L)**S)
    WRITE(9,4) T(L), G(L), GG
 60 CØNTINUE
    WRITE(9,5) U, UD, S
  5 FØRMAT(/'U=',1PE10.2/,'UD=',1PE10.2/,'S=',1PE10.2/)
    STØP
    END
```

FIGURE C1

INPUT DATA FORMAT FOR GFIT

EQUATIONS: G = U*(UD + T**S)

DATA BLOCK:

Device	Data Format: Energy Input	Data Format: Cell Resistance(Ω)	
1	________,	____________	(E16.4)
	________,	____________	
	________,	____________	
	.	.	
	.	.	
	.	.	
	___0.___,	Average Dark Resistance	

(Maximum of 75 lines of data)

TABLE CI

C3. ELFIT Program

This program fits an equation of the form:

$$B \equiv \text{Brightness} = D \cdot F^{\alpha} \exp\left(-\sqrt{\frac{A}{V}}\right),$$

where D, α, and A are constants; V is the applied r.m.s. voltage; and F is the applied frequency, to the brightness vs. voltage and frequency data obtained from sample EL material. The natural logarithm of both sides of the equation is taken and the resulting equation is fitted by the method of least-squares to the measured values. The program accepts up to 10 frequencies and 30 voltage-brightness number pairs per frequency. The data is stored in a data file and called for at program execution time.

In practice, it is best to first plot the measurements as ln B vs. $\sqrt{\frac{A}{V}}$ and determine the Voltage ranges over which the resulting curves are approximately straight lines. Usually, for thick film EL, the curves are straight lines for all practical voltages. TFEL curves are not and in the IR program, we make provisions for dividing up the brightness vs. voltage dependence of the TFEL into 3 voltage ranges. The ELFIT program is then used on the measurements falling into each separate range. The IR program then uses the α, A, and D parameters only when the EL voltage is in their range of validity.

Table CII lists the data format for the stored data file used by ELFIT. Figure C2 is a listing of the ELFIT program.

ELFIT PRØGRAM

```
*     EL EQUATIØN FIT
*      B=D*(F**ALPH)/EXP((A/V)**.5)
      DIMENSIØN CF(10),JJ(10),V(10,30)
     + ,B(10,30),F(10)
      DATA FN,S1,S2,S3,S4,S5,S6,S7,S8/ 9*0./
      DØ 10 I=1,10
      READ(1,2) F(I)
    2 FØRMAT(E12.3)
      IF(F(I)-0.) 30, 30, 40
   40 CØNTINUE
      FI=I
      II=I
      DØ 20 J=1,30
      READ(1,5) V(I,J), B(I,J)
    5 FØRMAT(2E12.3)
      IF(V(I,J)-0.) 10,10,22
   22 CØNTINUE
      CF(I)=J
      JJ(I)=J
   20 CØNTINUE
   10 CØNTINUE
   30 CØNTINUE
*
      DØ 50 K=1,II
   50 FN=FN+CF(K)
*
*
      DØ 60 L=1,II
*
      JJJ=JJ(L)
      DØ 70 MM=1,JJJ
*
      IF(II-1) 55, 55, 23
   55 S1=S1+ALØG(B(L,MM))
      S3=S3+(V(L,MM))**-.5
      S7=S7+(V(L,MM)**-.5)*ALØG(B(L,MM))
      S8=S8+(1./V(L,MM))
      GØ TØ 70
   23 CØNTINUE
*
      S1=S1+ALØG(B(L,MM))
      S2=S2+ALØG(F(L))
      S3=S3+(V(L,MM))**-.5
      S4=S4+(ALØG(F(L)))**2
      S5=S5+ALØG(B(L,MM))*ALØG(F(L))
      S6=S6+(V(L,MM)**-.5)*ALØG(F(L))
      S7=S7+(V(L,MM)**-.5)*ALØG(B(L,MM))
      S8=S8+(1./V(L,MM))
   70 CØNTINUE
   60 CØNTINUE
*
*
      IF(II-1) 44, 44, 45
*
   45 CØNTINUE
      DET=FN*(-S4*S8+S6*S6)-S2*(-S2*S8+S3*S6)-S3*(S2*S6-S3*S4)
```

FIGURE C2

ELFIT PROGRAM

