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**PERKIN-ELMER**  
AEROSPACE DIVISION

*CR-151112*

# SPACE SHUTTLE

IMAGE INTENSIFIER/  
IMAGE CONVERTER  
CAMERA

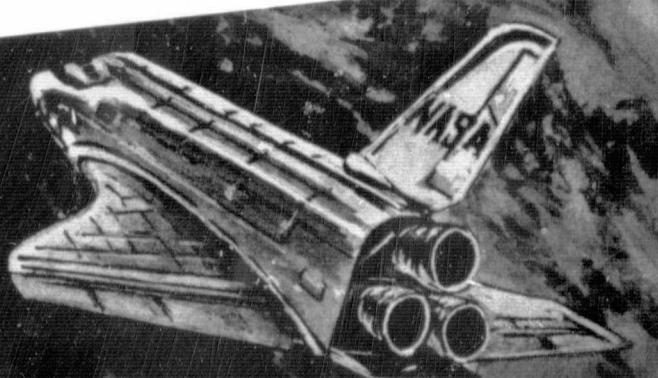
FINAL REPORT



N77-12365

(NASA-CR-151112) ENGINEERING DESIGN  
CRITERIA FOR AN IMAGE INTENSIFIER/IMAGE  
CONVERTER CAMERA Final Report (Perkin-Elmer  
Corp.) 124 p HC A06/MF A01 CSCL 14E

G3/35 Unclassified 55809



THE PERKIN-ELMER CORPORATION  
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FINAL REPORT  
ENGINEERING DESIGN CRITERIA  
FOR  
AN IMAGE INTENSIFIER/IMAGE CONVERTER CAMERA

by

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October 1976

Perkin-Elmer SPO 30348  
NASA Contract Number NAS9-14401

Prepared for  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
Johnson Space Center  
Houston, Texas 77058

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## 1.0 INTRODUCTION

This is the final report for a study to define an image intensifier/image converter ( $I^2/IC$ ) camera configuration which can be utilized in various requirements of Space Shuttle experiments. This work was performed under NASA Contract No. NAS9-14401, by the Perkin-Elmer Corporation, Aerospace Division, Pomona, California for the Johnson Space Center. Task 1, a trade-off study and analysis, was fully documented in a report submitted in February 1975. That report, which included a survey of the state-of-the-art, systems analysis, and discussion of design considerations and tradeoffs, demonstrated that an image intensifier camera, based on concepts established in Task 1 and discussed in the report, would meet the requirements established for it in the Statement of Work and during discussions between NASA and Perkin-Elmer personnel.

Four system configurations were proposed. Of these four, two were recommended for further development in the remainder of the study.

This report covers the remainder of the study, including the design and construction of two brass boards and a power supply, and their testing and evaluation. A summary of this activity is covered in Section 2.0.

Section 3.0 describes the brass board designs for demonstrating the relay lens approach and the cassette approach, and the power supply which was designed and constructed for use with the brass boards.

Section 4.0 covers the test results, and Section 5.0 presents a summary and conclusions from the study.

Analysis, data sheets, specifications and test plans which support the report are included in the appendix.

In the introduction to the Task 1 report, it was stated that military security requirements could prevent Perkin-Elmer from compiling a completely comprehensive survey of the state-of-the-art of image intensifiers, and that a need to know had been requested in order to overcome this barrier. If additional data was subsequently found which could have a significant impact on the conclusions of the Task 1 report, then this additional information would be submitted in a classified addendum. Since that time, however, nothing has been found in the classified literature which significantly changes the findings or conclusions of the Task 1 report, and thus a classified addendum is not necessary. The Task 1 report thus remains a firm foundation for further study, and provides the starting point for the efforts which are reported in this document.

## 2.0 PROJECT SUMMARY

The following summarizes the activities which occurred following submittal of the Task 1 report.

Contract Amendment/Modification 1 (S) added exhibit "B" to the Statement of Work, directing Perkin-Elmer to proceed with two brassboards, and a power supply, the two brassboards representing the most promising approaches from the Task 1 (tradeoff analysis) report.

The power supply was defined as a complete workable breadboard, capable of powering the intensifier utilized in the two brassboards. This amendment further defined that in each brassboard a 35 mm camera should be used, and also added a paper design for adapting the relay lens approach brassboard to a 16 mm format camera. All of this work has been accomplished, and is covered in the remainder of this report.

The first step in the procurement of an image intensifier tube was the preparation of a specification, Appendix A.

Requests for quotation were submitted to all known qualified manufacturers, 3 in number, and Galileo Electro-Optics, Inc. was selected on the basis of price and performance. Manufacturers data for this tube are included in Appendix B.

During the early testing phases of the relay lens approach, irrepairable damage was done to the image intensifier by inadvertent application of voltages above the safe operating level, causing several circular dead spots across the face of the tube. The power supply was corrected to prevent further occurrences of these high voltages, which were found to occur when the supply was shut off. Subsequent amendment 2 (S) directed Perkin-Elmer to purchase a second image intensifier from the same supplier, and also added a requirement to rework the relay lens approach brassboard to evaluate vignetting which had been observed.

The second image intensifier delivered by Galileo was installed in the cassette brassboard, and used for evaluation of night photography in the field, with the NASA Technical Monitor present. Pictures were obtained showing scene details which would have been undistinguishable to the naked eye or to an ordinary camera, and the overall performance of the system was quite encouraging. However, dead spots in the tube (present when received) made its performance unacceptable, and since Galileo was withdrawing from the image intensifier business, there was no possibility of obtaining another acceptable tube from that vendor. Contract Amendment/Modification 3 (S) directed Perkin-Elmer to deliver, in lieu of the Galileo image intensifier, a 25 mm proximity focussed image intensifier from any other source. Necessary delays in obtaining this image intensifier from ITT, the only remaining qualified vendor for this type of device, forced a delay in the Perkin-Elmer delivery

schedule, which was also modified in this amendment. Data for this tube are also included in Appendix B.

Since the ITT tube design is dimensionally different from the Galileo, this change required design modifications to both brassboards. With these modifications accomplished, the testing program was resumed.

During preliminary test of the new ITT tube in the cassette brassboard arcing occurred outside the tube, and the tube was damaged internally. This damage was manifested by a bright spot on the output face plate, which appeared only at the higher gain settings. The tube was returned to ITT for evaluation of the damage and its cause. It was Perkin-Elmer's contention that the damage was related to poor encapsulation of the tube by ITT, while ITT contended that the failure was related to Perkin-Elmer use of the tube. An attempt by ITT to repair the tube failed. Since a new tube was then required in order for Perkin-Elmer to complete the contract, the impasse in regards to responsibility was resolved by an agreement that the two companies would share equally in the cost of a replacement tube. A new tube was subsequently ordered and delivered, and used for the remainder of the testing program. This is also the tube that will be delivered with the brassboards.

The following sections of this report cover the details of the efforts following completion of Task 1.

## 3.0 BRASSBOARD DESIGN

### 3.1 RELAY LENS BRASSBOARD

This approach, which is discussed in Section 6.3 of the Task 1 report, is illustrated in Figure 3-1. It consists of the camera fore optics, an image intensifier module, the relay optics, and a Nikon F camera, all mounted in-line on an aluminum channel structure. The purpose of the channel is to provide a simple, rigid base for testing, without particular concern for minimum size and weight. Figure 3-1 also shows the power supply discussed in Section 3.3.

#### 3.1.1 IMAGE INTENSIFIER MODULE

The image intensifier module is shown in Figure 3-2. The image intensifier is held in the retainer ring, which is made of Vespel to help avoid electrical arcing due to the high voltage. The image intensifier is clamped into the retainer ring by the ring clamp as shown. Due to differences in thickness between the Galileo tube and the ITT tube, this assembly was modified as shown in the figure when the ITT tube replaced the Galileo tube. The four leads to the tube are brought out of the bottom of the assembly. Two lens mount assemblies join this assembly to the fore optics on one end, and to the relay lens assembly on the other end. Commercial bayonet mounts provide an economical and reliable means to quickly assemble and disassemble the image intensifier module.

Threaded joints in the lens mounts provide for optical focussing. They are locked in position with the locking rings.

The image intensifier module is cradled in two saddle blocks, and held in place with clamps and thumb screws. This assembly allows enough axial movement in the saddle blocks to accomodate changes in length due to focussing. The front and rear faces of the module are provided with mating halves to the bayonet mounts on the fore optics and the relay lens assembly respectively.

Figure 3-3 shows a fixture which was developed for testing the image intensifier by direct contact of the film to the output face, eliminating the relay lens, and any effects that it might have on results. This fixture consists of two pieces, the film retainer and the film cap. The film retainer takes the place of the clamp ring on the image intensifier module, eliminating all other parts from this point on back to the camera, including the camera. This fixture was used to help evaluate vignetting due to the relay lens.

#### 3.1.2 RELAY LENS

The relay lens was formed from two standard Nikon 55 mm, f/1.2 lenses, mounted input to input. This arrangement is not as compact as a specially designed relay lens assembly would be, but it offers a readily available assembly at modest cost, and it attaches to the camera without

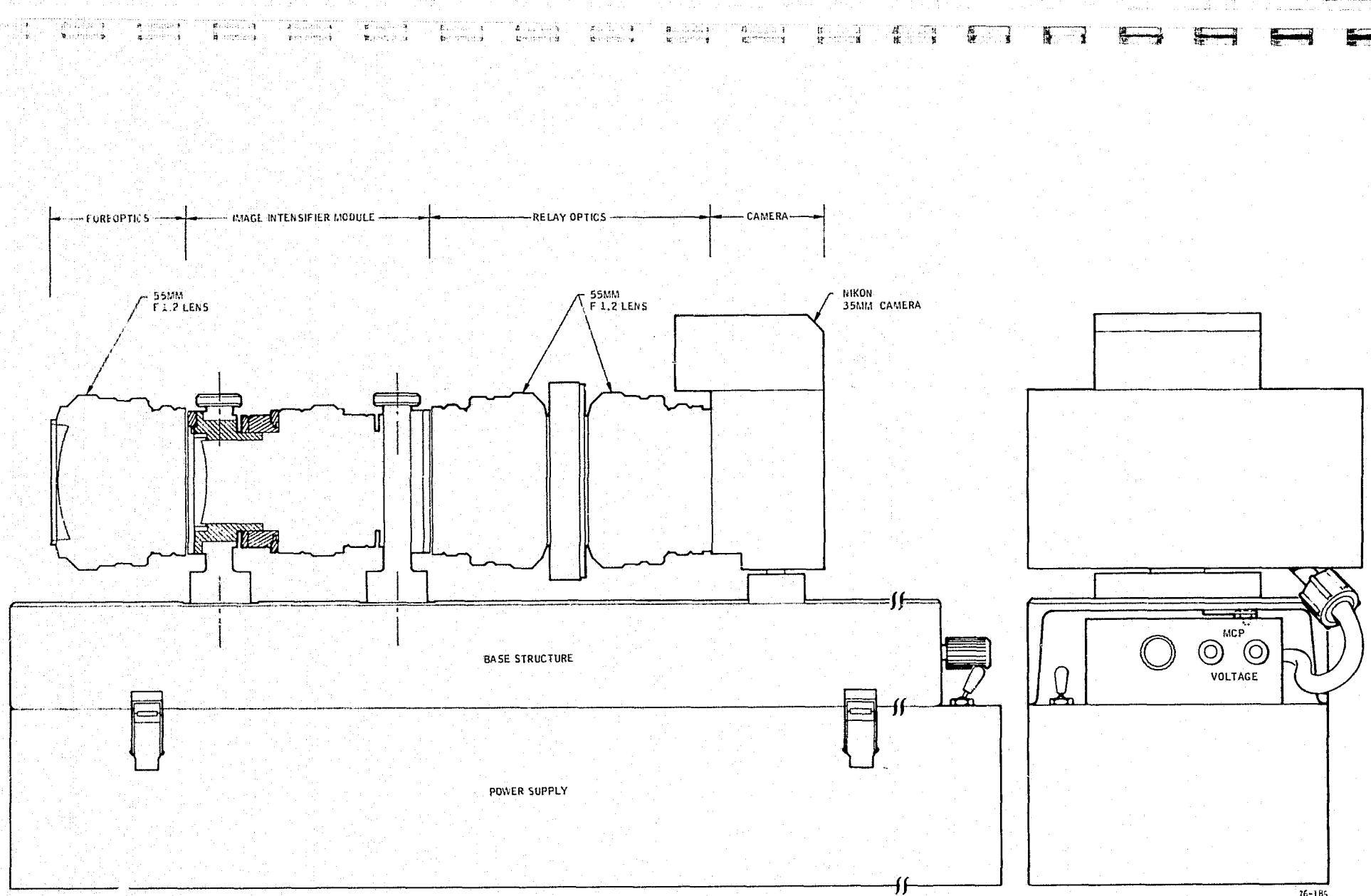
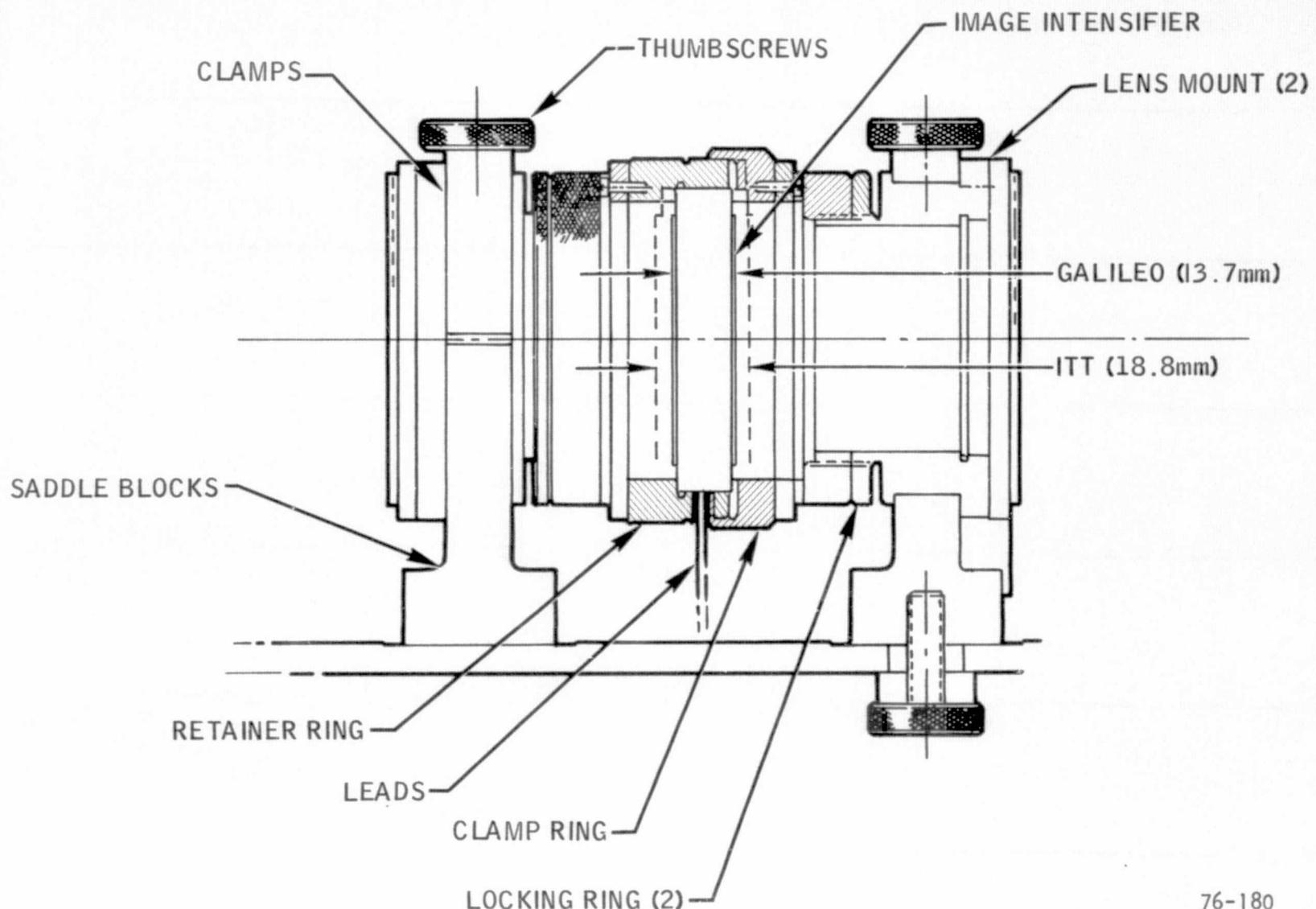


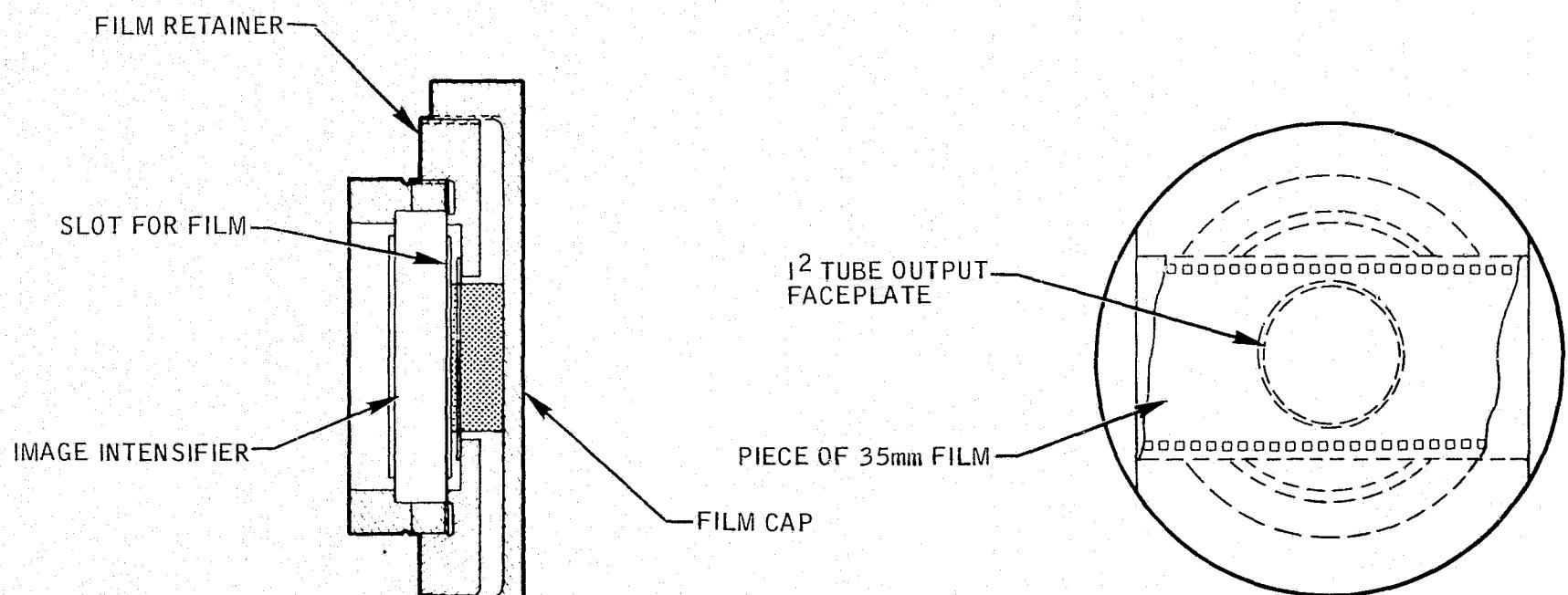
FIGURE 3-1  
Image Intensifier Camera Brassboard Using Relay Lens Approach



76-180

FIGURE 3-2

Image Intensifier Module for Relay Lens Approach Brassboard



76-181

FIGURE 3-3  
Fixture for Contact Exposure of Film

requiring modification to either the camera or the lens.

Since one lens mounts to the image intensifier module through a bayonet mount, and the other lens mounts to the camera in the same fashion, all that is needed to join the two lenses is a light shield, shown in Figure 3-4. This donut shaped assembly includes internal coiled springs in compression. To assemble it to the lenses, it is simply compressed and placed in position, and then allowed to expand so as to mate against the ends of the lenses. This arrangement makes it very easy to change lenses.

### 3.1.3 CAMERA

A NASA furnished Nikon F 35 mm camera was selected for the study. This camera is used in the relay lens approach brassboard without any modification whatsoever. It is secured to the mounting base of the brassboard with a thumb screw, using the tapped hole normally used for attachment to a tripod.

### 3.1.4 FOREOPTICS

Any standard Nikon lens can be used for the foreoptics. In all of the tests in this study, a 55 mm, f/1.2 lens, identical to those used in the relay optics, was used.

### 3.1.5 STRUCTURE

All of the components of the relay lens approach brassboard are assembled to a 1 3/4" x 5" aluminum channel. This provides a rigid, stable and economical base, allowing easy changes for development purposes. It could naturally be made smaller and lighter for flight use.

A support is provided on the underside of the channel, at the center of gravity of the assembly, for mounting to an optical bench for testing.

Figure 3-1 shows the brassboard attached to the power supply which was also developed under this study and which is described in Section 3.3. It is easily attached to the brassboard with the four hasps shown. This assembly greatly facilitates testing in the field.

### 3.1.6 ADAPTION TO 16 MM FORMAT

Amendment 1 (S) to the contract includes a paper design for adapting the brassboard system to a 16 mm format camera. This design was carried to the point of a design layout. The result is shown on Figure 3-5, which uses the NASA 16 mm DAC with a 25 mm lens. The right angle bracket (P/N SEB-33100277-304) which mounts the camera to the base is in NASA inventory.

The only modification required to the base is a longitudinal slot at the camera end to accomodate clearance for the camera connectors and the tee mount at the base of the bracket. In this case, the tee is not used for mounting the bracket. Instead, clearance holes are drilled in the bracket for two 6-32 screws, which match two holes in the channel.

The paper study also includes an analysis of the image illumination provided by a relay system made up of two lenses of different focal lengths, which

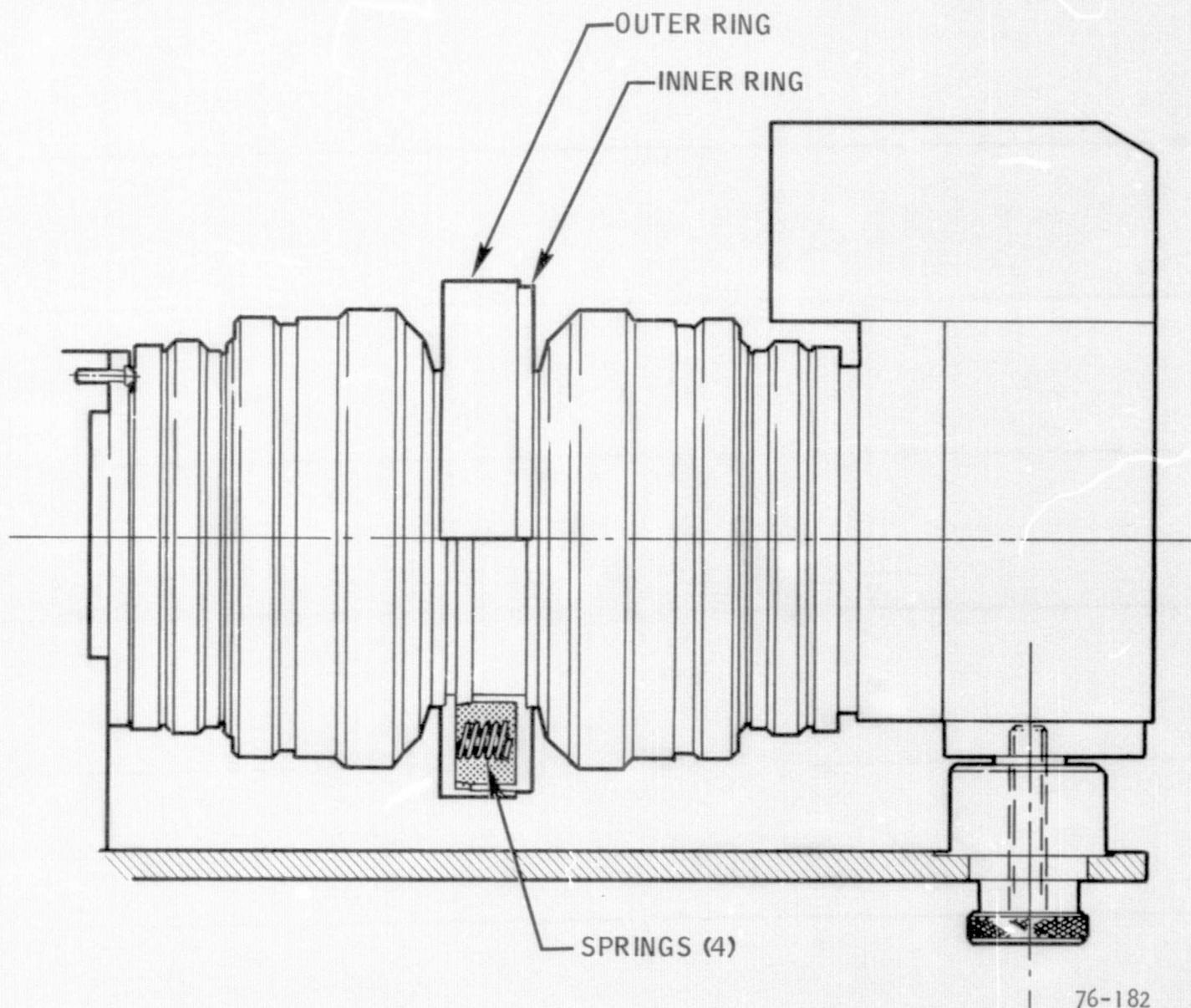


FIGURE 3-4  
Light Shield Assembly

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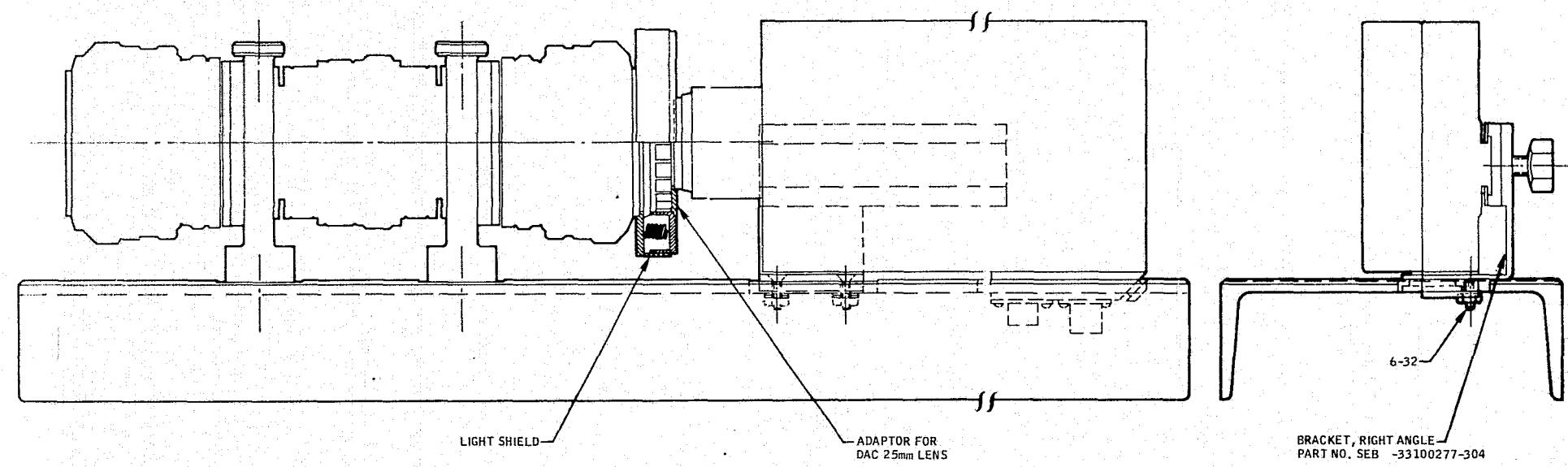


FIGURE 3-5  
Relay Lens Approach Brassboard Adapted for 16 mm Format Camera

would now be the case. This analysis is included in Appendix C of this report, and shows that the image illumination for the 55 mm Nikon/25 mm DAC combination of lenses would be essentially the same as for the combination of two 55 mm Nikon lenses.

Figure 3-6 compares the 16 mm camera film format with the image intensifier field for the same combination of Nikon and DAC lenses.

While performing the analysis for the image illumination, a small error was uncovered in Section 4.4 of the Task 1 report. Solving Equation 3 in that report for I/B, gives a value of .353. Comparing this with the value of .045 obtained in the analysis in Appendix C for the relay lens composed of two 55mm f/1.2 lenses gives a reduction in image illumination due to the relay lens of 7.8 to 1 instead of 10 to 1 reported in the Task 1 report. Although the new value is based on more rigorous analysis, the difference in results is not considered significant.

### 3.2 CASSETTE BRASSBOARD

This approach, which was discussed in Section 6.2 in the Task 1 report, is illustrated in Figures 3-7 and 3-8. Figure 3-7 shows the cassette attached to the Nikon 35 mm camera, while Figure 3-8 shows the cassette and camera separated.

The cassette, which includes the image intensifier and the film supply and film takeup, fastens to the camera in place of the standard camera slide-on back. The cassette can be loaded either on or off the camera. The objective is that a standard camera can be quickly converted to an image intensified camera, by removing the standard back and replacing it with a cassette loaded with film best suited for use with the image intensifier. With one minor exception, this goal has been met. That exception, which has to do with incorporating an image intensifier of standard configuration in the camera, is discussed further in Section 3.2.2.

#### 3.2.1 CASSETTE CONSTRUCTION

The cassette structure consists of four (4) pieces. These are the body, which is an aluminum hog-out, the base extension, which is taken from a standard camera slide-on back, a shield which engages in a groove in the camera and the swing back to the cassette, which is hinged to the body. The base extension and the shield are fastened to the body with screws. The aluminum parts are black anodized. In a design for production, the number of structural parts could be reduced to two, the body and the swing back.

#### 3.2.2 IMAGE INTENSIFIER INSTALLATION

The image intensifier is located in a circular cavity in the cassette body, with sufficient clearance to allow it to float against the film rails of the camera.

Figure 3-9 shows the modifications to the camera which were required in order to accomodate the 25 mm intensifier tube. In the standard camera, the film rests against the inner rails at the film plane, and is guided by the outer rails which are approximately 0.3 millimeter (.012 inch) higher than the inner rails. Since the surface of the input face plate of the intensifier is

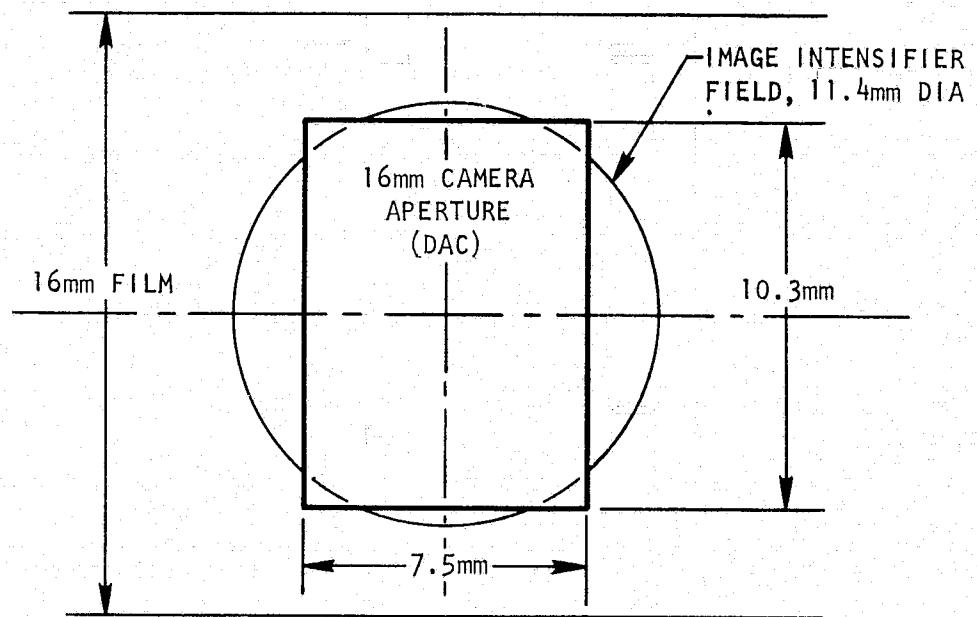


FIGURE 3-6

Comparison of 16mm Film Format and Field of a 25mm Image Intensifier  
Reduced by a 55mm/25mm Lens Combination



FIGURE 3-7  
Image Intensifier Camera With Cassette Attached

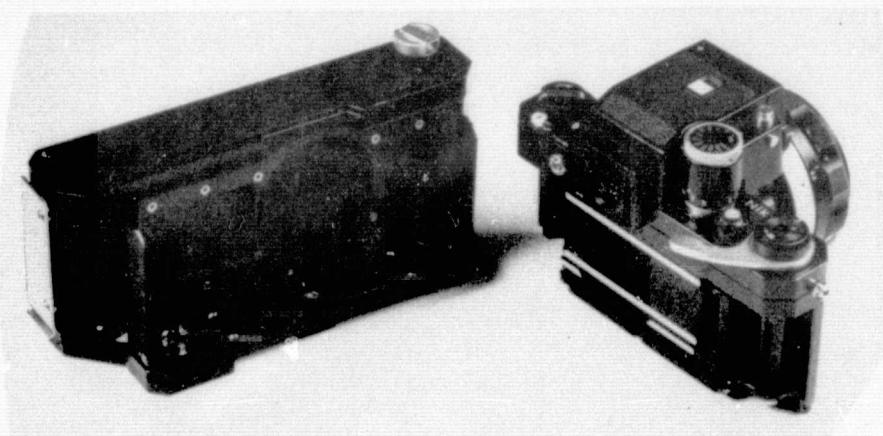


FIGURE 3-8

Image Intensifier Camera and Cassette Shown Separately

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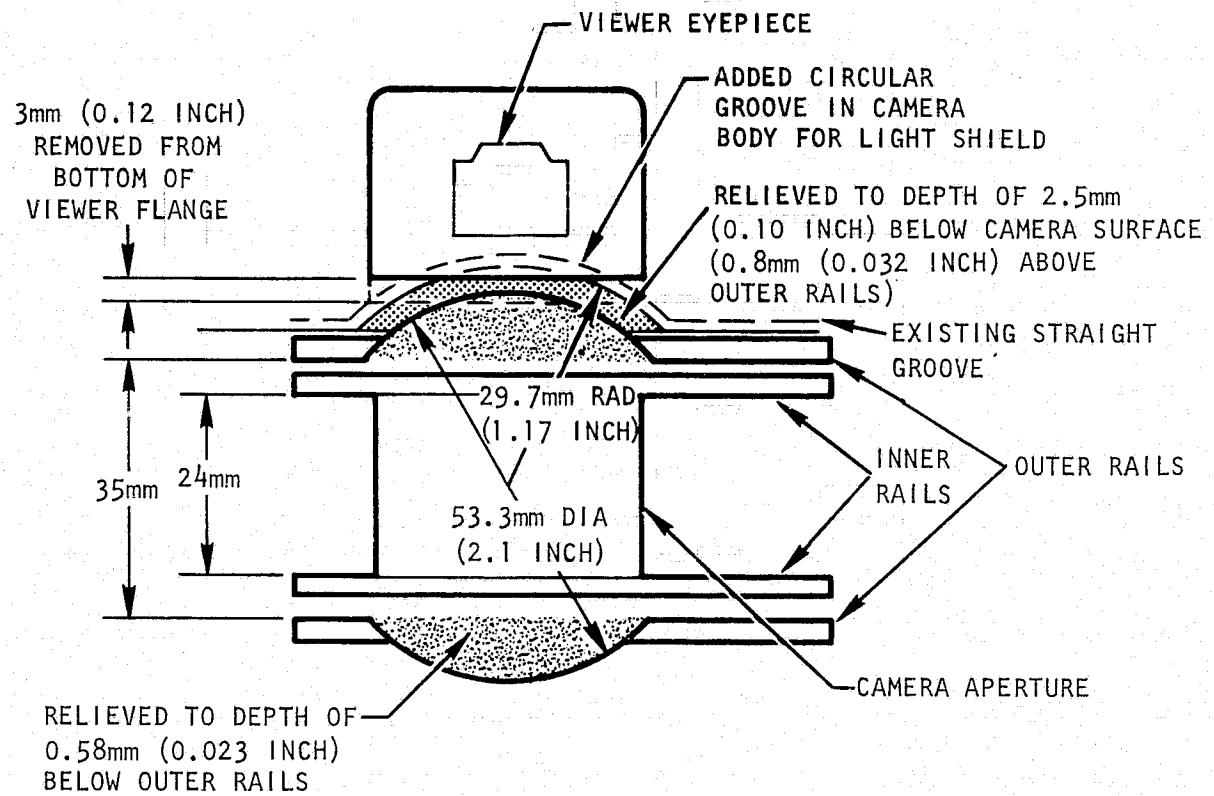
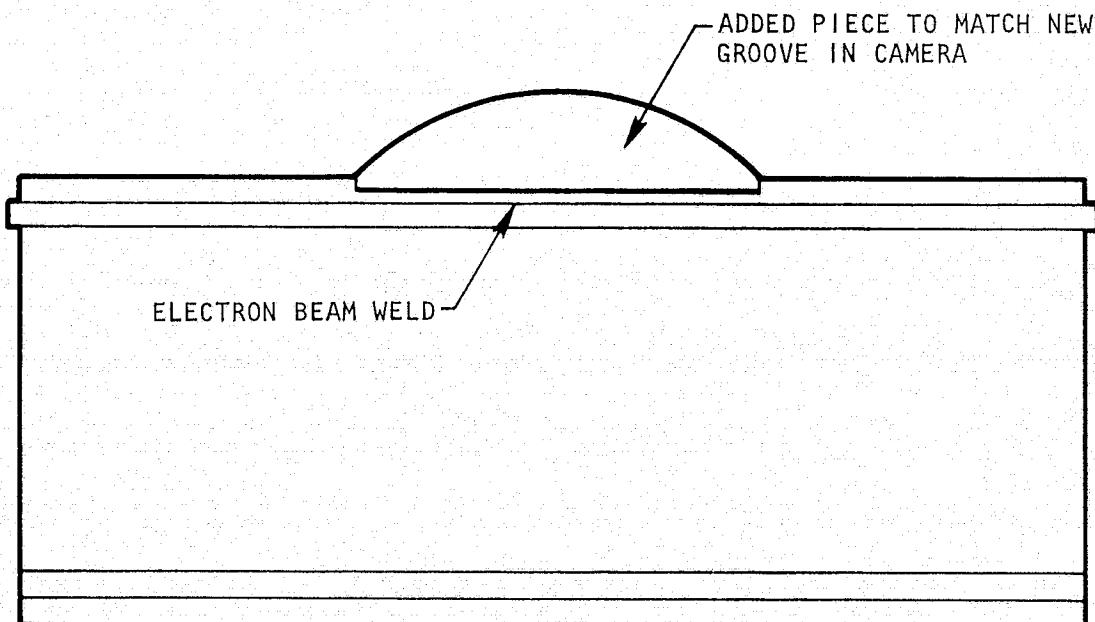


FIGURE 3-9

Modifications to Nikon Camera to Accommodate 25 mm Image Intensifier



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FIGURE 3-10

Modified Camera Slide on Back for Converting to a Standard Camera

greater than 35 mm in diameter, it was necessary to remove portions of the outer rails as shown in the figure. It was also necessary to remove material outside this diameter on the upper side of the camera aperture to clear the encapsulated body of the tube. Since this machining cut into the straight groove which normally receives the camera back, it was necessary to cut a new circular groove as shown. Also, it was necessary to remove about 3 mm (.12 inch) from the lower side of the plastic frame around the viewer eye piece of the camera.