```
      DLOG=(S1*(-S4*S8+S6*S6)-S2*(-S5*S8+S7*S6)-S3*(S5*S6-S7
 +          *S4)) / DET
      ALPH=(FN*(-S5*S8+S7*S6)-S1*(-S2*S8+S3*S6)-S3*(S2*S7
 +          -S3*S5)) / DET
      SORA=(FN*(S4*S7-S6*S5)-S2*(S2*S7-S3*S5)+S1*(S2*S6-
 +             S3*S4)) / DET
      GO TO 31
*
   44 CONTINUE
      DET=-FN*S8+S3*S3
      DLOG=(-S1*S8+S3*S7) / DET
      SORA=(FN*S7-S3*S1) / DET
      ALPH=0.
*
*
   31 A=SORA*SORA
      D=EXP(DLOG)
*
      WRITE(9,99)
   99 FORMAT(//'RESULTS'/,7('-'))
      DO 80 LL=1,II
      WRITE(9,6) F(LL)
    6 FORMAT(//'FREQ.'/,1PE10.2/,'VOLT.',5X,'BRIGHTNESS',
 +      2X,'CALC. BR.'/)
      JJJJ=JJ(LL)
      DO 90 M=1,JJJJ
      IF(II-1) 71, 71, 72
   71 BR=D/EXP((A/V(LL,M))**.5)
      GO TO 73
   72 CONTINUE
      BR=D*((F(LL))**ALPH)/EXP((A/V(LL,M))**.5)
   73 CONTINUE
      WRITE(9,7) V(LL,M), B(LL,M), BR
    7 FORMAT(1P3E10.2)
   90 CONTINUE
   80 CONTINUE
      WRITE(9,8) D, A,ALPH
    8 FORMAT(//'D=',1PE10.2/,'A=',1PE10.2/,'ALF=',E10.2//)
      STOP
      END
```

FIGURE C2

INPUT DATA FORMAT FOR ELFIT

EQUATION: B = D*(F**ALPH)/EXP((A/V)**.5)

DATA BLOCK:

Device	Data Format			
1	Frequency ______	(E12.3)		
	Voltage ______,	Brightness ______	(E12.3)	
	______,	______		
	______,	______		
	,			
	,			
	,			
	______,	______		
	0.	(0. voltage - ready for new frequency)		
	0.	(0. frequency terminates data input)		

Maximum: 10 Frequencies
30 Volt, Brightness/frequency

TABLE CII

C4. SLPLOT Subroutine

This subroutine generates a four-cycle, base ten, semi-logarithmic plot of up to five curves. The subroutine uses an X-array (linear scale), a Y-array (log scale) and a variable named DEC which determines the lowest ordinate on the plot. The lowest ordinate is 10^{DEC}.

The program automatically determines the end points of the linear scale and picks a convenient scale factor for reading values from the plot.

For plotting brightness data of EL lamps, the PLDATA program discussed in the next section is used as a calling program. Table CIII summarizes the calling arguments of the subroutine. Figure C3 is a listing of the SLPLOT subroutine.

SUBRØUTINE SLPLØT

```
      SUBRØUTINE SLPLØT (X,Y,DEC)
      DIMENSIØN MCT(5),PLØT(5),LINE(62),SCALE(7),X(5,50),Y(5,50)
      INTEGER BLANK,DØT,XPLØT,PLUS,PLØT
*     ARRAY CØMPRESSIØN
      DØ 200 I=1,5
      MC=0
      DØ 201 J=1,50
207   IF(J-(50-MC)) 208,206,206
208   IF(X(I,J)-0.) 202,202,201
202   MC=MC+1
      JJ=J
203   X(I,JJ)=X(I,JJ+1)
      Y(I,JJ)=Y(I,JJ+1)
      JJ=JJ+1
      IF((50-MC)-(JJ-1)) 205,207,207
205   GØ TØ 203
201   CØNTINUE
206   MCT(I)=50-MC
200   CØNTINUE
*
*     DEP. VARIABLE RANGE
      XMIN=X(1,1)
      XMAX=X(1,1)
      DØ 10 I=1,5
      MAXJ=MCT(I)
      DØ 20 J=1,MAXJ
      IF(X(I,J)-0.) 20,20,11
 11   IF(X(I,J)-XMIN) 30,30,31
 30   XMIN=X(I,J)
 31   IF(X(I,J)-XMAX) 20,20,32
 32   XMAX=X(I,J)
 20   CØNTINUE
 10   CØNTINUE
*
*     SCALE DEP.VARIABLE
      IX=0
      XRANGE=XMAX-XMIN
      XRSAV=XRANGE
 12   IF(XRANGE-60.) 13,14,14
 13   XRANGE=10.*XRANGE
      IX=IX+1
      GØ TØ 12
 14   IF(XRANGE-600.) 15,15,16
 16   XRANGE=XRANGE/10.
      IX=IX-1
      GØ TØ 14
 15   CØNTINUE
      XDIV=XRANGE/60.
      IF(XDIV-1.) 61,61,63
 61   DIV=1.
      GØ TØ 69
 63   IF(XDIV-2.) 62,62,64
62    XDIV=2.*(10.**(-IX))
      DIV=2.
      GØ TØ 69
 64   IF(XDIV-5.) 65,65,66
```

FIGURE C3

SUBROUTINE SLPLOT