It was the original intent to design the cassette so as to require no alterations whatsoever to the camera. However, this proved to be impossible if a standard off-the-shelf intensifier tube was to be used. In the future, it will be possible to avoid these modifications by specifying a diameter and thickness for the input face plate which will locate the body of the tube far enough back to avoid interference with the camera. This would only add 3 or 4 millimeters to the length of the face plate, which should have negligible effect on the performance or cost of the tube other than a first time charge for tooling.

In order to be able to easily return the brassboard to a "standard" camera configuration, a new slide-on back was ordered and modified as shown on Figure 3-10. The circular piece added to the top of the back engages the new circular groove which was cut in the camera.

A protective cover is provided for the input face of the image intensifier tube, to be used when the cassette is removed from the camera. It is hinged to the cassette body, and is retracted into a cavity in the body before the cassette is attached to the camera.

### 3.2.3 FILM TRANSPORT

Figure 3-11 is a plan view of the cassette in schematic form showing how the film is transported across the output face of the image intensifier.

The cassette is designed to receive a standard commercial 35 mm film cartridge, as shown in the figure. It is placed in the cavity as shown, and is held by the leaf spring when the swing back is closed. The special NASA cartridge, P/N SEB33100775-301 can also be used, provided that the light trap in the cartridge is opened before the swing back on the cassette is closed, which requires that the cassette be loaded in a darkroom. In the standard camera, this light trap is opened by a cam on the attachment mechanism on the camera back, precluding darkroom loading. In actual production a similar mechanism could be added to the cassette to provide this function.

After leaving the cartridge, the film passes over a guide spool, and then between the pressure plate and the output face of the image intensifier tube. (The pressure plate is pushed against the back of the film when the cassette back is closed). From here it proceeds over the drive sprocket and onto the take-up spool.

The configuration shown in Figure 3-11 is for the ITT Image Intensifier tube, which was the final configuration used. The plane of the output face for the original tube, manufactured by Galileo Electro-Optics, Inc., is also shown on the figure. The change in tubes required moving the pressure plate

mechanism back, but this presented no problem. With the ITT tube, the film contacts an edge of the tube encapsulation as it passes to the drive sprocket, but since the encapsulation is a soft pliable material, no damage to the film has been noted.

Figure 3-11 also shows schematically the gear train which drives the sprocket and take-up spool from a coupling on the camera. This coupling is already available, normally being used for connection to an electrically powered film magazine designed for remote operation. It is spring loaded axially so that it slips into engagement with a mating piece in the cassette, when the cassette is attached to the camera. The drive sprocket is geared directly to this coupling, while the take-up spool is driven through a slip clutch, since its rotation relative to the drive sprocket must be reduced as the film builds up on the take-up spool. The drive sprocket, the take-up spool with clutch, and the film re-wind mechanism were all salvaged from an inexpensive 35 mm camera which had been scrapped, thus avoiding the high cost of manufacturing these parts specifically for this design.

The film is advanced by actuating the film transport mechanism on the Nikon, in the same manner as operating the standard camera. Thus one operation cocks the shutter, advances the film, and operates the film footage indicator.

The film advance in the cassette is designed to move the film 39 millimeters for each exposure, the same as in the standard camera. This results in the film format shown on Figure 3-12. The gear train could be redesigned to bring the film frames closer together, putting more frames on a roll of film, if this is desired. The present format could readily accomodate data annotation between the frames, and there is sufficient space in the cassette to accomodate film annotation capability, including the associated electronics.

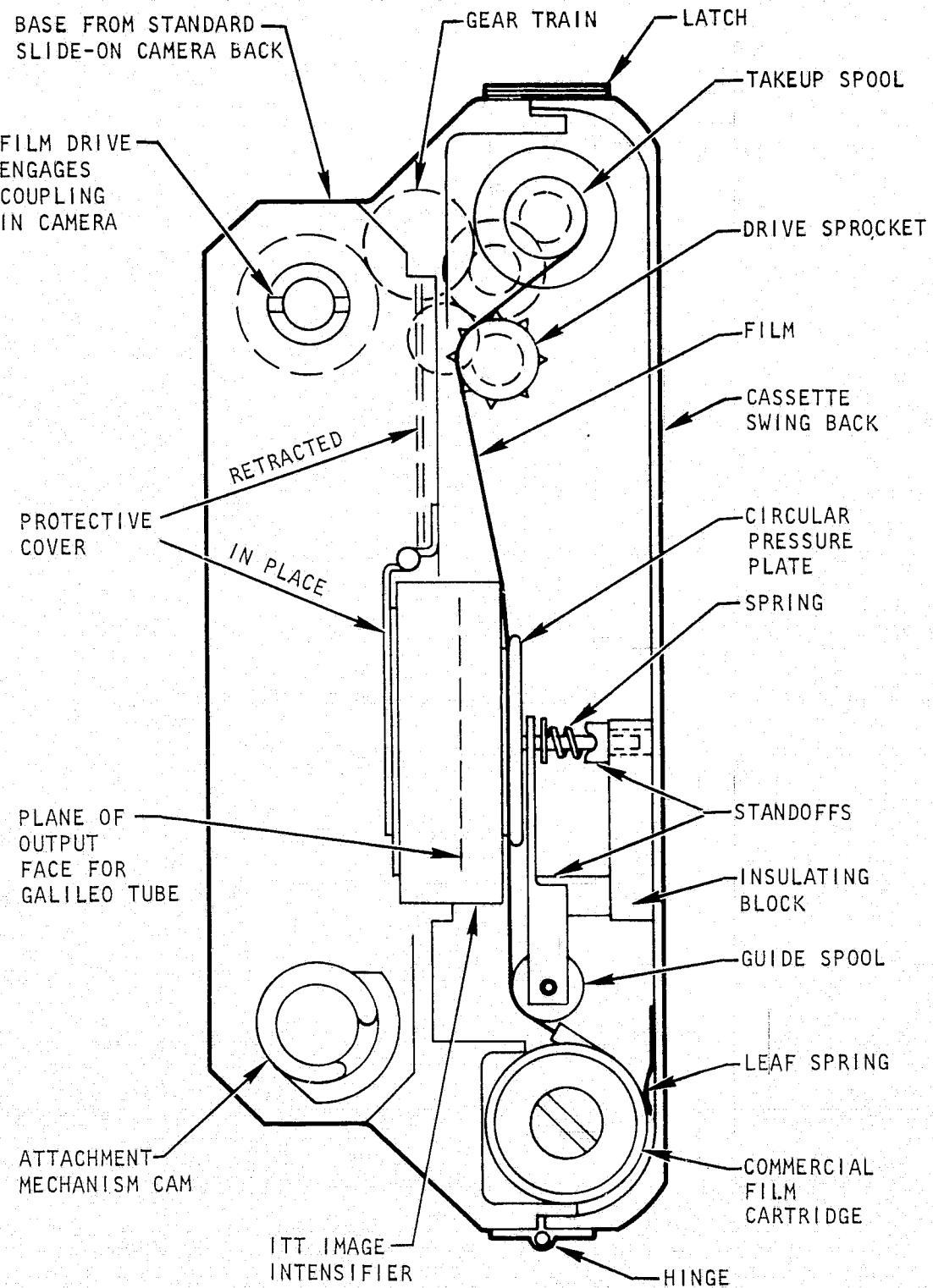
### 3.3 HIGH VOLTAGE POWER SUPPLY

#### 3.3.1 INTRODUCTION

As the Image Intensifier/Image Converter Study progressed from the study phase to the breadboard phase, power supply requirements and options necessary to support breadboard testing were defined. Among these requirements was the capability to modify the power supply circuitry in order to facilitate breadboard testing and optimize total system performance. Direct accessibility to the power supply circuitry also facilitates repair in the event of a failure during testing of the system.

Circuit flexibility and accessibility is not available in commercially available image intensifier power supplies due to either circuit hybridization or potting of vendor proprietary circuits. Therefore, the decision was made to design and build a power supply which would meet the requirements of system breadboard testing and also be adaptable to flight hardware construction.

A block diagram, showing the major building blocks of the Image Intensifier Power Supply is shown in Figure 3-13. The blocks are interconnected to show the direction of signal flow and power flow. The circuitry contained within each of these blocks is shown in the Image Intensifier Power Supply Schematic, Figure 3-14. The following discussion describes the design objectives which the power supply must satisfy, a detailed description of circuit operation, and



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FIGURE 3-11

Method of Film Transport in the Cassette

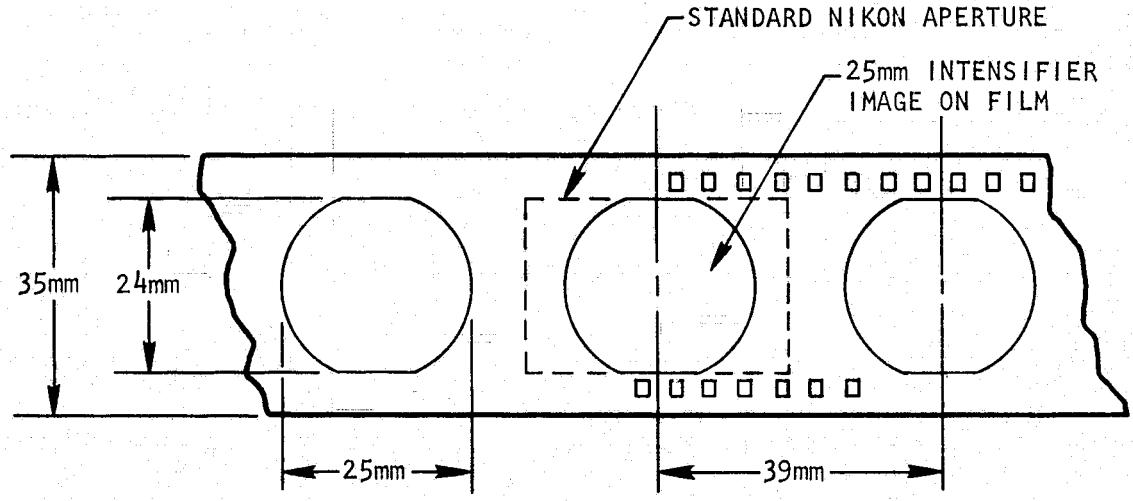


FIGURE 3-12

Film Format for Cassette Brassboard

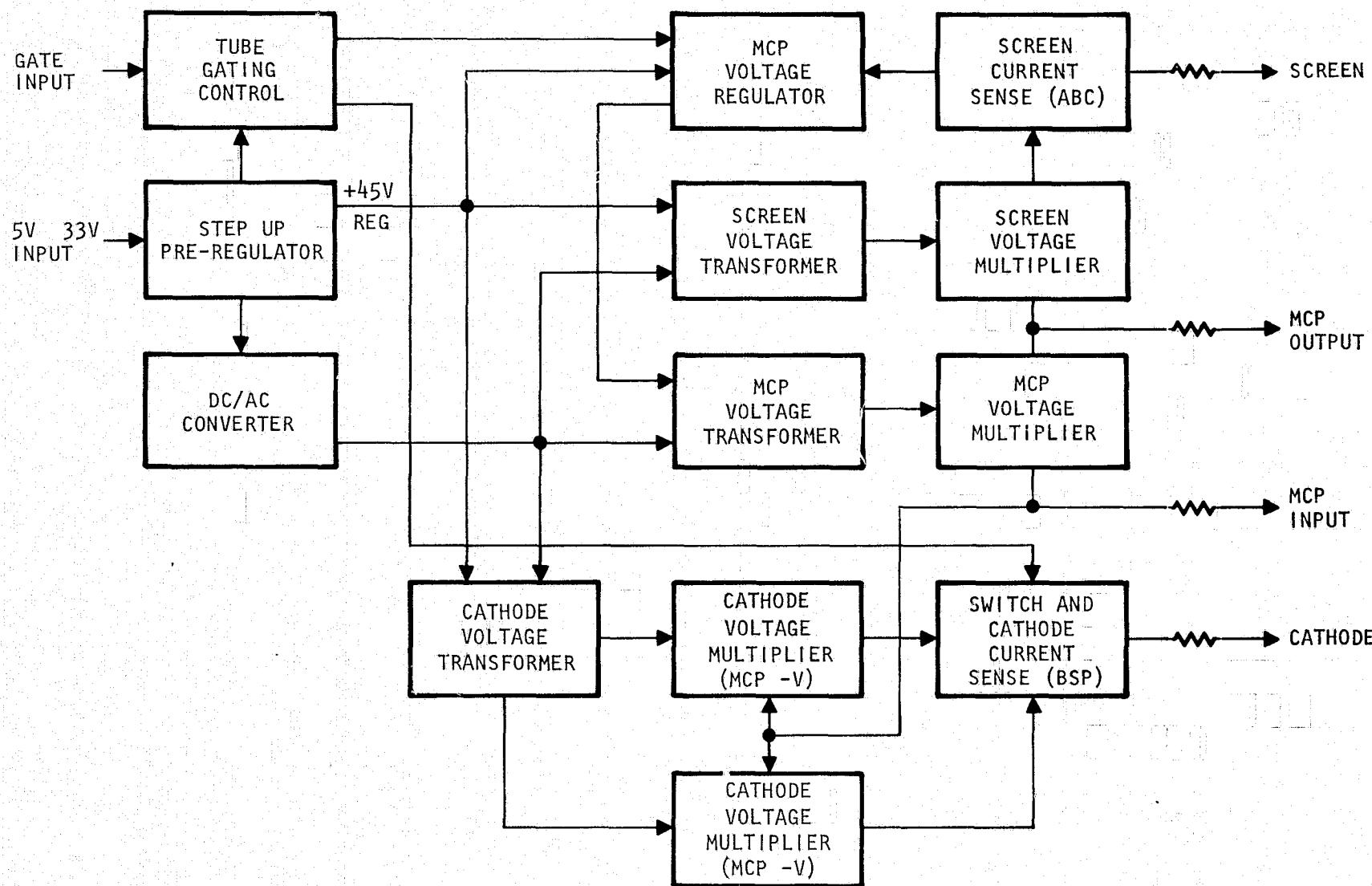


FIGURE 3-13

Image Intensifier Power Supply Block Diagram

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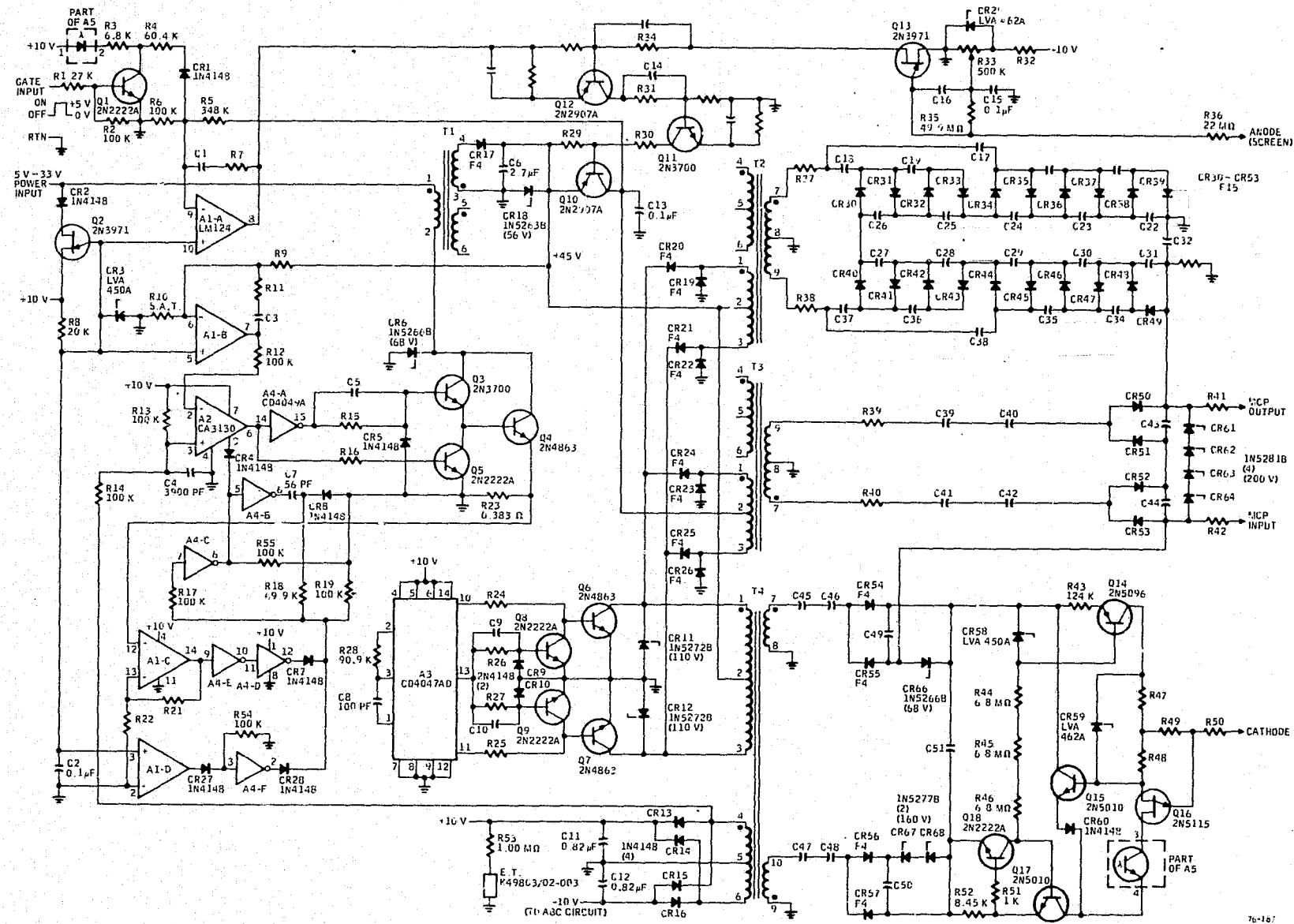


FIGURE 3-14  
Power Supply Schematic

circuit features which have been incorporated in the design of the power supply.

### 3.3.2 DESIGN OBJECTIVES

The design objectives are listed below:

1. Design a supply to convert the raw primary power into voltages and currents required by the tube for proper operation.
2. Provide protection to the tube and the supply to prevent damage which could occur during system operation. Bright Source Protection (BSP) is included in this objective.
3. Make the output screen at ground potential. This eliminates high voltage gradients across the output window and on the film when used in the cassette configuration.
4. Provide Automatic Brightness Control (ABC). This option serves the function of an automatic exposure control, within limitations to be described later.
5. Provide the option of operating the system in either the gated mode or the non-gated mode.
6. Maintain circuit flexibility in the breadboard stage in order to allow the optimization of circuit and system performance.
7. Utilize low power circuits to minimize input power drain, thus extending battery life when the supply is powered by a self-contained battery.
8. Minimize component count and make use of small components in order to minimize the overall size of the power supply.
9. Operate from a power source ranging from +5 volts to +33 volts. This allows the supply to be operated from either a self-contained battery or spacecraft power without the need of special adapters.
10. Use circuits and components which can be readily converted into flight hardware.
11. Make use of circuits which are easily produced and tested, and employ a minimum of select-at-test components.

All of these objectives were considered during the design phase of the power supply. Many design trade-offs and compromises were made to optimize the power supply performance with readily available components.

### 3.3.3 CIRCUIT FEATURES

Certain desirable circuit features were included in the Image Intensifier High Voltage Power Supply during the design phase. Some of these features were incorporated to protect the tube or the power supply in the event of a failure in the power supply. Others were incorporated to enhance overall system performance and still others were incorporated to add flexibility to the power

supply during breadboard testing of the total system.

Wide operating input voltage range is an important feature. The supply will operate from a +5 volt to +33 volt source, which could include a self-contained battery or spacecraft power. This wide input voltage range is accomplished by using a flyback transformer in a step-up pre-regulator.

One feature that protects the power supply in the event of a short circuit on one of the supply outputs is a current limited pre-regulator. This regulator limits the maximum energy transfer from the primary winding of transformer T1 to the secondary winding. Under a short circuit condition, the pre-regulator voltage (and therefore the secondary voltages) will fall due to the energy transfer limitation. This energy limitation is also desirable for starting a power supply driving a capacitive load such as voltage multipliers. The charging rate of the capacitors is limited thus avoiding high charging current peaks.

Two features that protect the tube from damage are BSP (Bright Source Protection), described in Section 3.3.4, and the inclusion of the zener diode CR18. The zener diode limits the maximum pre-regulator voltage and in so doing, limits the maximum secondary voltages applied to the tube.