```
 65 XDIV=5.*(10.**(-IX))
    DIV=5.
    GO TO 69
 66 CONTINUE
 70 XDIV=10.*(10.**(-IX))
    DIV=10.
 69 CONTINUE
 *
 *  LOWEST SCALE VALUE
    XS=XMIN
    IXM=0
 80 IF(XS-1.) 72,75,73
 72 XS=XS*10.
    IXM=IXM+1
    GO TO 80
 73 IF(XS-10.) 75,75,74
 74 XS=XS/10.
    IXM=IXM-1
    GO TO 73
 75 XS=XS*10.
    IXS=XS/5.
    XS=IXS
    XS=XS*5.
    XS=XS*(10.**(-IXM-1))
    IF( (XMIN-XS).GE.(10.*XDIV) ) XS=XS+(10.*XDIV)
 *
 *  CHOOSE PLOT SYMBOLS
    BLANK=1H
    DOT=1H*
    XPLOT=1HX
    PLUS=1H+
    PLOT(1)=1H1
    PLOT(2)=1H2
    PLOT(3)=1H3
    PLOT(4)=1H4
    PLOT(5)=1H5
 *
 *  SCALE THE POINTS
    DO 300 I=1,5
    MAXJ=MCT(I)
    DO 301 J=1,MAXJ
    X(I,J)=(X(I,J)-XS)/ XDIV
    IF(Y(I,J).LE.0.) Y(I,J)=1.E-10
    Y(I,J)=(ALOG10(Y(I,J))*18.)-(18.*DEC)+1.
301 CONTINUE
300 CONTINUE
 *
 *  PRINT  BORDER
    SCALE(1)=XS
    DO 120 I=2,7,1
120 SCALE(I)=SCALE(I-1)+(10.*XDIV)
    WRITE(9,400)
400 FORMAT(///)
    WRITE(9,121) SCALE
121 FORMAT(7(1PE8.2,2X))
    WRITE(9,122)
```

FIGURE C3

SUBRØUTINE SLPLØT

```
122 FØRMAT(7('I',9X))
    DØ 123 I=1,61
123 LINE(I)=PLUS
    DØ 124 I=1,61,10
124 LINE(I)=XPLØT
    WRITE(9,125)(LINE(IDUM),IDUM=1,61)
125 FØRMAT(61A1)
 *  BLANK THE LINE
    DØ 126 I=1,61
126 LINE(I)=BLANK
 *
 * PLØT THE PØINTS
    IDEC=DEC+4.
    IDØT=0
    IXPLØT=0
    LINE(62)=0.
    DØ 310 N=1,71
    LINE(1)=PLUS
    IDØT=IDØT+1
    IF(IDØT.NE.6) GØ TØ 315
    IDØT=0
    LINE(1)=DØT
    IXPLØT=IXPLØT+1
    IF(IXPLØT.NE.3) GØ TØ 315
    IXPLØT=0
    LINE(1)=XPLØT
    LINE(61)=XPLØT
    IDEC=IDEC-1
    LINE(62)=IDEC
315 IPY=73-N
    DØ 311 I=1,5
    MAXJ-MCT(I)
    DØ 312 J=1,MAXJ
    IY=Y(I,J)*1.001
    IX=X(I,J)
    IF(IY-73) 316,317,317
317 Y(I,J)=0.
    IY=0
316 IF(IY-IPY) 312,313,313
313 LINE(IX+1)=PLØT(I)
    Y(I,J)=0.
312 CØNTINUE
311 CØNTINUE
    IC=61
    DØ 314 IDUM=1,61
    IF (LINE(IC).NE.BLANK) GØ TØ 384
314 IC=IC-1
384 IC=IC+1
    WRITE(9,380) (LINE(NDUM),NDUM=1,IC)
380 FØRMAT(61A1,'1.0E',I2)
    DØ 382 II=1,61
382 LINE(II)=BLANK
310 CØNTINUE
    DØ 383 I=1,61
383 LINE(I)=PLUS
    DØ 385 I=1,61,10
```

FIGURE C3

SUBRØUTINE SLPLØT