Two of the features that enhance overall system performance are ABC (Automatic Brightness Control) and gateability, both described in Section 3.3.4, Circuit Operation. If desired, the gating feature can be easily bypassed so that the tube will be ON continuously. This would be desirable for through-the-intensifier viewing.

Setability of the ABC screen current level and the BSP cathode current limit level add operational flexibility to the power supply. Also, the tube gain during the tube OFF state can be adjusted to a predetermined value by adjusting the MCP voltage while the tube is gated OFF. This decreases the time required for the tube to reach the proper gain after it is gated ON by starting from the middle of the dynamic gain range instead of starting from maximum tube gain. However, this response time, as determined from the brassboard tests, is still too great to make the ABC feature useful in the cassette configuration, except for very long exposure times. This is because the ABC cannot start controlling screen brightness until after the camera shutter is open and the film is being exposed. A better approach, based on automatically controlling the exposure time by integrating the screen current (which is a measure of total luminance energy delivered to the film), is discussed in Section 3.3.4. Another approach, based on using a separate light sensor, is also discussed. The speed of response limitation for the present system of ABC does not apply of course when the power supply is used with the relay lens approach.

Other features include the use of low power circuits, both integrated and discrete component, where possible. Also, transformer sizes are minimized by the elimination of high primary to secondary voltage gradients, thus minimizing primary to secondary insulation requirements. The turns ratios of the transformers are also minimized to reduce the amount of wire required on the secondaries, further reducing transformer size. This was accomplished by using voltage multipliers on the transformer secondaries and a high pre-regulator voltage (45 volts).

### 3.3.4 CIRCUIT OPERATION

Proceeding *ca* a block by block basis in accordance with Figure 3-13, the following discussion references the Image Intensifier Power Supply Schematic shown in Figure 3-14.

When power is initially applied to the power supply input, the pre-regulator starts functioning in a start-up mode of operation. In this mode, power is applied to the pre-regulator electronics via Q2, which is in the "ON" state. The output of the comparator, A2, is low, forcing the output of the inverter, A4-A, high and turning Q4 "ON". The current through Q4 and the primary winding of the flyback transformer, T1, increases at a linear rate. This current is sensed across R23 and the signal is amplified by A1-C. The inverter, A4-E, is used as a comparator, and when the output of A1-C reaches 45% of the A4-E supply voltage, A4-E changes state. This fires the one-shots, A4-B and A4-C, which in turn strobe A2 and turn OFF Q4. Q4 is held OFF for the duration of the one-shot time. This off time allows the energy which has been stored in the magnetic field of T1 to transfer to the secondary winding and discharge into the storage capacitor C6. At the end of the one-shot time, Q4 is turned "ON" and the cycle repeats. Each cycle builds the voltage on C6 until it reaches 45 volts, at which time the pre-regulator assumes a voltage control mode of operation.

In the voltage control mode of operation, 10 volts is supplied to the pre-regulator electronics via a secondary winding on transformer T4. Q2 is held "OFF" as long as the 10 volts is present. Also, operating in this mode, a portion of the 45 volts developed across C6 is fed back to the pre-regulator input by the voltage divider consisting of R9 and R10. The sampled signal is compared to the reference voltage of CR3 to develop an error signal which is amplified by A1-B and fed into the negative input of comparator A2.

A triangular wave with a 500 mV peak-to-peak amplitude and centered around 5 volts is developed at the positive input of comparator A2. This triangular wave provides hysteresis to the comparator to ensure a positive switching action of Q4. A4 is switched "OFF" during the positive peaks of the triangular wave and switched "ON" during the negative peaks. When the amplified error voltage from A1-B is equal to the triangular wave average voltage, Q4 is switched with a 50% duty cycle. If the amplified error voltage drops below the triangular wave average voltage (C6 voltage increases) the Q4 "ON" time will decrease and the "OFF" time will increase. This change in duty cycle reduces the C6 voltage to bring it back into regulation. Likewise, if the amplified error voltage rises above the triangular wave average voltage, the Q4 "ON" time is increased and the "OFF" time decreased, again bringing the C6 voltage back into regulation.

The regulated C6 voltage is fed directly to the primary winding of transformers T2 and T4 and to the primary winding of T3 through the series pass element of a linear regulator, Q10. The DC primary voltage of each transformer is converted into an AC voltage at the secondary windings of each transformer by the DC/AC converter consisting of A3, Q6 and Q7. A3 is a free running astable multivibrator with a 50 KHz output (Pin 13) and two symmetrical 25 KHz squarewave outputs 180° out of phase (Pins 10 and 11). The two 25 KHz output signals drive the chopper transistors, Q6 and Q7, which in turn ground one end of each primary winding during the Q6 ON time and ground the other end during

the Q7 ON time. The 50 KHz squarewave drives Q8 and Q9 which holds Q6 and Q7 OFF for one-half of the normal chopper ON time. This eliminates any "cross over" current spikes during chopper switching times and also cuts the transformer power losses in half because each transformer is driven with a 50% duty cycle. The secondary windings of each transformer peak charge the voltage multiplier capacitors, and therefore, the secondary voltages are not affected by driving the transformers with the 50% duty cycle. Thus, the DC at the primary of each transformer is converted to AC at the secondaries with an amplitude which is a function of the transformer turns ratios and the pre-regulator voltage.

The AC voltages at the secondaries are multiplied in amplitude and rectified by each of the voltage multiplier circuits. The screen voltage multiplier circuit is actually two times 4 and two times 6 multiplier circuits stacked in series. It supplies the required 5 kV between the MCP output element and the screen element of the tube. The screen current from this multiplier circuit is sensed by the screen current sense circuit to control the voltage impressed across the micro channel plate (MCP) of the tube. Controlling the MCP voltage controls the tube gain and thus the screen current.

The MCP voltage is determined by the output voltage of the MCP voltage regulator. When the tube is gated "ON", the output of the gating amplifier, A1-A, is driven high and the output voltage of the MCP voltage regulator is controlled by the screen current sense circuit. The screen current is sensed by R35 and amplified by Q13. This amplified current is level shifted by Q11 and Q12. The level shifted current controls the MCP voltage regulator series pass element, Q10, thereby maintaining the screen current at the pre-set ABC level.

The MCP voltage on the secondary side of transformer T3 is developed by two times 2 voltage multiplier circuits stacked in series and referenced to the -5 kV screen voltage. The MCP voltage, as described above, is a function of the MCP regulator output voltage and is variable within the range of zero volts to -1 kV.

The MCP voltage regulator has a second mode of operation besides the gated "ON" mode described above. This is the gated "OFF" mode which maintains the MCP regulator output at a constant voltage. While in this mode, the screen current is zero and Q13 is fully ON. The MCP regulator output voltage is fed back to the gating amplifier, A1-A, by the voltage divider R5-R6 and compared to the reference voltage of CR3. The developed error voltage is amplified by A1-A which controls the MCP regulator output voltage by controlling the drive current of Q12. The MCP regulator output voltage when the tube is gated "OFF" is set in the middle of the regulator dynamic range in order to minimize the time required for the regulator to assume the ABC voltage level when the tube is gated "ON". Gating the tube "ON" turns Q1 "ON" and pulls the center tap voltage of R5-R6 down causing the A1-A output voltage to go high. While in this state, the MCP regulator output voltage is controlled by the screen current sense circuit as described above.

Two voltages are developed on the secondary side of transformer T4 to provide the cathode voltage potentials. These voltages are developed in the same manner as is the MCP voltage except that the two voltages are not of equal magnitude and they are referenced at the center cap of C49 and C50 to the MCP input voltage. The voltages developed across C49 and C50 are +60 volts and -300 volts respectively, both referenced to the MCP input voltage. The +60 volts is used to reverse bias the cathode of the tube in order to gate the tube OFF. The -300 volts biases the cathode to the ON state.

The switch and cathode current sense circuit controls the cathode voltage and has two modes of operation; the gating mode and the cathode current limit mode (BSP). The circuit is comprised of a constant current source, a current limit circuit and the control circuit. The current source which includes CR58, R43 and Q14, provides a constant bias current to the control circuit. The current limit circuit includes Q17, Q18, and R52 and limits the amount of current the -300 volts supply can sink. The gating signal is provided from the collector of Q1 in the tube gate control circuit by the opto-isolator, A5. With absence of a gating signal, A5 is turned OFF and all current from the current source (Q14) is diverted to the base of Q15. This results in the emitter current of Q15 being greater than Q17 can sink. Therefore, the Q17 collector voltage rises to the upper limit of +50 volts and the tube is in the cutoff state.

A gating signal will turn A5 ON, and under operating light levels Q16 is ON, so that the current from Q14 is shunted from Q15, turning Q15 OFF. The Q17 sink current is then reduced to that of the current source which is within the current range of Q17. Therefore, the Q17 collector voltage assumes the lower limit of -300 volts and the tube is in the ON state.

While operating in the ON state, the cathode current is sensed by R49. Should the tube be exposed to excessive light levels, the cathode current and thus the voltage across R49 will increase to the BSP (Bright Source Protection) limit and Q16 will begin to turn OFF. This diverts a portion of the current source current to Q15 which increases the current Q17 must sink. As the cathode current increases, more current is diverted to Q15, and Q17 begins current limiting which raises the collector voltage of Q17. The cathode bias voltage is thus reduced, which in turn reduces the cathode current. Therefore, the cathode current is limited to the maximum BSP (Bright Source Protection) value by automatically reducing the cathode bias voltage at high light levels.

Additional bright source protection is provided to the cathode by the current limiting resistor, R50. The value of R50 is 2 gigaohm which will limit the maximum cathode current to a safe level in the event the cathode is exposed to excessive illumination.

### 3.3.5 DISCUSSION

During the initial tests of the image intensifier power supply and image intensifier tube as a system, it was noticed that permanent black spots were appearing on the tube screen. Further investigation and consultation with the tube vendor (Galileo Electro-Optics, Inc.) revealed that the spots were due to dead sections in the micro channel plate, which were caused by excessive voltage across the MCP during power supply turn off transients. These voltage transients caused arcing through the MCP channels which burned the secondary

emitting material within the channel, leaving the channel dead. To prevent further damage to the tube, zener diodes were added across the MCP output voltage and the cathode voltage to clamp these voltages and maintain them within a safe level. No additional spots have developed after the diodes were added. As a further precaution, the enclosure for the power supply was changed from sheet aluminum to acrylic plastic, to prevent charge build-up which could be hazardous to personnel and possibly damaging to the tube.

The arcing through the MCP also caused the Galileo tube to become noisy at high tube gains. As a result, this tube cannot be operated at the higher gains. Therefore, the power supply tests described in Section 4.3 were conducted with a limited maximum tube gain.

The power supply tests revealed some power supply areas in which performance improvements may be desirable. Three of these areas include ABC response, ABC regulation, and gating response. The ABC response and regulation could be improved by replacing the single FET screen current sense transistor (Q13) with a dual FET pair, increasing the DC gain, and changing frequency compensation of the feedback loop. The dual FET pair would compensate for variations in the FET pinch off voltage with temperature. The increased DC gain would improve regulation and the change in the loop frequency compensation would improve the ABC response. Improvements in the gating response would require modifications to the cathode voltage switching circuit.

There are also areas in the power supply in which the circuitry can be simplified. For example, transformer T2 can be eliminated by transferring winding 7-8-9 on transformer T2 to transformer T4. This not only eliminates one transformer but it also reduces the input power requirements to the power supply.

The cathode voltage gating circuit can also be simplified by eliminating the active bright source protection circuitry and using a resistor to accomplish the BSP function. Thus CR59, R47, R48, R49 and Q16 can be eliminated without effecting the gating capability of the remaining circuit.

One of the most desirable and useful features of the image intensifier power supply when used for photographic purposes is that of automatic exposure control. In the present configuration, the ABC circuit performs this function by maintaining a constant screen brightness and the exposure time is varied for different film exposures. This method performs well in the relay lens configuration but has inherent difficulties in the cassette configuration. In the latter configuration, the camera shutter prevents light from falling on the tube until time to expose film. At this time, the shutter opens and the ABC must compensate for scene illumination while film is being exposed. For each exposure time this results in different film exposures for different scene illuminations because of the variable time delay in reaching the desired brightness level. The circuit changes mentioned earlier would help, but would not completely solve the problem.

Two new approaches for an improved automatic exposure control should be considered for use with the cassette configuration. The first method would utilize a fixed tube gain, a screen current integrating circuit, and either the gating circuit which is used for an electronic shutter or the camera shutter. Film exposure would commence by opening the shutter or by gating the tube ON with an external signal. Exposure would continue until a given amount of screen current is integrated by the screen current integrating circuit, at which time the tube

would be automatically gated OFF or the shutter closed. Thus, the exposure time would be automatically varied to compensate for different screen illumination levels, and even though the tube screen brightness varies during exposure, the total light energy for each exposure would remain constant. Since the film itself is an integrator of energy, it makes sense to control exposure by controlling the integrated energy output of the tube. A serious practical limitation to the application of this principle may be the very low screen current levels that are involved.

The second method would use a separate sensor not behind the shutter for automatic brightness control. However, since an image intensifier is probably the only reasonably sized sensor capable of detecting the low light levels for which the image intensifier camera will be used, a second image intensifier would be required on the camera. For economic reasons this could be a lower cost, 18mm tube, and it could be incorporated in the viewer, so that the camera user would have benefit of an image intensified scene when setting up the camera. This is a feature which is not presently available in the cassette approach. A common power supply could power both tubes, but there would be electronic design considerations which would have to be worked out.

Of the two approaches just discussed, the screen current integration method appears to offer the better solution, although it does not provide image intensified viewing, which the second approach offers. On the other hand, this feature was never considered to be available in the cassette approach as it was conceived in the trade-off analysis phase of this study.

## 4.0 TEST RESULTS

### 4.1 INTRODUCTION

A test and calibration plan was prepared during Task 2 of the study, to establish approaches and procedures for testing the brassboards. This plan was submitted to NASA/JSC for approval. A copy is included in Appendix D of this report.

The purpose of the testing was to evaluate performance predictions and conclusions established in the Trade-Off-Analysis, Task 1 of the study. Because there was little background to go by, this test plan was made open ended, with the direction for the testing being established as the program progressed. The original plan was admittedly ambitious. Some of the tests gave firm results, while others were of doubtful value due to technical difficulties which probably could have been overcome had the tests been of sufficient importance. However, the really significant questions relate to what kind of pictures can be taken as determined by appearance to the eye. System performance in regards to details such as spectral range, distortion and uniformity are almost completely determined by the image intensifier tube itself. The manufacturers of the image intensifiers are better equipped for determining this information, and complete test data was supplied with each tube. This is included in this report in Appendix B. Certifications were also supplied with all data. Photography of actual scenes, in the laboratory and in the field, are considered the most important part of the test program. This is discussed further in the appropriate section.

The power supply development was a major part of the study, and considerable electronic testing was performed to determine its characteristics. These tests are reported in Section 4.7.

Tubes used during the course of the program are listed in Table 4-1, in the order in which they were used. Section 2.0, Project Summary, explains the reason why more than one tube was required.

The test program unfortunately was fragmented due to the lead times required in obtaining tubes, and difficulties that occurred in their application. As a result it was impossible to carry out a completely formal program of testing in exact conformance with the plan, which was designed to be flexible in the first place. The most important result of the testing was that it provided experience in the use of image intensifiers in camera systems. It is felt that the really important results were the photographs taken in the laboratory and the field which show what the image intensifier camera can do.

In summary, the test program has established that the image intensifier camera meets the objectives which were established in Task 1, and has led to certain recommendations which are covered in Section 5.0.

Manufacturer	Model No.	Serial No.	Phosphor Type	Notes
Galileo Electro-Optics Corporation	9025-2121	440	P-20	Used in the Laboratory Only
Galileo Electro-Optics Corporation	9025-2122	453	P-11	Used in Field Photo- graphy only (cassette)
ITT, Electro- Optical Products Division	F4112	587/2	P-11	To be delivered with the brassboards

TABLE 4-1  
Image Intensifier Tubes Used  
In The Study

#### 4.2 SCENE LUMINANCE

The procedure for the scene luminance tests is outlined in Appendix D, Test and Calibration Plan. Its purpose is to test response of the camera system to various scene luminance levels, and to establish guidelines for setting optimum combinations of exposure times and intensifier gains for different scene conditions. Results were obtained by photometric measurements and by exposure of film.

Figure 4-1 shows the photometric results for the first Galileo tube, in the relay lens brassboard. Luminance gains were set by adjusting the microchannel plate voltage, using the calibration curve in Appendix B supplied by the manufacturer. Table 4-2 shows how scene luminance was obtained by combination of light sphere output and neutral density filter, using the procedure in the Test and Calibration Plan. The output of the phosphor screen was measured with a United Detector Technology Incorporated PIN-5DP planar diffused silicon photodiode light sensor, used in the current mode in an operational amplifier circuit. This arrangement provides a linear voltage output for up to 10 decades of light level change. These signals were not calibrated, but they provided a reliable relative indication of tube output.

Ideally, Figure 4-1 would plot as lines of constant slope across the range of scene luminance levels. A possible explanation for the consistently high data points at  $3 \times 10^{-5}$  foot-lamberts input, relative to the other readings, is that due to a limited selection of filters it was necessary to start with 30 foot-lamberts, while three foot-lamberts were used for all other inputs. However, this theory was at least partially refuted in later tests with the ITT tube. Other deviations from the ideal can be assumed to be due to the tube and to measurement errors.

The data appear more consistent at the highest and lowest decades of scene luminance than they do in the mid range. Figure 4-2 is derived from Figure 4-1 by plotting rate of change of output for one decade of input, at both ends of the input range. At the high light level end, there is a very consistent relation between luminance gain settings and rates of change of output. At the low light level end of the scale, the deviations from the ideal straight line relation are probably due to the low signal to noise ratio. However, the results are reasonably consistent and indicate that the system is usable even down at these very low light levels.

The flattening of the curves in the middle of the scene luminance range could indicate a poor performance tendency for this tube. Although the tube gain in terms of output over input is high in this region, the flat or nearly constant output over two decades of luminance indicates a very low modulation over this range, or in other words, the contrast for scenes between  $3 \times 10^{-5}$  and  $3 \times 10^{-3}$  foot-lamberts would be expected to be poor. Above this range the contrast should be excellent, below this range it should also be good, although the picture quality will be adversely effected by the low signal to noise ratio.