```
385 LINE(I)=XPLØT
    WRITE(9,125)(LINE(IDUM),IDUM=1,61)
    WRITE(9,122)
    WRITE(9,121) SCALE
    WRITE(9,400)
    RETURN
    END
```

FIGURE C3

DATA BLOCK FOR SLPLOT SUBROUTINE

(X, Y, DEC)

Dimensions of Arrays:

X(5,50)

Y(5,50)

X direction is linear scale

Y direction is Log_{10} scale

Maximum of 5 curves plotted

DEC: Bottom ordinate of the Plot is 10^{DEC}

TABLE CIII

C5. PLDATA Program

PLDATA converts raw measurements of brightness of EL vs. voltage at a fixed frequency into a data block for plotting by the SLPLOT subroutine. The program lets you choose at execution time whether to plot vs. voltage or the inverse square root of the voltage. This second form allows the operator to determine ranges of applied voltage over which the ELFIT program can provide accurate results.

Table CIV summarizes the format of the data file used with the program. Figure C4 is a listing of the PLDATA program. It must be loaded with the SLPLOT subroutine.

PLDATA PROGRAM

```
      * PLØT DATA WITH SLPLØT
        DIMENSIØN X(5,50),Y(5,50)
        DATA X/250*0./,Y/250*0./
        DØ 10 I=1,5
        DØ 20 J=1,50
        READ(1,1) X(I,J),Y(I,J)
        IF(X(I,J).LE.0.) GØ TØ 21
     20 CONTINUE
     21 CONTINUE
     10 CONTINUE
        READ(1,2) DEC
      1 FØRMAT(2E16.3)
      2 FØRMAT(E16.2)
        WRITE(9,3)
      3 FØRMAT(///'STYLE ØF PLØT'/
      +  '1= X-VALUES AS READ'/
      +  '2= X=1/SQRT(X)'/
      +  )
        READ(9,4) IS
      4 FØRMAT(I1)
        GØ TØ (30,40),IS
     40 DØ 50 I=1,5
        DØ 60 J=1,50
        IF(X(I,J).NE.0.) X(I,J)=1./SQRT(X(I,J))
     60 CØNTINUE
     50 CØNTINUE
        GØ TØ 100
     30 CØNTINUE
    100 CALL SLPLØT(X,Y,DEC)
        IF(IEØF(1)) 102,102,103
    102 READ(1,101)
    101 FØRMAT('                                              ')
        WRITE(9,101)
        WRITE(9,200)
    200 FØRMAT(///)
    103 STØP
        END
```

FIGURE C4

INPUT DATA FORMAT FOR PLDATA (Uses SLPLOT Subroutine)

DATA FORMAT:

Device	Linear Scale	Log Scale	
1	X______,	Y______	(2 E16.3)
	______,	______	
	'	'	
	'	'	
	'	'	
	0.	(terminates a curve)	
	0.		
	0.		
	0.		
	0.	(After five zero. X inputs, ready for DEC)	
DEC	______	(E16.2)(Lowest ordinate plotted = 10^{DEC})	

(Optional 30 Character Line for Data Identification)

Beware of Blank Records in File!!

TABLE CIV

C6. ELDG Program

This program generates a set of EL brightness vs. voltage and frequency values computed from the equation:

$$\text{Brightness} = D \cdot F^{\alpha} \exp(-\sqrt{\frac{A}{V}})$$

where D, α, and A are constants, F is the applied frequency, and V is the applied voltage. This program is useful in checking the results of the ELFIT program. The resultant data file is ready for use by the PLDATA program.

The program asks for the D, α and A values along with their ranges of validity at execution time. All data is entered at the keyboard. The program will accept five voltage ranges but the IR program can only use three ranges.

Table CV lists the formats for the input data. Figure C5 is a listing of the ELDG program.

ELDG PRØGRAM