These tests were repeated for the ITT F4112 tube in the cassette configuration, with the results shown in Figure 4-3. Although the flattening of the curves at mid range of input is still apparent, it is not nearly as pronounced as for the Galileo tube. Also Figure 4-3 does not show the same inconsistency found at  $3 \times 10^{-5}$  foot-lamberts with the Galileo tube. This definitely suggests better

Light Sphere Luminance Output (Ft-Lamberts)	Filter Value (% Transmission)	Input to Camera (Ft-Lamberts)
3	1 %	$3 \times 10^{-2}$
3	.1 %	$3 \times 10^{-3}$
3	.01 %	$3 \times 10^{-4}$
30	.0001 %	$3 \times 10^{-5}$
3	.0001 %	$3 \times 10^{-6}$

TABLE 4-2

Combinations Used To Obtain Light  
Inputs For Photometric Tests

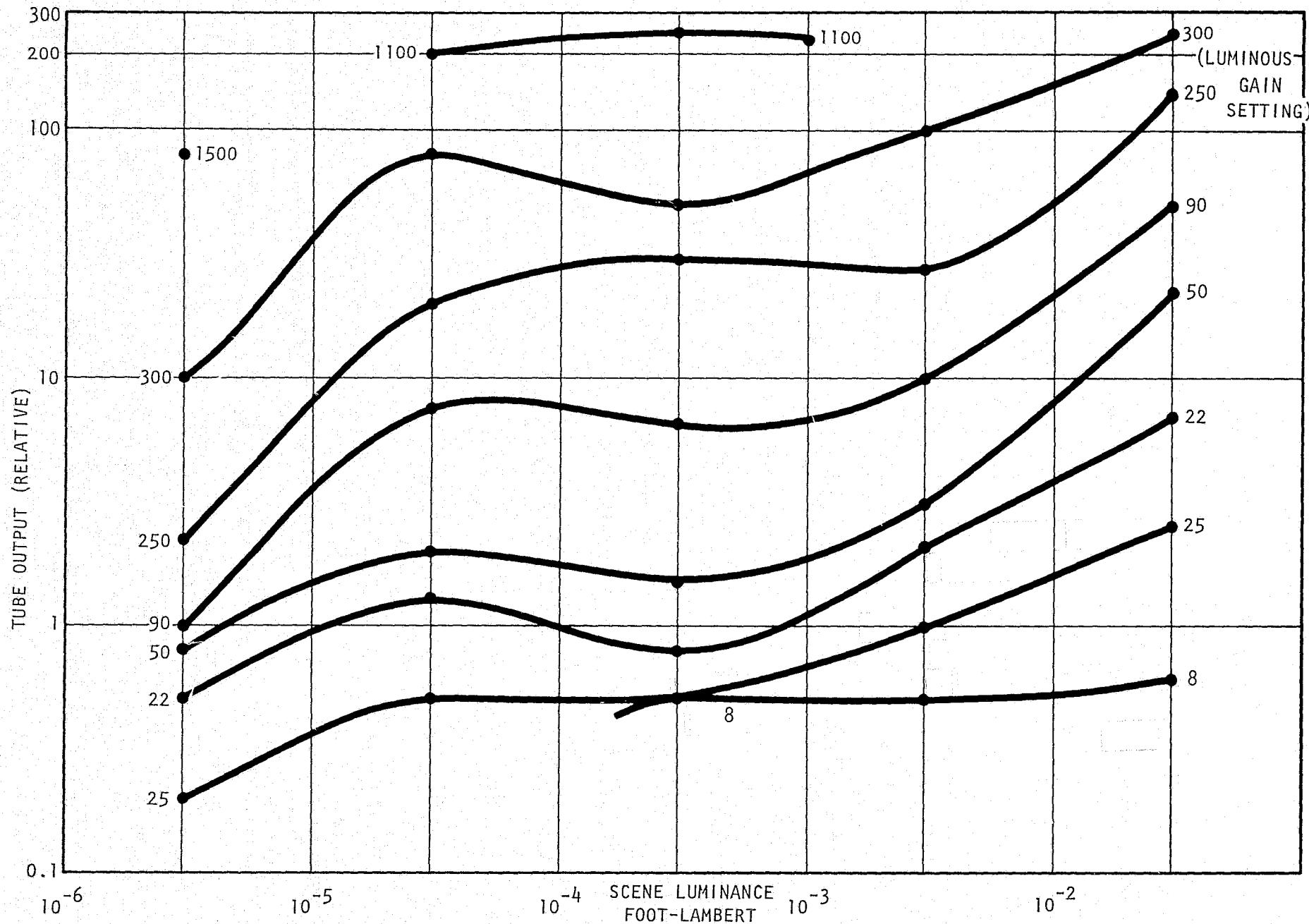


FIGURE 4-1  
Tube Output (Relative) vs Scene Luminance  
Tube 9025 - 2121, S/N 440 Relay Lens Brassboard

GALILEO 9025-2121 TUBE  
IN RELAY LENS BRASSBOARD

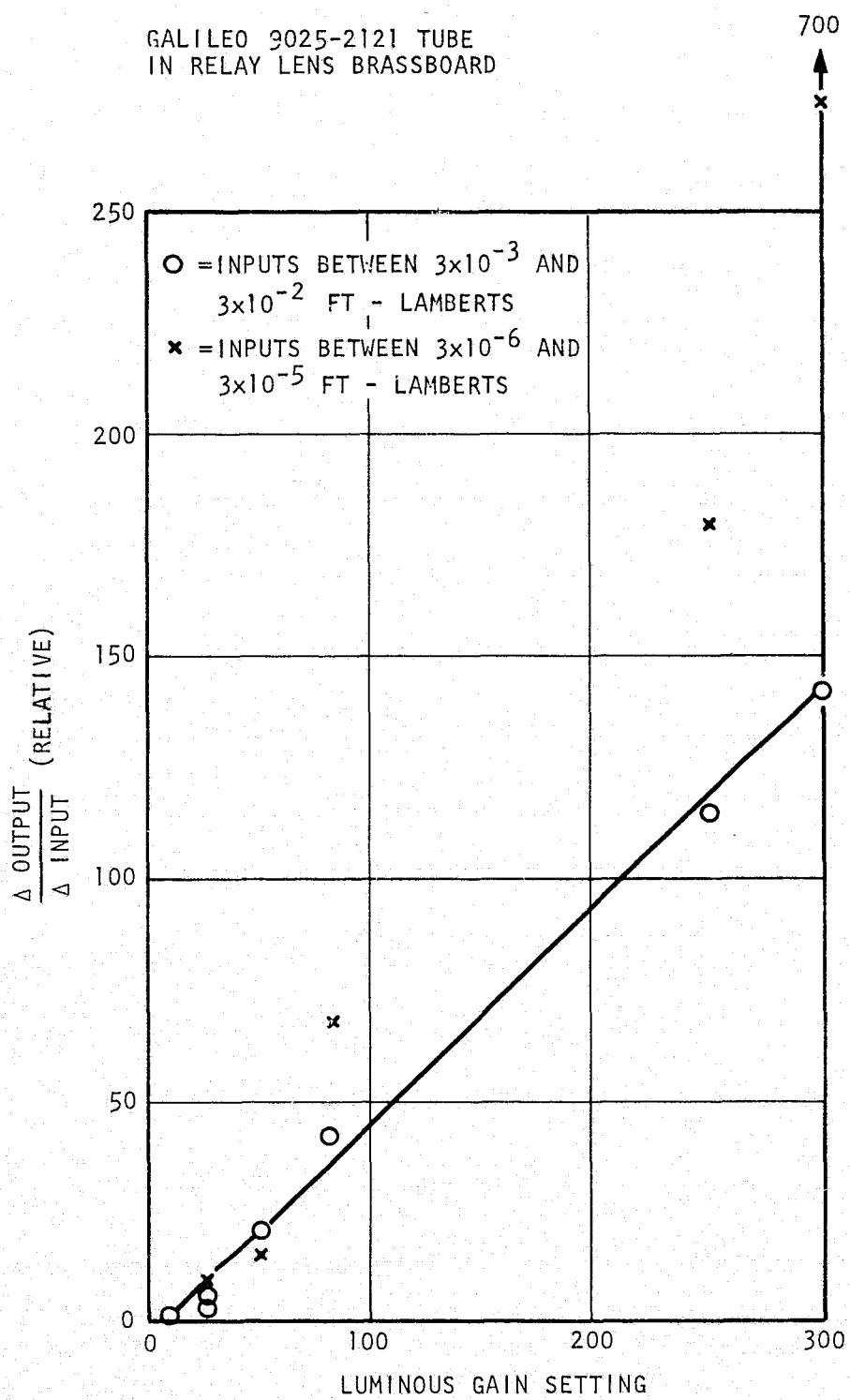


FIGURE 4-2  
Rate of Change of Tube Output, as a Function of Gain Setting

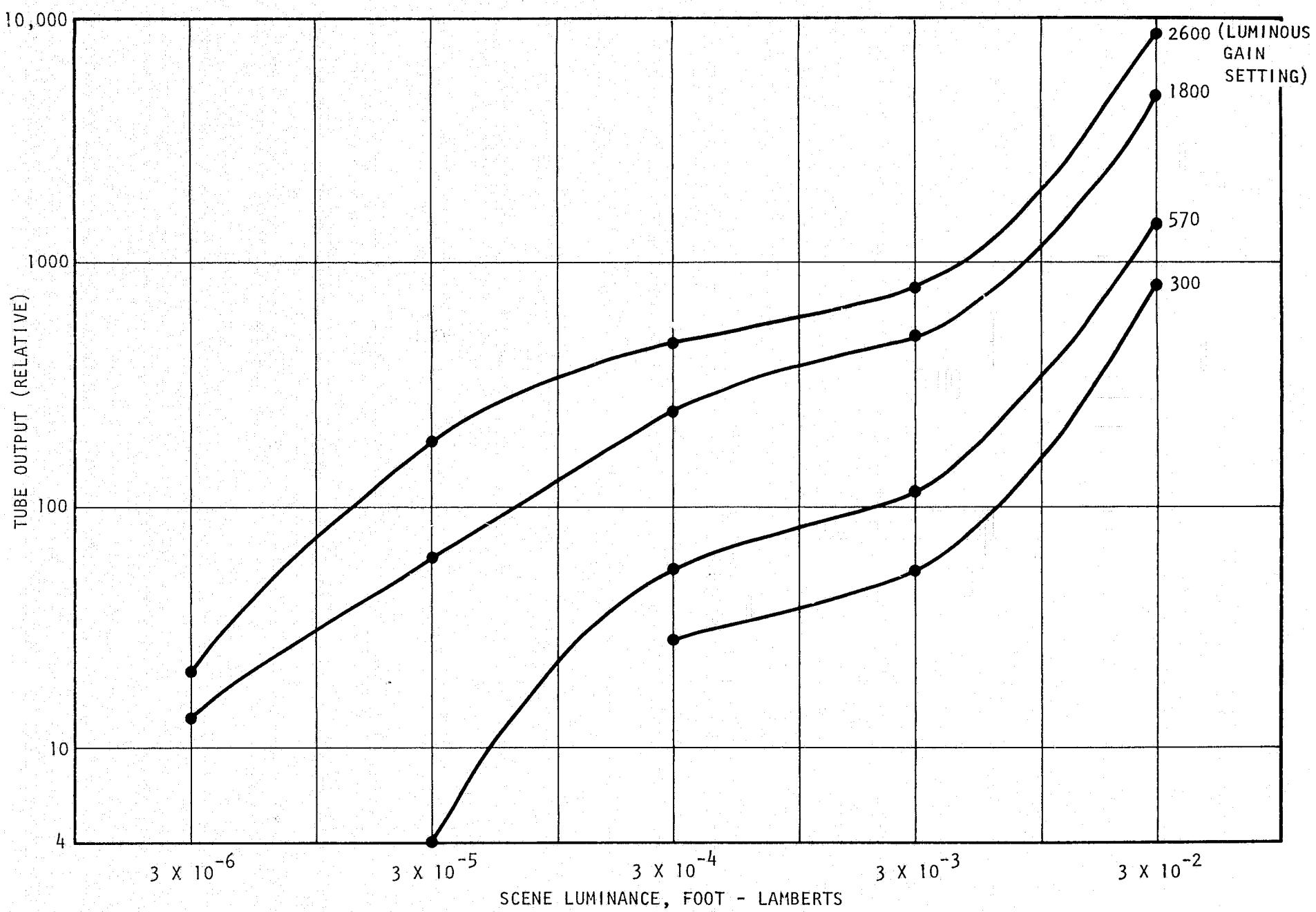


FIGURE 4-3  
Tube Output (Relative) vs Scene Luminance  
Tube - ITT F4112, S/N 582/2 Cassette Brassboard

overall performance for the ITT tube, and this conclusion was verified when real scenes were recorded both in the laboratory and in the field.

Table 4-3 summarizes results which were obtained with film in the cassette configuration with the ITT F4112 tube. These results were obtained by photographing a USAF standard resolution target back lighted at three scene luminance levels, with a variety of exposure times and tube luminous gains. The pictures were developed and evaluated, and the best exposure time for each combination of luminance and tube gain was selected based on appearance to the eye when the film negatives were viewed on a light box. Although these results may be considered subjective, they should be useful as a guide in future photographic efforts with the image intensifier camera.

As a precaution against repeating the conditions which caused damage to the original Galileo tube, a piece of .127 millimeter (.005 inch) thick clear mylar film was installed between the tube input faceplate and the camera rails, for high voltage insulation. In one test a rectangular opening was cut in the mylar to provide a determination of the optical effect of the mylar, if any. Figure 4-4 is a reproduction of one of the photographs, which showed that except for the edge of the opening it was not possible to detect any difference. In other tests it was determined that the mylar did not effect the camera focus except at very short distances. Since there appeared to be no degradation of performance, the mylar insulation was used in all tests of the cassette brassboard with the ITT tube, although it was not positively determined that this was necessary to protect the tube.

As noted in Table 4-3, the longer exposure times were obtained by using the camera time exposure setting and a stop watch. Shorter times were obtained by using the shutter settings on the camera. Because of the importance of shutter time in this test, the camera shutter was calibrated for speed by using a photo diode at the film plane in a special electronic circuit. These results are shown in Table 4-4 and it can be seen that they don't agree precisely with the nominal time values engraved on the camera shutter control. Thus the exposure times shown in Table 4-3 must be modified by the results shown in Table 4-4 if greater precision is desired, but this is not necessary for most applications of the camera. The two settings which are in greatest error, one second, and one eighth second were avoided in the test.

#### 4.3 SPECTRAL RESPONSE

An evaluation of the spectral response of the system was attempted using the approach outlined in Appendix D. Two narrow band-pass filters, with centers at 400 nanometers and 850 nanometers, roughly representing the short and long wave length response limits of the Galileo tube, were used in conjunction with the neutral density filters. Film was exposed at various shutter speeds, and film densities were measured in percent transmission with the microdensitometer.

Points were plotted for each exposure as a function of shutter speed and scene luminance. This data is shown in Figure 4-5, with the numbers adjacent to each point being the percent transmission measured for the conditions of the exposure.

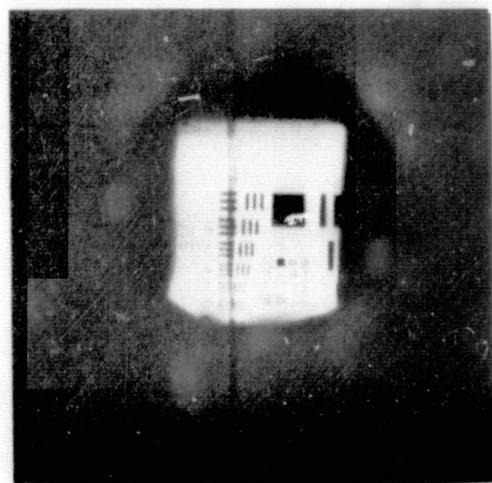
Scene Luminance (Foot-Lamberts)	Luminance Gain Settings			
	200	520	1800	2600
$3 \times 10^{-2}$	<.5 sec	<.5 sec	1/30 sec	1/60 sec max
$3 \times 10^{-4}$	1 sec	1 sec	1/15 sec	1/15 sec
$3 \times 10^{-6}$	10 sec	5 sec	2 sec	1/2 sec

Cassette configuration:

ITT F4112 tube (P-11 phosphor) Plus -x film (for Tri -x reduce times by factor of 1/2 or 1/4)

Decimal figures were time exposures, set by stop watch. Fractions were camera shutter settings (see Table 4-4)

TABLE 4-3  
Exposure Time for Best Photographic Results



REPRODUCIBILITY OF THE  
ORIGINAL PAGE IS POOR

FIGURE 4-4

Photograph made with a Cutout in the Mylar  
Insulation in front of the Tube

Image Intensifier: ITT  
Film: Plus X  
Iris: f 1.2

Camera Exposure Settings	Nominal Time Value (ms)	Measurement (ms)
1	1000	11 - 12
2	500	400 - 425
4	250	160 - 170
8	125	11 - 14
15	67	50 - 52
30	33	25 - 26
60	17	11 - 14
125	8	5 - 6
250	4	1 - 2

TABLE 4-4  
Results of Camera Shutter  
Speed Tests

Scene luminance with the band-pass filters was approximately corrected to account for the transmission losses through these filters at their center frequencies. However, no attempt was made to correct for the great reduction in total transmitted energy due to the narrow pass-bands of these filters, because this difficult task would be of doubtful value when considered against the very approximate nature of the measurements and the results.

With the data plotted in the form shown in Figure 4-5, it is possible to draw lines of approximately constant density across the field of the plot. In the center of the scene luminance scale, where neutral density filters only were used, the shapes of the curve show a similarity to the luminance response data plotted on Figures 4-1 and 4-3, that is, the slopes are reduced in the center of the scene luminance range, and become steeper at the two ends. Of course, the two figures are not directly comparable because different parameters are plotted on the ordinants, but it is suggested that this tendency is a characteristic of the tubes, particularly the Galileo tube.

The data on the far right at high luminance and with the spectral filters shows the same trend, but with an offset of about one decade increase in shutter time and a greater downward slope. This is understandable, since the band-pass filters pass only a very narrow band of energy, and therefore the total energy reaching the tube is greatly reduced. As a matter of fact, comparison of the filter curves against the spectral response curve of the tube in Appendix B indicates that the reduction should be greater than one decade, and according to the reciprocity principle this should require an increase in the shutter time by the same factor to maintain constant film density. These observations indicate that the spectral range of the tube at the higher luminance levels is in general agreement with the spectral data supplied by the manufacturer.

At the other end of Figure 4-5 (Low Luminance Level), the data for the band-pass filters is not consistent with the rest of the data. In particular, the one decade or more offset found at high luminance is not apparent, and the curves appear to take a reverse slope. There are several explanations, none perfect. For one thing it is difficult to make measurements with these extremely low light levels and the data may not be reliable. Also, the spectral response characteristic of the tube may change at these low levels. For instance, the change in slope may be due to the fact that the tube is more responsive to the shorter wave lengths and this characteristic may increase greatly at very low light levels.

Although the apparent lack of consistency in the limited data that was taken is disappointing, it definitely shows that the system is responsive to light over the full spectral range of the image intensifier tube. The manufacturer's data, undoubtedly more precisely obtained under more favorable conditions, is probably a better indication of the range of system spectral capability.

#### 4.4 DISTORTION AND RESOLUTION

Measurements for determining distortion were made using the cassette brassboard with the Galileo tube. The results are shown in Figure 4-6. The four center measurements from the film (2 in the X and 2 in the Y directions) were averaged and the percentages shown in Figure 4-6 are deviations from this average figure for the locations shown.