```
*  EL DATA GENERATØR FØR PLDATA
   DIMENSIØN F(10),A(5),VL(5),VU(5),DV(5),AV(5)
   DØ 10 I=1,5
   WRITE(9,1)
 1 FØRMAT('VOLTAGE RANGE; VL,VU'/)
   READ(9,2) VL(I),VU(I)
 2 FØRMAT(2E10.2)
   IF(VL(I)-0.) 30, 30, 20
20 II=I
   WRITE(9,3)
 3 FØRMAT('DV , AV , ALPHA'/)
   READ(9,4) DV(I),AV(I),A(I)
 4 FØRMAT(3E10.2)
10 CØNTINUE
30 CØNTINUE
   ZERØ=0.
*
   WRITE(9,5)
 5 FØRMAT('FREQUENCIES'/)
   DØ 40 J=1,10
   READ(9,6) F(J)
 6 FØRMAT(E10.2)
   IF(F(J)-0.) 50,50,60
60 JJ=J
40 CØNTINUE
50 CØNTINUE
   WRITE(9,7)
 7 FØRMAT(/'EXPØNENT ØF SMALLEST ØRDINATE (F10.1)'/)
   READ(9,8) DEC
 8 FØRMAT(F10.1)
*
   DØ 80 L=1,JJ
   DØ 70 K=1,II
   C=1.
   V=VL(K)
   INTV5=VL(K)/5.
   V5=INTV5
   VM5=V5*5.
90 CØNTINUE
   IF(V-VU(K)) 21,22,22
22 V=VU(K)
   C=200.
21 CØNTINUE
   ELØG=SQRT(AV(K)/V)
   FLØG=A(K)*ALØG(F(L))
   DVLØG=ALØG(DV(K))
   BLØG=DVLØG+FLØG-ELØG
   B=EXP(BLØG)
   WRITE(1,9) V,B
 9 FØRMAT(2E16.3)
   IF(C.EQ.1.) V=VM5+5.
   IF(C.GT.1.) V=V+5.
   C=C+1.
   IF(C.GE.200.) GØ TØ 70
   GØ TØ 90
70 CØNTINUE
```

FIGURE C5

ELDG PRØGRAM

```
      WRITE(1,9) ZERØ,ZERØ
   80 CONTINUE
      IF(JJ.EQ.5) GØ TØ 99
      DØ 98 KK=JJ,4,1
      WRITE(1,9) ZERØ,ZERØ
   98 CONTINUE
   99 WRITE(1,11) DEC
   11 FØRMAT(E16.2)
      STØP
      END
```

FIGURE C5

INPUT DATA FORMATS FOR ELDG

EQUATION: B = (F(L) **A(K))*DV(K)/SQRT(AV(K)/V)

DATA BLOCK:

Device	Formats
TTY (as asked for)	VL__________, VU__________ (E10.2)
	DV__________, AV__________, ALPHA__________ (E10.2)
	VL__________, VU__________
	DV__________, AV__________, ALPHA__________
	____0.____ (0 Voltage terminates parameter inputs)
	Frequencies__________ (E10.2)
	__________
	__________
	____0.____ (0 frequency terminates data input)
	Exponent of Smallest Ordinate__________ (E16.2)

Maximum of 5 voltage ranges

Maximum of 10 frequencies

VL < Voltage Range < VU

TABLE CV

C7. FM, AM and MASSA Programs

The MASSA program condenses the data file created by the IR program into a more compact form for use with the AM and FM programs. Figure C6 lists the MASSA program . It calls for the input data file at program execution time.

The FM program uses the brightness vs. radiation input data generated by the IR program and condensed by the MASSA program to approximate the operation of an image conversion panel driven by several applied frequencies in rotation. The simulation is that a panel is driven at a constant voltage and one frequency (F_1) for a short time (t_1), then driven at another frequency (F_2) for a short time (t_2), and so on up to F_n for time t_n and then driven again at F_1, etc. If the sum $\sum_{i=1}^{n} t_i$ is less than the time for the eye to see flicker in the brightness of the panel, the viewer perceives a simple average brightness of the panel. The FM program sorts through the response curves generated by the IR program and weights the output brightnesses for a selected frequency by the fraction $t_j/\sum_{i=1}^{n} t_i$ for that frequency. The program will accept up to 20 desired frequencies but seldom is it worthwhile to construct a data base large enough for use with that many frequencies.

Figure C7 is a listing of the FM program. Table CVI is a summary of the data file format for the FM program. The FM program may also be used to effectively sort and condense data for use in the CASCAD program. The FM program must be loaded with the PLOT subroutine.

The AM program works in an identical manner to the FM program only it computes a weighted average of different voltages applied for short time periods at one frequency. Figure C8 is a listing of the program. Table CVII describes the formats of the data file. This program may also be used to sort data for CASCAD. The AM program must be loaded with the PLOT subroutine.

MASSA PRØGRAM

```
*  MASSAGE LIGHT AMP DATA
     IFLAG=1
     READ(1,4) LP
     WRITE(2,4) LP
   4 FØRMAT(I2)
  10 READ(1,1) B,T,V,F
   1 FØRMAT(4E12.4)
  12 I=0
     BS=B
     TS=T
     VS=V
     FS=F
     WRITE(2,2) V,F
   2 FØRMAT(2E12.4)
*
  20 READ(1,1) B,T,V,F
     IF(IEØF(1)) 30,30,100
  30 IF(F-FS) 40,50,40
  40 IF(I-19) 60,70,70
  60 DØ 80 J=1,18,1
     WRITE(2,3) BS
   3 FØRMAT(E12.4)
  80 CØNTINUE
     GØ TØ (70,110), IFLAG
  70 GØ TØ 12
*
  50 WRITE(2,3) BS
     I=I+1
     BS=B
     TS=T
     VS=V
     FS=F
     GØ TØ 20
*
 100 IFLAG=2
     GØ TØ 40
 110 STØP EØF
     END
```

FIGURE C6

PAGE 1

FM PRØGRAM

```
*    FM DRIVEN LIGHT AMP
*
     DIMENSIØN FD(20),FRA(20),BØ(19,5),VS(5),XX(19,5)
     CØMMØN XX,BØ,LP
     DATA VS/5*0./
     DØ 23 I=1,19
     DØ 24 J=1,5
     XX(I,J)=0.
     BØ(I,J)=0.
  24 CØNTINUE
  23 CØNTINUE
     WRITE(9,4)
   4 FØRMAT(/'CREATE DATA FILE? 0=NØ, 1=YES'/)
     READ(9,5) ISWIT
   5 FØRMAT(I1)
     ISWIT=ISWIT+1
     WRITE(9,99)
  99 FØRMAT(/'WANT PLØT? 0=NØ, 1=YES'/)
     READ(9,5) ISWIT2
     ISWIT2=ISWIT2+1
     WRITE(9,2)
   2 FØRMAT(/'FREQ. ,FRACTIØNS'/'TERMINATE WITH 0.'/)
     IGØØD=1
     DØ 10 I=1,20
     READ(9,1) FD(I),FRA(I)
   1 FØRMAT(2E12.4)
     IF(FD(I)) 11,12,11
  11 IC=I
  10 CØNTINUE
  12 CØNTINUE
     FS=FD(1)
*
     READ(1,7) LP
   7 FØRMAT(I2)
     IF(ISWIT.EQ.2) WRITE(2,7) LP
  20 READ(1,1) V,F
     DØ 30 I=1,IC
     IF(ABS(FD(I)-F)-1.) 21,21,30
  21 IGØØD=2
     ISAVE=I
     GØ TØ 22
  30 CØNTINUE
     IGØØD=1
  22 CØNTINUE
     GØ TØ (40,60), IGØØD
  40 DØ 50 J=1,19
     READ(1,3)
   3 FØRMAT(E12.4)
  50 CØNTINUE
     IF(IEØF(1)) 20,20,80
*
  60 DØ 69 K=1,5
     IF(ABS(V-VS(K))-1.) 66,66,69
  69 CØNTINUE
    DØ 68 K=1,5
     IF(VS(K)) 68,67,68
```

FIGURE C7

FM PRØGRAM

```
   68 CONTINUE
      IGOOD=1
      GØ TØ 22
   67 VS(K)=V
   66 CONTINUE
      DØ 70 I=1,19
      READ(1,3) B
      BØ(I,K)=BØ(I,K)+(FRA(ISAVE)*B)
   70 CONTINUE
      FS=F
      IF(IEØF(1)) 20,20,80
   80 CØNTINUE
      GØ TØ(91,92),ISWIT
   92 CONTINUE
      DØ 93 K=1,5
      DØ 94 J=1,19
      IF(BØ(J,K)) 93,93,95
   95 WRITE(2,6) BØ(J,K)
    6 FORMAT(E12.4)
   94 CONTINUE
   93 CONTINUE
   91 GØ TØ (97,96),ISWIT2
   96 CALL ' GPL
   97 CØNTINUE
      STOP
      END
```

FIGURE C7

INPUT DATA FORMATS FOR FM

Device:	Data Format:
TTY (as asked for)	Frequency________, Fraction__________ (E12.4)
	________, __________
	________, __________
	___0.___ (maximum of 20)
1	Voltage__________, Frequency__________ (E12.4)
	Brightness____________ (E12.4)
	____________
	'
	19 values
	'
	____________
	Voltage__________, Frequency__________
	Brightness____________
	____________
	etc.

TABLE CVI

AM PRØGRAM