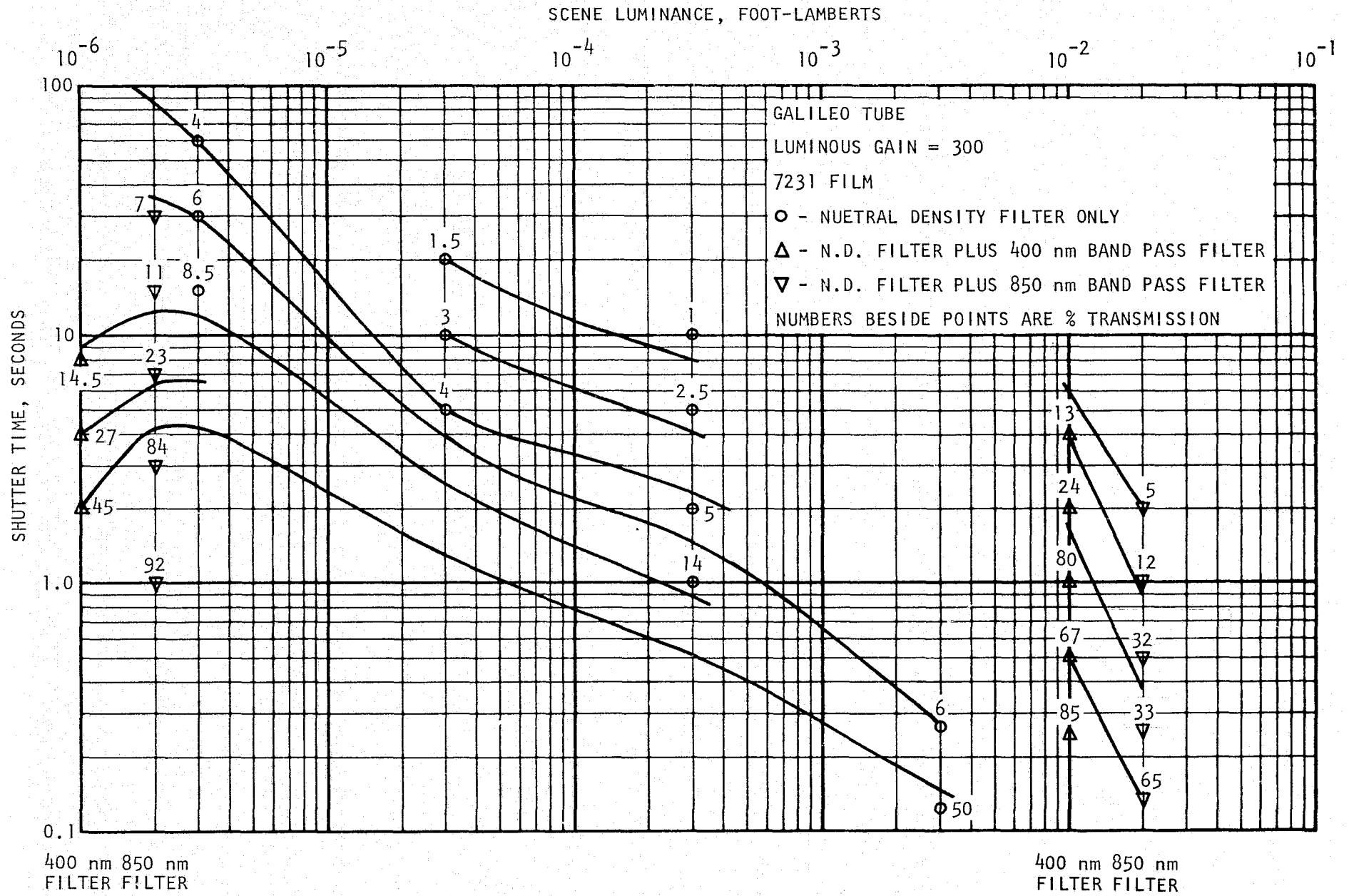


FIGURE 4-5  
Film Density Measurements  
%Transmission Plotted as Function of Shutter Speed and Scene Luminance

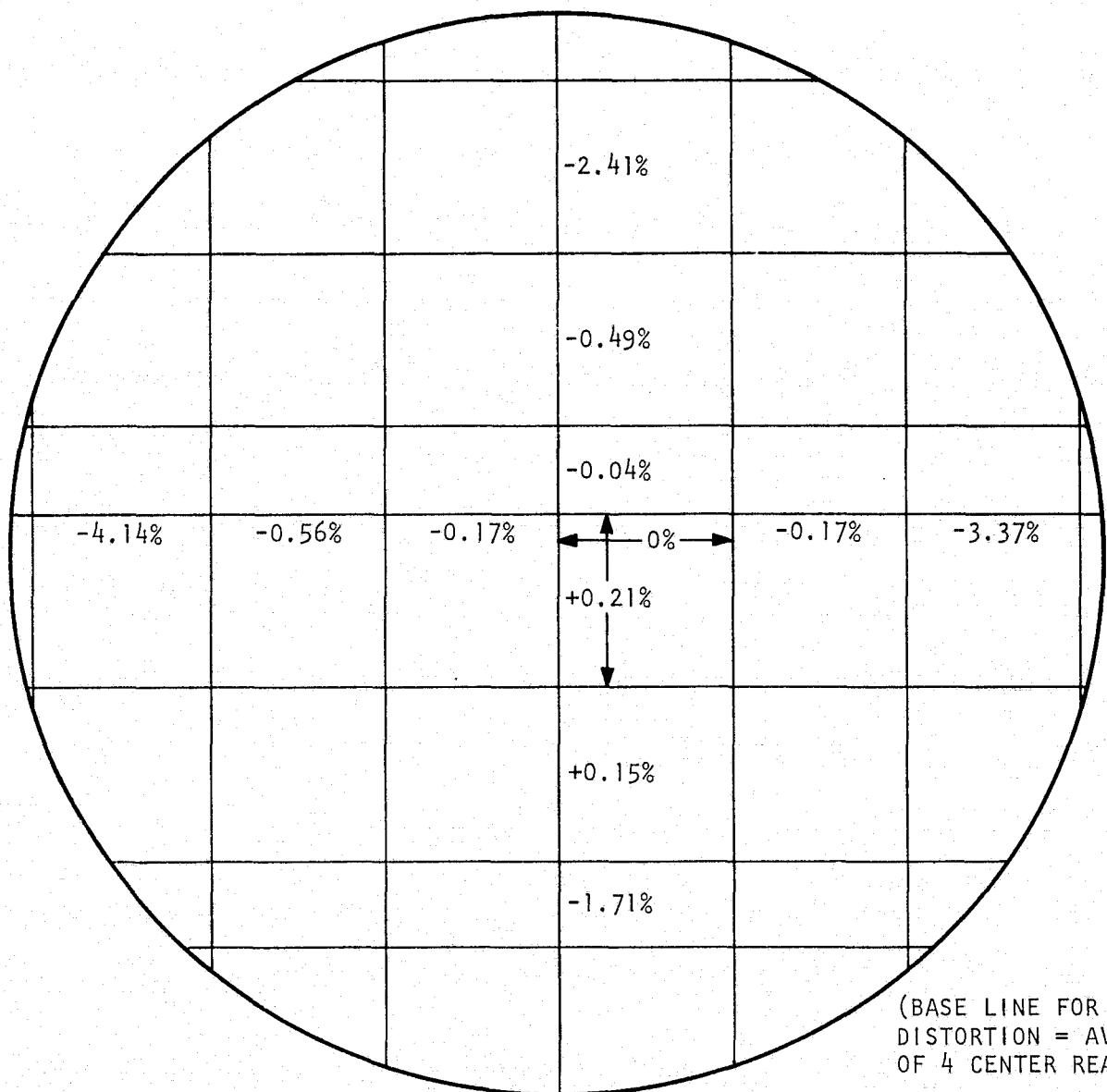


FIGURE 4-6

Results of Distortion Measurements for Cassette Brassboard With Galileo Tube  
(Target Grid Lines are Spaced 1 inch and 1/2 inch Apart, as Shown)

The results are fairly typical for a good quality commercial photographic lens, with low distortion at the center, and a consistant increase towards the edges of the format. Since distortion due to the tube alone would be random, because of the way it is constructed, it is reasonable to conclude that the image intensifier is contributing very little to the overall system distortion. No distortion was evident in any of the indoor and outdoor photographs that were made with any of the three image intensifier tubes, except for a special case shown in Figures 4-7 and 4-8. Figure 4-7 was illuminated by starlight only, while in Figure 4-8 a flashlight was pointed at the pole from several hundred feet away. The distortion of the pole is caused by the blooming effect of the phosphor at high intensity, coupled with an exposure time necessary to bring out details in the area outside the light beam. From the above it can be concluded that the distortion of the image intensifier tube is not a limiting parameter in its application to a good quality 35 mm photographic camera, as long as portions of the scene are not over illuminated.

System resolution was also determined. The most reliable determination, in terms of test conditions and laboratory technique, was performed with the ITT tube in the cassette configuration. This resolution was determined to be 16 line pairs per millimeter (lp/mm), which compares with 22 lp/mm for the tube alone as determined by the manufacturer. The theoretical figure computed in Task 1 for the system with a 25 lp/mm tube was 18 lp/mm for 2485 film, and 19.5 lp/mm for SA/1 film, these two types representing typical low and high resolution films respectively. The Panatomic X film used in the test falls between these two. From the above, it is concluded that the performance of the system in regards to distortion and resolution is in general agreement with predictions. However, it should be understood that these results were obtained at approximately average input light levels for the tube, not the very lowest levels at which the tube can perform.

#### 4.5 RELAY LENS VIGNETTING TEST

As explained in Section 3.1.2, the relay lens is formed from two standard Nikon 55 mm, f/1.2 lenses, mounted input to input. This arrangement was selected as a low cost expedient, since a relay lens designed specifically for this study would not be compatable with either the budget or the original schedule. However, it was recognized that the standard lens arrangement could have limitations due to vignetting. Therefore, as part of Amendment 1 (S) to the contract, tests were made to evaluate the seriousness of the vignetting. These results are summarized in Figure 4-9.

As seen from the figure, the degree of vignetting is indeed significant compared to the camera lens by itself. Since this characteristic would have a serious effect on system performance, and would impose unfair limitations on the evaluation of the image intensifier, the decision was made to use the cassette brassboard for all remaining tests. This includes all of the real world photography reported in Section 4-7.



FIGURE 4-7

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1/4 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light

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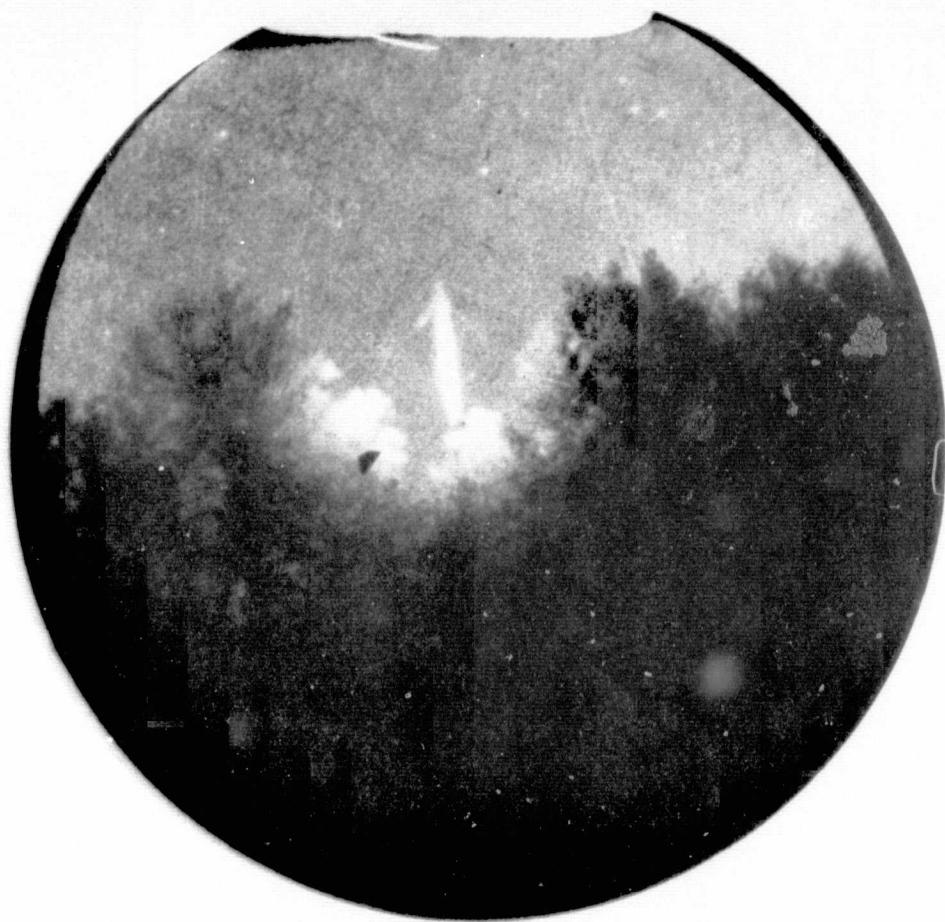


FIGURE 4-8

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1/4 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light Plus Flashlight

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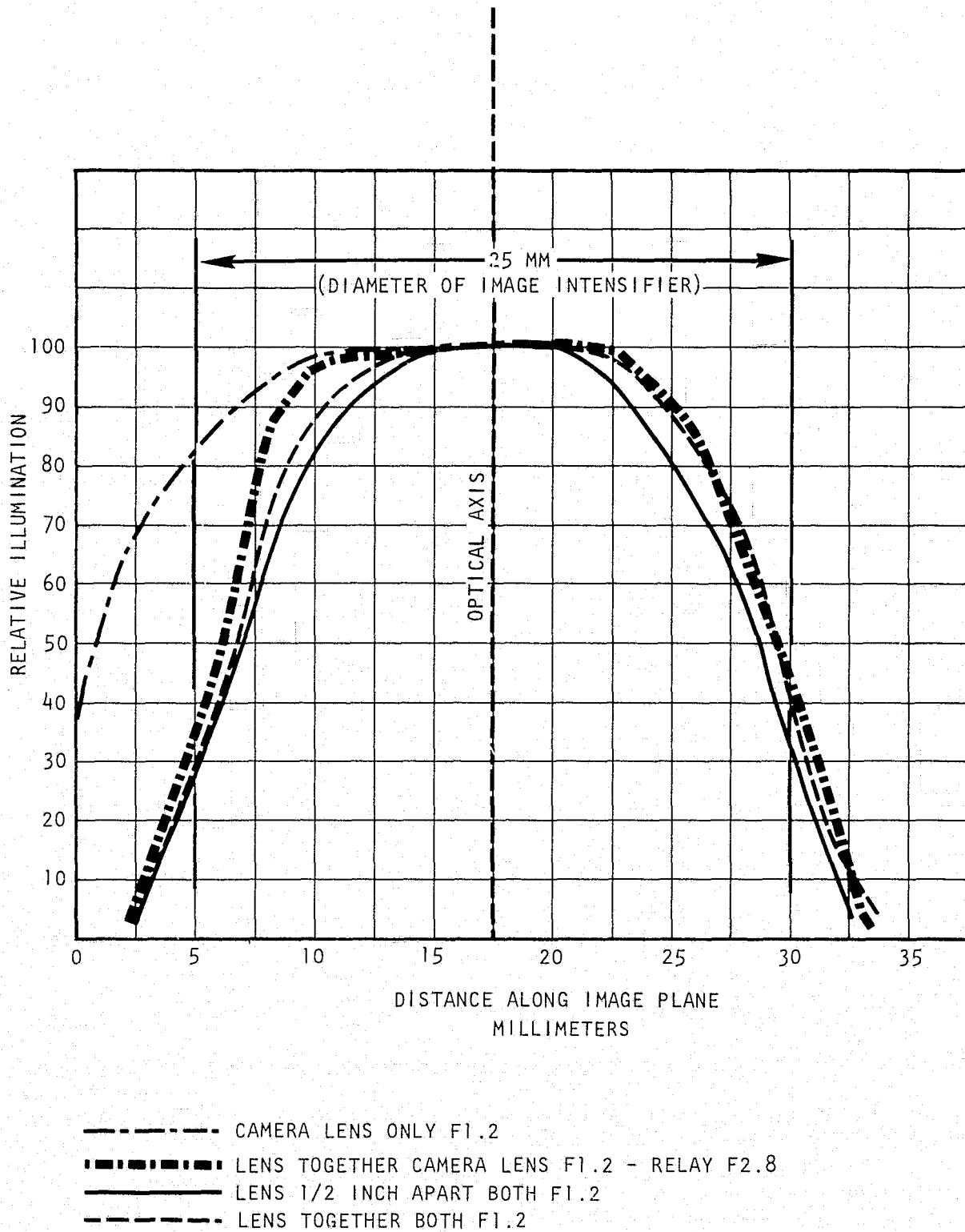


FIGURE 4-9  
Results of Relay Lens Vignetting Test

#### 4.6 POWER SUPPLY TEST RESULTS

The image intensifier power supply was tested in the laboratory to evaluate performance. Such parameters as input power, line regulation, load regulation, etc. were evaluated and the results are summarized in the following sections. In all tests, the original image intensifier tube, (Galileo type 9025-2121, S/N 440) was used as a load for the power supply.

##### **4.6.1 INPUT POWER**

The power supply input current was measured for five different levels of input voltage. From these measurements, the input power was calculated. A summary of the data and calculations is listed in Table 4-5.

<u>Input DC Voltage</u>  (volts)	<u>Input Average Current</u>  (amps)	<u>Calculated Input Power</u>  (watts)
4.00	0.230	0.92
10.00	0.079	0.79
20.00	0.036	0.72
30.00	0.024	0.72
40.00	0.019	0.76

Table 4-5

From these data, it can be seen that the power supply operates at maximum efficiency with an input voltage in the 20 to 30 volt range. It should be mentioned that the input current is not a DC level, but rather, a series of current ramps (saw tooth waveform). The DC current meter reading is the average value of these ramps and is used to calculate average input power.

##### **4.6.2 MINIMUM INPUT VOLTAGE**

Two minimum input voltages were determined in this test, the minimum voltage required to start the power supply and the minimum voltage required to maintain regulated output voltages. The minimum input start voltage was determined by setting the lab supply (input to the image intensifier supply) to zero volts and gradually increasing the voltage until the image intensifier power supply started. The minimum start voltage was determined to be 3.98 volts. Circuitry is included in the image intensifier power supply to prevent it from attempting to start under extremely low line voltage conditions which could cause power supply damage. This was done to ensure that the current sense amplifier (A1-C) has sufficient supply voltage to trigger the one-shot as described in the start-up mode paragraphs of Section 3.3.4. If the one-shot does not trigger, the pre-regulator switch (Q4) will remain in the ON state and the inductor will saturate causing an over current condition in the switch. Amplifier A1-D and inverter A4-F perform this function.

The second minimum input voltage was determined by reducing the lab supply voltage, after the image intensifier supply was running, and monitoring the pre-regulator output voltage. The lab supply voltage was noted when the pre-regulator output voltage began falling out of regulation. This voltage was 2.75 volts. From the two minimum voltage test results, it is concluded that as long as the image intensifier power supply starts, the outputs will be regulated.

#### 4.6.3 LINE REGULATION

Line regulation measurements were performed on the pre-regulator output as well as all the high voltage outputs. These tests consisted of monitoring each output voltage while varying the input voltage to the image intensifier power supply. Also monitored was the peak-to-peak ripple voltage on each of the outputs. From the test data, per cent line regulation and per cent ripple were calculated. The results of the line regulation tests and calculations are tabulated in Table 4-6. Referring to Table 4-6, it can be seen that the pre-regulator voltage remained within plus or minus one least significant digit (.01 volt) on the DVM (Digital Volt Meter). Therefore, the accuracy of this reading is limited by the DVM. Also, it can be seen that the ripple voltages (in per cent) on the high voltage outputs are greater than the per cent ripple voltage of the pre-regulator output. However, moderate ripple voltage does not appear to effect the performance of the image intensifier tube.

#### 4.6.4 LOAD REGULATION

Load regulation tests were performed on all the high voltage outputs. During these tests, the image intensifier power supply was operated with a fixed input voltage of 5.0 volts and a fixed MCP primary voltage of +28 volts (fixed tube gain). The input light level to the tube was varied, providing a changing load to the image intensifier power supply. The voltage of each output and the peak-to-peak ripple voltage was recorded for three different input light levels. This data is tabulated in Table 4-7 along with the calculated per cent ripple for each output voltage.

Table 4-7 shows that the input light level to the tube has a negligible effect on the power supply output voltages. This is because the total power requirements for the tube are very much less than the power used by the power supply in generating the high voltage inputs to the tube. Therefore, any load variation caused by the tube is masked by the internal load of the power supply and the total power supply load appears to remain essentially constant.

#### 4.6.5 GATING RESPONSE

The time required to gate the image intensifier tube ON and OFF was determined by a gating response test. While performing this test, the image intensifier power supply input voltage was set at 5.0 volts, the MCP primary voltage was set at 28 volts (fixed tube gain), and the tube was exposed to the room ambient light so as to flood the entire screen area of the tube. A 10 volt, 100 msec pulse was used for the gating signal while the cathode voltage was monitored on an oscilloscope. The cathode voltage was monitored with a 10,000 to 1,30 gig ohm high voltage probe buffered by a Keithley VTVM. The VTVM output was then monitored on the oscilloscope.