```
*   AM DRIVEN LIGHT AMP
*
    DIMENSIØN VD(20),FRA(20),BØ(19,5),FS(5),XX(19,5)
    CØMMØN XX,BØ,LP
    DATA FS/5*0./
    DØ 23 I=1,19
    DØ 24 J=1,5
    XX(I,J)=0.
    BØ(I,J)=0.
 24 CØNTINUE
 23 CØNTINUE
    WRITE(9,4)
  4 FØRMAT(/'CREATE DATA FILE? 0=NØ, 1=YES'/)
    READ(9,5) ISWIT
    ISWIT=ISWIT+1
  5 FØRMAT(I1)
    WRITE(9,99)
 99 FØRMAT(/'WANT PLØT? 0=NØ, 1=YES'/)
    READ(9,5) ISWIT2
    ISWIT2=ISWIT2+1
    WRITE(9,2)
  2 FØRMAT(/'VØLTAGES,FRACTIØNS'/'TERMINATE WITH 0.'/)
    IGØØD=1
    K=0
    DØ 10 I=1,20
    READ(9,1) VD(I),FRA(I)
  1 FØRMAT(2E12.4)
    IF(VD(I)) 11,12,11
 11 IC=I
 10 CØNTINUE
 12 CØNTINUE
    VS=VD(1)
*
    READ(1,7) LP
  7 FØRMAT(I2)
    IF(ISWIT.EQ.2) WRITE(2,7) LP
 20 READ(1,1) V,F
    DØ 30 I=1,IC
    IF(ABS(VD(I)-V)-1.) 21,21,30
 21 IGØØD=2
    ISAVE=I
    GØ TØ 22
 30 CØNTINUE
    IGØØD=1
 22 CØNTINUE
    GØ TØ (40,60), IGØØD
 40 DØ 50 J=1,19
    READ(1,3)
  3 FØRMAT(E12.4)
 50 CØNTINUE
    IF(IEØF(1)) 20,20,80
*
 60 DØ 69 K=1,5
    IF(ABS(F-FS(K))-1.) 66,66,69
 69 CØNTINUE
    DØ 68 K=1,5
```

FIGURE C8

AM PROGRAM

```
      IF(FS(K)) 68,67,68
   68 CONTINUE
      IGOOD=1
      GO TO 22
   67 FS(K)=F
   66 CONTINUE
      DO 70 I=1,19
      READ(1,3) B
      BO(I,K)=BO(I,K)+(FRA(ISAVE)*B)
   70 CONTINUE
      VS=V
      IF(IEOF(1)) 20,20,80
   80 CONTINUE
      GO TO (91,92),ISWIT
   92 CONTINUE
      DO 93 K=1,5
      DO 94 J=1,19
      IF(BO(J,K)) 93, 93, 95
   95 WRITE(2,6) BO(J,K)
    6 FORMAT(E12.4)
   94 CONTINUG
   93 CONTINUE
   91 GO TO (97,96), ISWIT2
   96 CALL LOCPL
   97 CONTINUE
      STOP
      END
```

FIGURE C8

INPUT DATA FORMATS FOR AM

Device:	Data Format:
TTY (as asked for)	Voltage__________, Fraction__________(E12.4)
	__________, __________
	__________, __________
	____0.____ (maximum of 20)
1	Voltage__________, Frequency__________(E12.4)
	Brightness__________(E12.4)
	__________
	19 values
	Voltage__________, Frequency__________
	Brightness__________
	__________
	__________
	etc.

TABLE CVII

C8. CASCAD Program and MASSA 2 Program

The MASSA 2 program converts the data files generated by IR and MASSA into a form compatible with the CASCAD program. The IR program can generate up to 25 output brightness curves for different voltage and frequency combinations. The CASCAD program will only plot data for 5 possible output combinations of the second stage panel. The operator should edit his data files to make sure that the files used in device 2 contain no more than 5 curves. The AM or FM program can be used to sort the files generated by IR and MASSA. For instance, if the operator using AM selects 100% of one voltage to be used, the output data file will contain brightness curves at only that operating voltage and all frequencies that were available.

The CASCAD program takes a set of 19 output brightnesses from the first image panel and uses these brightnesses with linear interpolations from all sets of output brightnesses for the second state image panel to generate an approximate simulation for a two-stage image converter. The program permutes all curves of the second stage panel on each curve of the first stage panel.

Either or both of the simulated image conversion panels may have been AM or FM simulated panels. At this stage in the simulations, operator discretion is mandatory or one may drown in output curves.

Figure C9 is a listing of the MASSA 2 program. Figure C10 is a listing of the CASCAD program. Table CVIII is a summary of input data formats for CASCAD.

MASSA2 PRØGRAM

```
*   MASSA2
*   PREPARES MASSAGED DATA FØR CASCAD
    DIMENSIØN B(19)
    READ(1,1) LP
    WRITE(2,1) LP
  1 FØRMAT(I2)
  2 FØRMAT(E12.4)
  3 FØRMAT(2E12.4)
 30 READ(1,3)V,F
    DØ 10 I=1,19
    READ(1,2) B(I)
 10 CØNTINUE
    DØ 20 I=1,19
    WRITE(2,2) B(I)
 20 CØNTINUE
    IF(IEØF(1)) 30,30,40
 40 STØP EØF
    END
```

FIGURE C9

CASCAD PROGRAM

```
*  CASCAD
* COMPUTES OUTPUT OF CASCADED LIGHT AMPS
   DIMENSION B1(19),B2(19),T(19),BJ(19,5),XX(19,5)
   COMMON XX,BJ,LP
   DATA T(1),T(2),T(3)/1.E-6,2.E-6,5.E-6/
   DATA T(19)/1./,J/0/
   DO 12 I=1,19
   DO 13 J=1,5
   XX(I,J)=0.
13 CONTINUE
12 CONTINUE
   DO 10 I=4,16,3
   T(I)=T(I-3)*10.
   T(I+1)=T(I-2)*10.
   T(I+2)=T(I-1)*10.
10 CONTINUE
*
   WRITE(9,1)
 1 FORMAT(/'CREATE DATA FILE? 0=NO, 1=YES'/)
   READ(9,2) ISWIT
 2 FORMAT(I1)
   ISWIT=ISWIT+1
   WRITE (9,3)
 3 FORMAT(/'BEGINNING INPUT RADIATION'/)
   READ(1,6) LP
   WRITE(9,7) LP
   READ(2,6) LP
   WRITE(9,7) LP
   IF(ISWIT.EQ.2) WRITE(3,6) LP
 6 FORMAT(I2)
 7 FORMAT(10X,'1.E ' I2)
 4 FORMAT(E12.4)
   TB=10.**LP
*
  DO 20 I=1,19
   T(I)=T(I)*(TB/1.E-6)
20 CONTINUE
*
30 IF(IEOF(1).EQ.1) GO TO 101
   DO 31 I=1,19
   READ(1,5) B1(I)
31 CONTINUE
 5 FORMAT(E12.4)
35 CONTINUE
   DO 32 I=1,19
   READ(2,5) B2(I)
32 CONTINUE
   J=J+1
   N=2
40 DO 50 I=1,19
   DO 60 K=N,19,1
   IF(B1(I)-T(K)) 70,70,80
80 IF(K-19) 60,90,90
60 CONTINUE
90 BJ(I,J)=B2(K)
   GO TO 50
```

FIGURE C10

PAGE 2

CASCAD PRØGRAM

```
 70 N=K
    BØ(I,J)=B2(K-1)+((B2(K)-B2(K-1))*(B1(I)-T(K-1))
  +   /(T(K)-T(K-1) ) )
    IF(BØ(I,J).LE.0.) BØ(I,J)=1.E-10
 50 CØNTINUE
    IF(IEØF(2).EQ.1) GØ TØ 100
    GØ TØ 35
  *
  *
100 GØ TØ (103,102),ISWIT
102 WRITE(3,4)  ((BØ(L,M),L=1,19),M=1,J,1)
103 CALL LØGPL
    DØ 25 I=1,J,1
    DØ 26 K=1,19
    BØ(K,I)=0.
 26 CØNTINUE
 25 CØNTINUE
    J=0
    REWIND 2
    GØ TØ 30
101 STØP
    END
```

FIGURE C10

INPUT DATA FORMAT FOR CASCAD

Device:	Data Format:
1 (First Stage)	LP__________(I2)(Beginning input Radiation = 10^{LP})
	Output Brightness____________(E12.4)
	____________
	'
	19 values
	'
	____________
	Brightnesses are in groups of 19
2 (Second Stage)	LP__________ (I2)
	Output Brightness ____________
	____________
	'
	19 values
	'
	____________
	(Same format as for device 1)
	(Maximum of 5 groups of Brightnesses)

TABLE CVIII