A photograph of the gating signal and the gated cathode voltage is shown in Figure 4-10. The gated cathode voltage swings a total of 250 volts and has a rise and fall time (from 10% to 90%) of 51 milliseconds. The results of this test

Input Voltage	Pre-Reg Voltage	Pre-Reg Ripple	MCP Out Voltage	MCP Out Ripple	MCP In Voltage	MCP In Ripple	Cathode Voltage	Cathode Ripple
4.00	47.93	140 mV p-p	-4931	60 V p-p	-5475	50 V p-p	-5738	90 V p-p
10.00	47.92	135	-4936	55	-5482	75	-5745	80
20.00	47.92	140	-4939	50	-5484	80	-5746	80
30.00	47.92	145	-4938	55	-5485	80	-5748	80
40.00	47.92	200	-4939	60	-5485	80	-5747	85
% Reg.	$\pm 0.01\%$		$\pm 0.08\%$		$\pm 0.09\%$		$\pm 0.09\%$	
% Ripple (max)		0.42 %		1.21 %		1.46 %		1.57 %

TABLE 4-6  
Line Regulation Test Results

Input Light Level	MCP Out Voltage	MCP Out Ripple	MCP In Voltage	MCP In Ripple	Cathode Voltage	Cathode Ripple
0.03 F-L	-4906	60 V p-p	-5451	80 V p-p	-5713	85 V p-p
0.003	-4905	60	-5450	80	-5711	80
0.000003	-4906	60	-5450	80	-5711	85
% Reg.	Negligible		Negligible		Negligible	
% Ripple		1.22 %		1.47 %		1.49 %

TABLE 4-7  
Load Regulation Test Results

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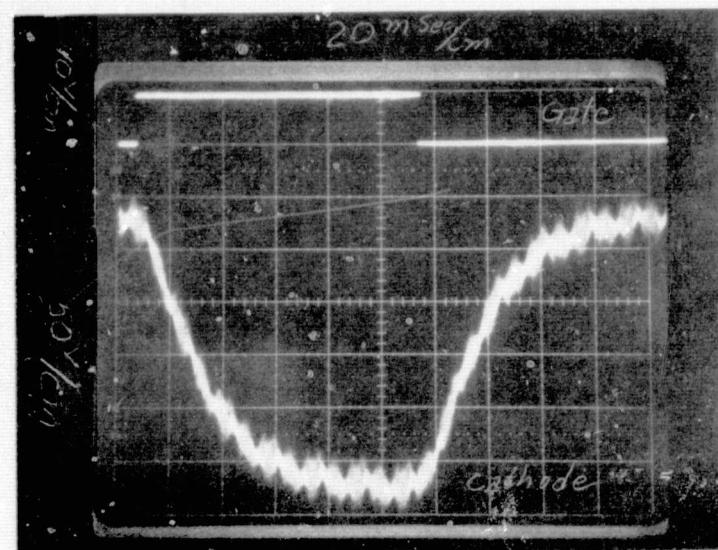


FIGURE 4-10  
Cathode Gated Voltage Response

indicate that the minimum exposure time for taking pictures is limited to around 50 to 100 milliseconds when using the gating feature for an electronic shutter. This is a shorter exposure time than will be required in any anticipated applications of the image intensifier camera.

#### 4.6.6. AUTOMATIC BRIGHTNESS CONTROL REGULATION

The ABC circuitry was enabled in the image intensifier power supply and tests were conducted to determine the extent of screen brightness variations with varying input light levels. The screen brightness was detected with a photometer consisting of a photo diode, an amplifier, and a meter. The photodiode was mounted at the film plane of the camera. The camera system (relay lens configuration) was focused on a uniform white screen which was indirectly illuminated with a variable light source. The image intensifier cathode (input) was thus evenly illuminated. The variable light source was set at a nominal level and the ABC screen brightness adjustment was set for a mid scale reading on the photometer. This condition is referred to as screen brightness setting number one in the following discussion.

After the initial test setup, the light source was increased in illumination in increments that caused the MCP primary voltage to decrement in 2 volt steps. The MCP primary voltage and the photometer reading were recorded for each light level step. For screen brightness setting number two, the ABC adjustment was readjusted to reduce the  $I^2$  screen brightness by one half and the test was repeated. The results of these tests and the calculated per cent regulation are listed in Table 4-8 (The first photometer reading for both tests was not used in the per cent regulation calculation because the input light level was not within the dynamic range of the ABC circuit).

The voltage across the MCP can be calculated by multiplying the MCP primary voltage by 19.8. For screen brightness setting number 1, the MCP output voltage ranged from 628 volts to 299 volts. From the luminous gain curve received with the tube (included in Appendix B), it can be seen that tube gain doubles for every 40 volts increase in MCP voltage. Therefore, the dynamic gain range covered by this test was 8.2 stops. Over this dynamic range, the screen brightness varied a total of 26% or  $\pm 13\%$  from the average screen brightness value. The screen brightness change therefore averaged 3.2% per stop change in tube gain.

The MCP output voltage for screen brightness setting number 2 varied from 617 volts to 257 volts, a dynamic gain range of 9.0 stops. The screen brightness varied 56% over this range, or  $\pm 28\%$  from the average screen brightness value. Thus, the screen brightness change averaged 6.2% per stop change in tube gain.

The MCP primary voltage remained constant for the first two readings in this test. This indicates that leakage current at the input to the screen current sense circuit was larger than the screen signal current. The variations in screen brightness throughout the ABC dynamic range of both tests indicates low gain in the screen current sense amplifier.

Screen Brightness Setting Number 1.	
MCP Primary Voltage	Photometer Reading
31.86	1.05
31.74	1.12
30.00	1.13
28.00	1.15
26.07	1.20
24.07	1.24
22.00	1.28
20.10	1.33
18.10	1.39
16.07	1.44
15.09	1.45
% Regulation $\pm 13\%$	

Screen Brightness Setting Number 2.	
MCP Primary Voltage	Photometer Reading
31.17	0.26
31.17	0.41
30.00	0.46
28.00	0.48
26.00	0.52
24.00	0.55
22.00	0.57
20.00	0.60
18.00	0.63
16.00	0.67
14.00	0.70
12.98	0.73
$\pm 28\%$	

TABLE 4-8  
ABC Regulation Test Results

#### 4.6.7 AUTOMATIC BRIGHTNESS CONTROL RESPONSE

The same test setup was used to determine the ABC response to an input light step as was used to determine the ABC regulation. The variable light source was adjusted to cause a 300 volt MCP output voltage swing when the light was turned ON and OFF. The light source was then turned ON and OFF while monitoring the cathode voltage. (NOTE: The cathode voltage remains a constant 250 volts below the MCP output voltage and therefore has the same waveshape in these tests). Two response tests were performed, one for each of the ABC screen brightness settings used in the ABC regulation tests. Figure 4-11 shows the ABC response for screen brightness setting number 1. The light sequence was ON-OFF-ON which caused the tube gain to increase from the minimum set value to maximum gain and back to the minimum value. As can be seen in Figure 4-11, the response time of the ABC is longer for an increasing gain excursion than for a decreasing gain excursion. The total MCP voltage change is 300 volts which is a gain change of 7.5 stops. The increasing gain response time is about 1 second, therefore, the maximum ABC response time for screen brightness setting number 1 is 133 milliseconds per stop change in gain.

Figure 4-12 shows the ABC response for screen brightness setting number 2. Comparing Figure 4-12 with Figure 4-11, it can be seen that for the same cathode voltage excursion, the response time in Figure 4-12 is about twice that in Figure 4-11. Therefore, the maximum ABC response time for screen brightness setting number 2 is 266 milliseconds per stop change in gain.

It can be seen from Figures 4-11 and 4-12 that the ABC loop is very underdamped. Therefore, the ABC response time could be reduced by changing the loop frequency compensation.

#### 4.7 PHOTOGRAPHIC RESULTS

The photographs of real world scenes are considered to be the most important part of the image intensifier camera test program. All of these photographs were made with the cassette configuration camera, using the second Galileo tube and the ITT tube.

Unfortunately it is not possible to economically reproduce these photographs for this report without losing some definition in the printing process. However, their importance to the overall evaluation of the image intensifier camera makes it desirable to include a sufficient number of examples covering a variety of types of scenes and conditions. Several hundred photographs were taken for this study. Glossy prints with times 5 enlargement were made from the best negatives. These enlargements were further screened and the most suitable ones reproduced for this report by the half tone printing process.

Figures 4-13 through 4-16 were taken on 19 November 1975 with the Galileo tube, using Plus X film. The location was Cow Canyon Saddle about 15 miles north of Pomona in the San Gabriel Mountains. This location was selected because it is almost completely free of artificial lighting, the only light that night being a three quarter moon in the eastern sky. Other conditions are shown below the figures.

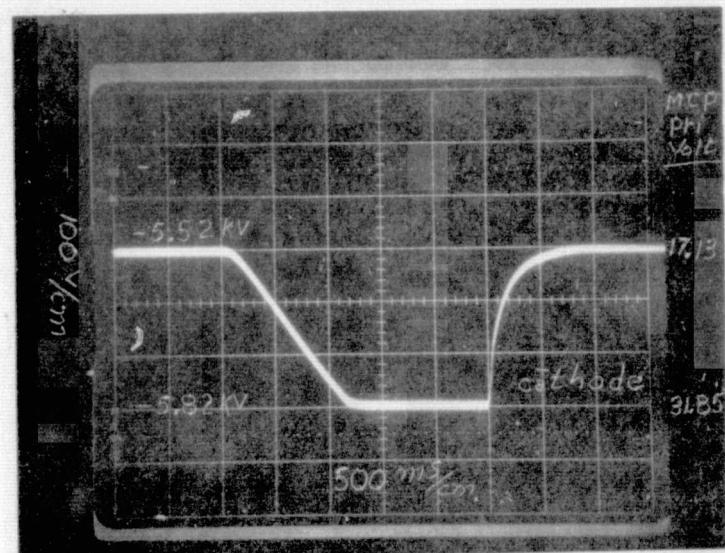


FIGURE 4-11

ABC Response for Screen Brightness  
Setting Number 1

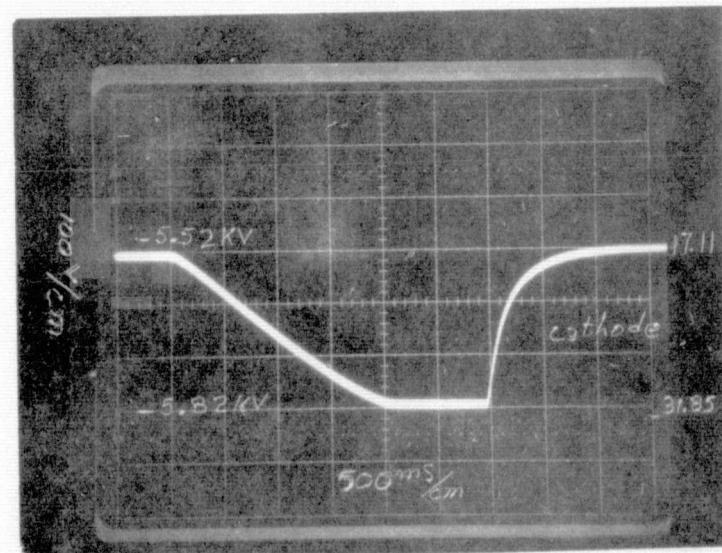


FIGURE 4-12

ABC Response for Screen Brightness  
Setting Number 2

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Figure 4-13 was taken in a northerly direction on a narrow dirt road in a brushy area. The black spots were caused by the dead spots in the tube which were the cause for its rejection to the vendor. Other blemishes were probably caused by film handling.

Figure 4-14 was taken in a southerly direction of a small hill with telephone poles and a fire break, in an otherwise very brushy area.

Figures 4-15 and 4-16 are through a notch formed by two mountain ridges, looking towards the city of Pomona. Figure 4-15 was processed to bring out foreground details, while Figure 4-16 was processed to obtain resolution of the city lights. Most of the difference was obtained in the enlarging process. The white streaks at the very top of Figure 4-15 are believed to be caused by electrostatic discharges at the tube face. This phenomena occurred occasionally in the tests with the Galileo tube, but did not occur with the ITT tube.

Figure 4-17 was taken in a southerly direction, using Kodacolor II film for the negative which was then made into an 8 x 10 color print. The print appeared in shades of blue only, of course, but a better definition was obtained than with black and white film. This is largely lost in the half tone process used in printing the figures for this report.

The next four photographs were taken in the dark room of the Perkin-Elmer Photographic Laboratory, using the ITT tube. Conditions under which the photographs were taken are shown in Figure 4-18.

Figure 4-19 is of a paper resolution target taped to a plastic paper towel holder on the wall. Also shown is various apparatus on the bench to the right, and a reflector of a photo flood light on the left. The triangular black spot just below the rectangular square on the target is due to a particle which lodged between the input face of the tube and the mylar sheet. Unfortunately it appears in all of the photographs with the ITT tube, although it was easily removed after the photographs were taken. The only illumination for this photograph was from an LED numerical display on a digital voltmeter, in the location shown in Figure 4-18.

Figure 4-20 is the same scene illuminated only by a lighted cigarette in the location shown in Figure 4-18. The two bright spots are of unknown origin and appear to be reflections near the right hand edge of the target.

Figure 4-21 is illuminated only by a lighted cigarette in the hand of the subject. The response of the tube to infrared undoubtedly was of assistance in making this photograph. The shadow of the subject on the rear wall is clearly visible. The square pattern seen in the background is caused by the fiber optic mosaic in the input face plate, and is typical of many proximity focussed image intensifiers, although it was not apparent with the Galileo tube. The white marks below the subject are from the developing or enlarging processes.

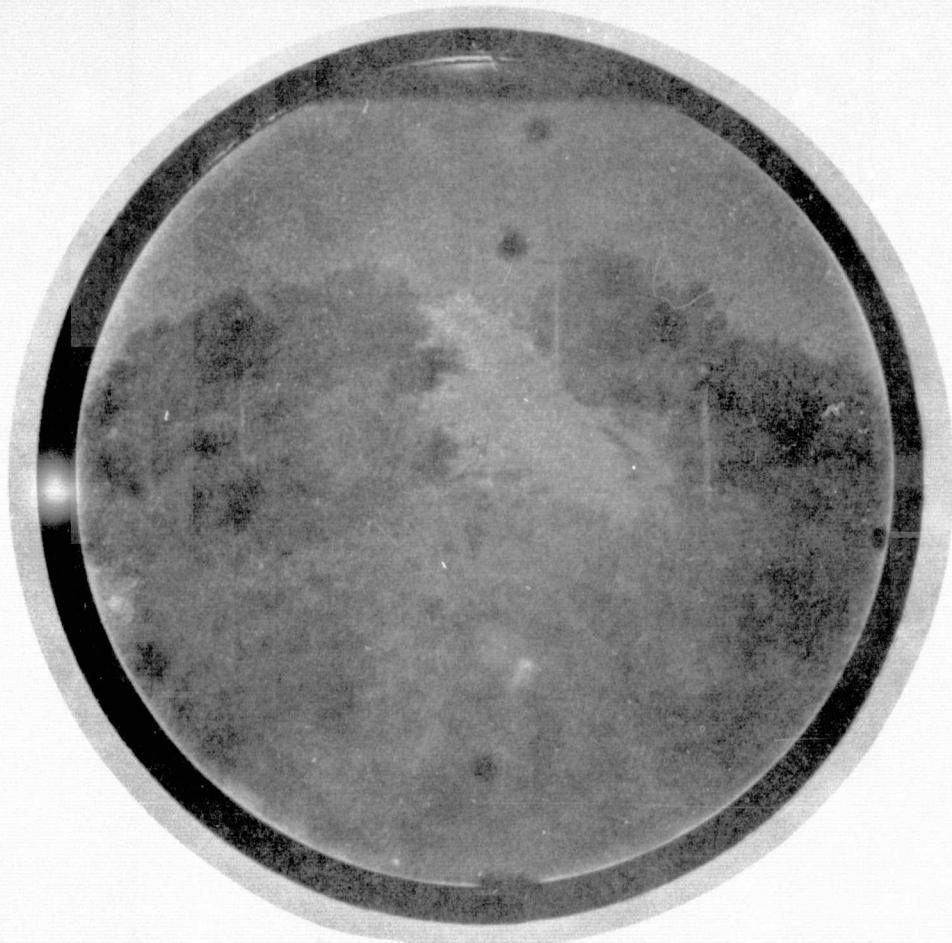
Figure 4-22 is a photograph of a wristwatch with luminescent face and hands. The time is 9:50. The background behind the watch is a black cloth. The only illu-



FIGURE 4-13

Photograph Taken With Image Intensifier Camera

Image Intensifier:	Galileo
Luminous Gain:	140
Exposure:	1/4 second
Film:	Plus X
Iris:	f 1.2
Illumination:	3/4 Moonlight

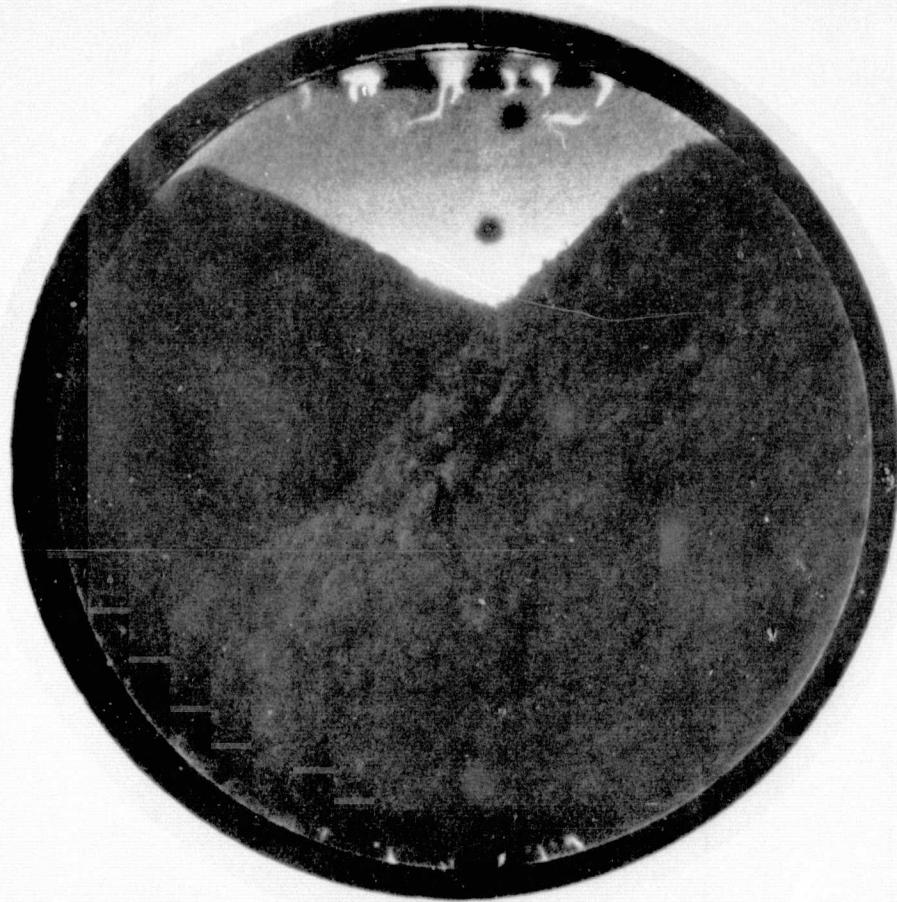


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FIGURE 4-14

Photograph Taken With Image Intensifier Camera

Image Intensifier:	Galileo
Luminous Gain:	140
Exposure:	1/8 second
Film:	Plus X
Iris:	f 1.2
Illumination:	3/4 Moonlight



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FIGURE 4-15

Photograph Taken With Image Intensifier Camera

Image Intensifier:	Galileo
Luminous Gain:	140
Exposure:	1/8 second
Film:	Plus X
Iris:	f 1.2
Illumination:	3/4 Moonlight and City Lights in Background



FIGURE 4-16

Photograph Taken With Image Intensifier Camera

Image Intensifier:	Galileo
Luminous Gain:	140
Exposure:	1/8 second
Film:	Plus X
Iris:	f 4
Illumination:	3/4 Moonlight and City Lights in Background

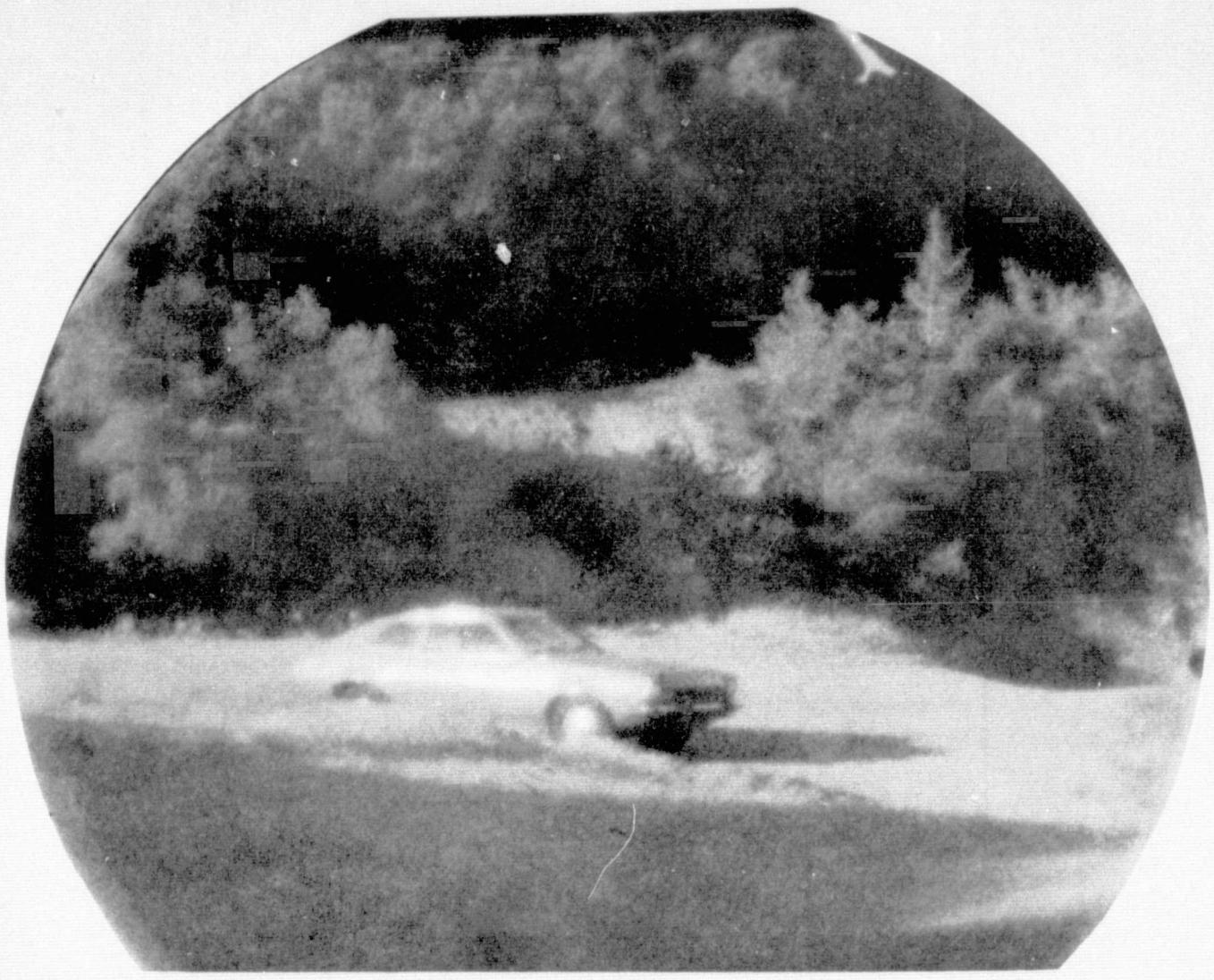


FIGURE 4-17

Photograph Taken With Image Intensifier Camera

Image Intensifier:	Galileo
Luminous Gain:	140
Exposure:	1/4 second
Film:	Kodacolor II
Iris:	f 1.2
Illumination:	3/4 Moonlight

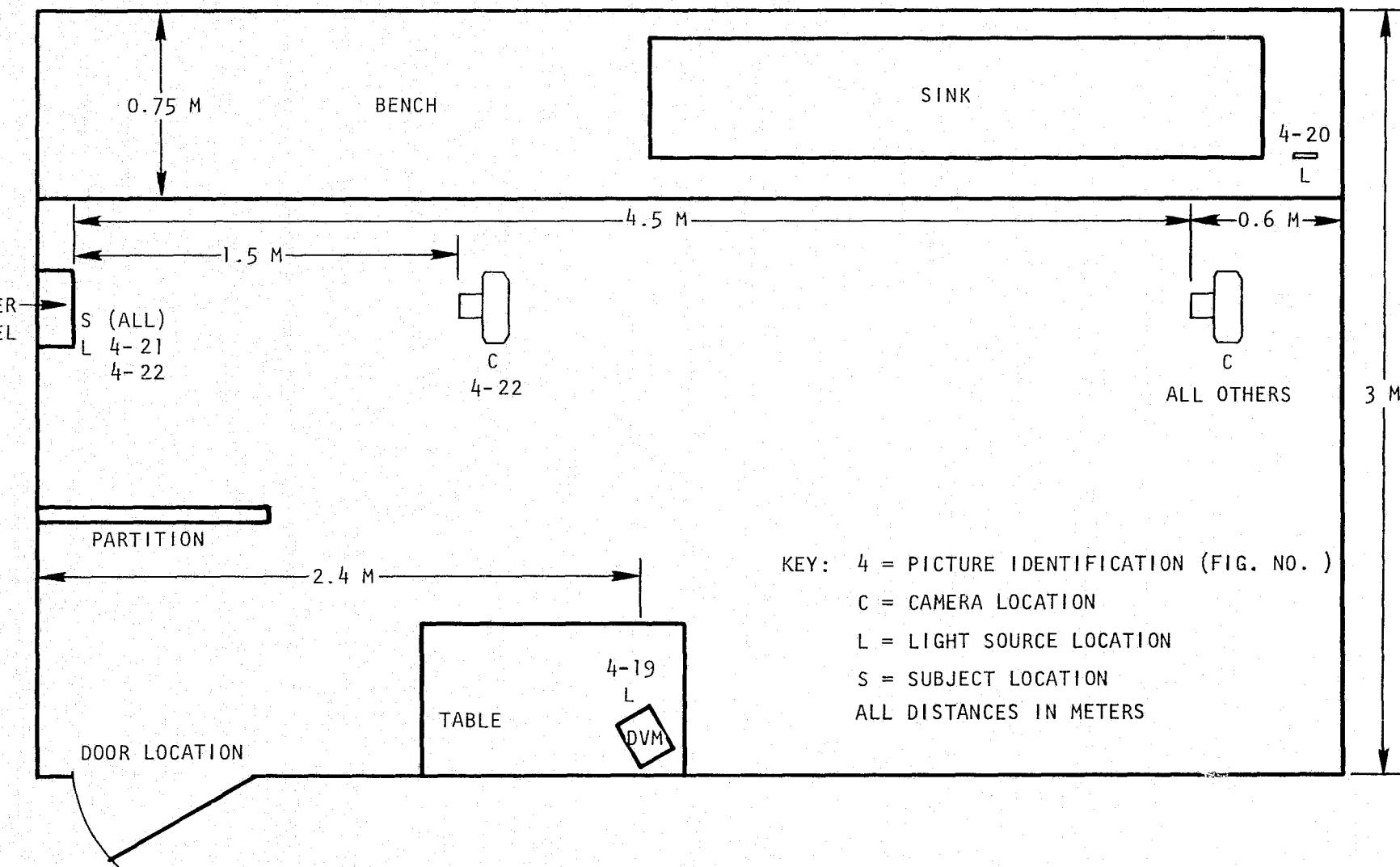
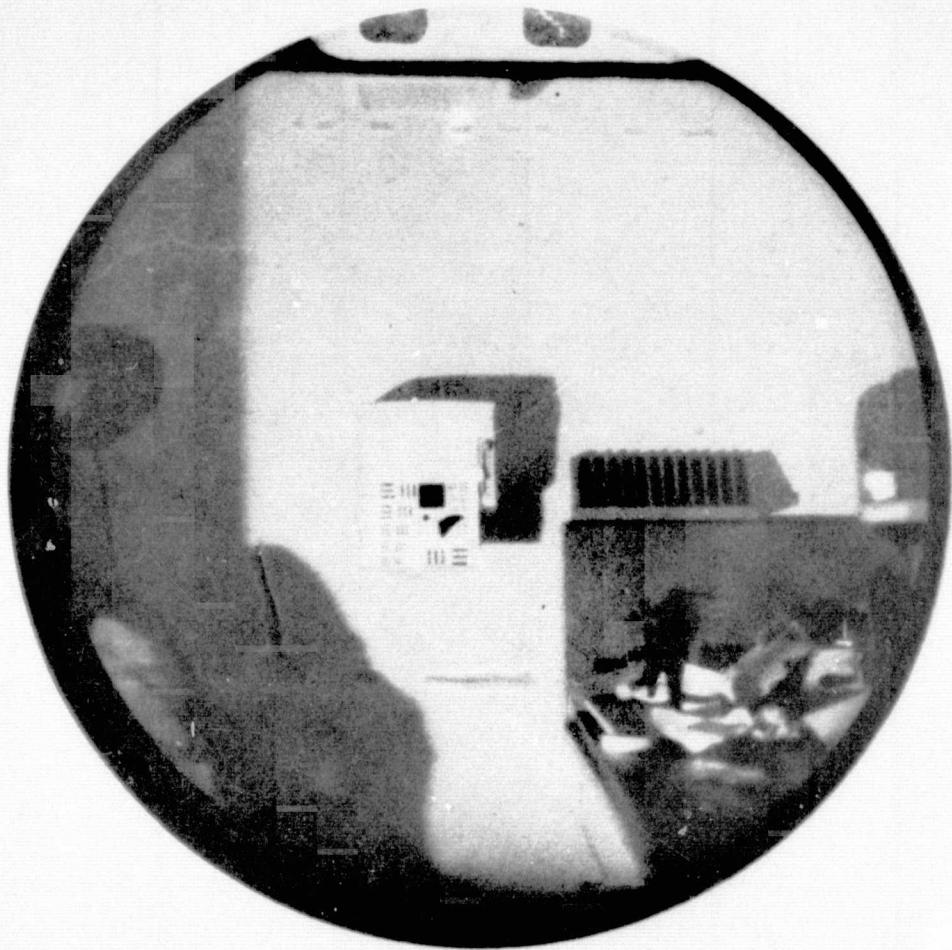


FIGURE 4-18  
Darkroom Layout for Photographic Tests



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FIGURE 4-19

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1100
Exposure:	2 seconds
Film:	Plus X
Iris:	f 1.2
Illumination:	See Figure 4-18

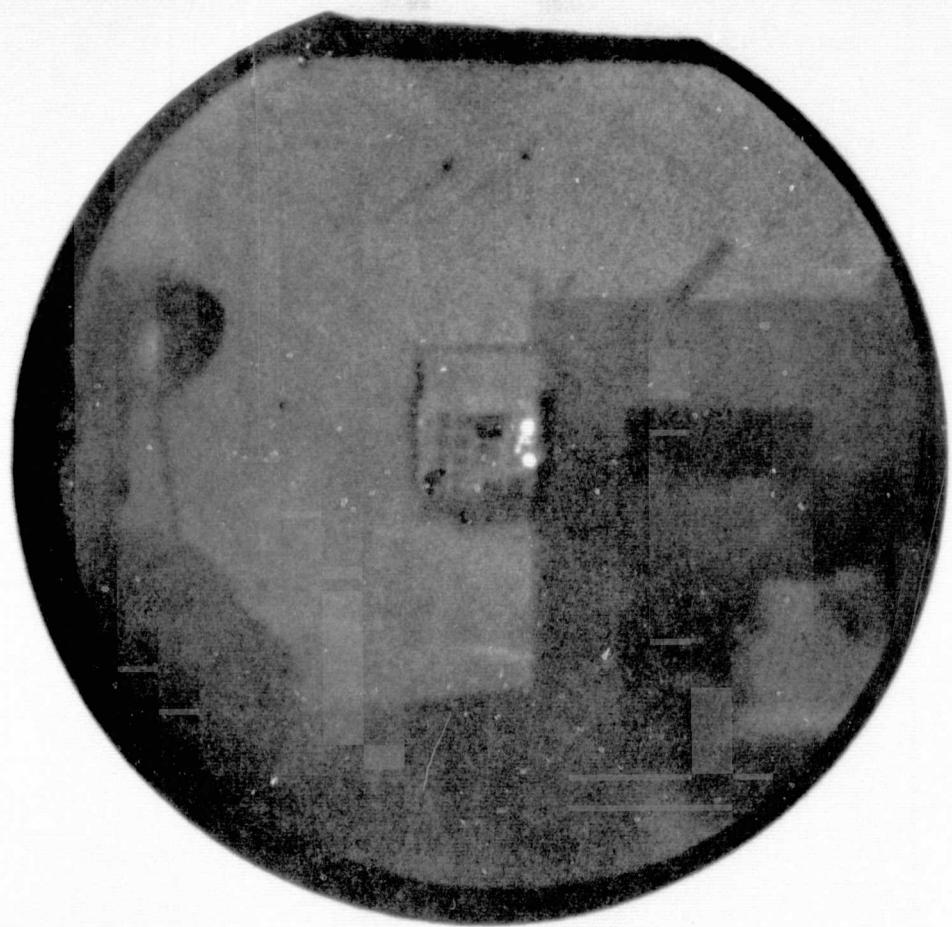


FIGURE 4-20

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1100
Exposure:	10 seconds
Film:	Tri X
Iris:	f 1.2
Illumination:	See Figure 4-18

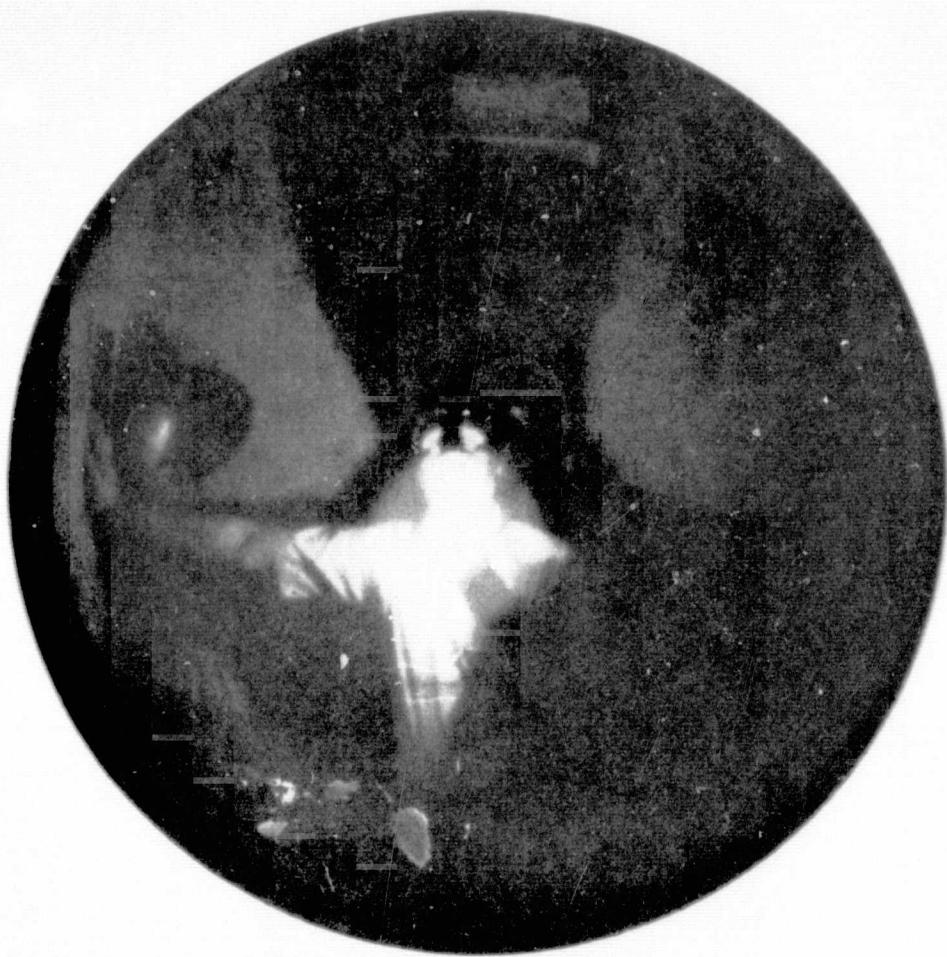


FIGURE 4-21

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1100
Exposure:	5 seconds
Film:	Plus X
Iris:	f 1.2
Illumination:	See Figure 4-18

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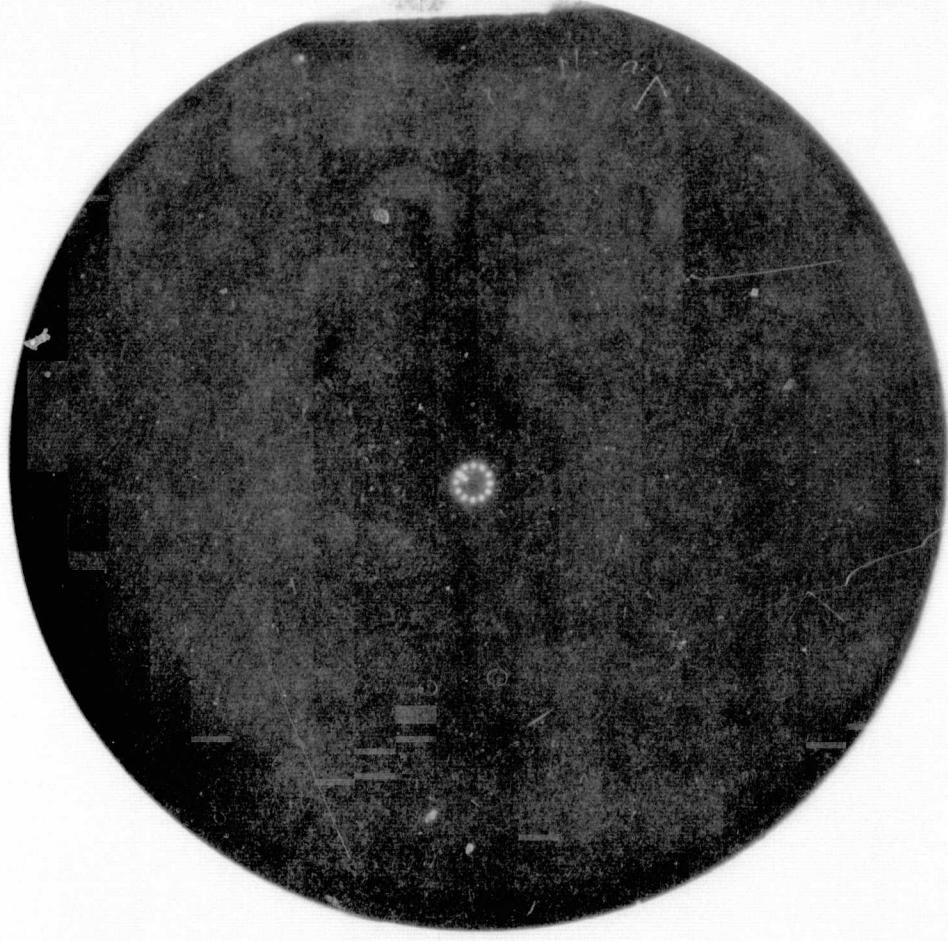


FIGURE 4-22

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1100
Exposure:	60 seconds
Film:	Tri X
Iris:	f 1.2
Illumination:	See Figure 4-18

mination is the watch itself.

Figures 4-23 through 4-30 were taken on 18 October 1976 with the ITT tube at the Cow Canyon Saddle location, with only starlight for illumination. The elevation at this point is between 4000 and 5000 feet, above the overcast which covered the city that night. Figure 4-23 was taken in the westerly direction. The smudge over the truck in the background is from the enlarging process.

Figure 4-24 was taken at nearly the same location and in the same direction as Figure 4-13. This time of course, the illumination was much lower. The buttons on the shirt are apparently accentuated by high reflectance.

Figure 4-25 was taken on the same road and in the same direction as Figure 4-24. The bright square shape is a notebook. With the unaided eye it was possible to barely make out the gate only. All other features were invisible.

Figure 4-26 is nearly the same scene as Figure 4-14. However, a brush fire crossed this area between the times when the two photographs were made. The brush in Figure 4-26 is the remnant of that shown in Figure 4-14. Also, the poles are no longer present.

Figure 4-27 is the same scene as Figure 4-15 and 4-16. However, this time the city lights were obscured by overcast, leaving only a glow which illuminates the background. Points of light were completely obscured to the unaided eye but did appear faintly in the enlarged photograph. The black spot is the same one that appears in all of this series, as explained earlier.

Figure 4-28 is a close-up of burned vegetation on a ridge, back lighted by the sky. It demonstrates the detail which can be picked out by the image intensifier camera when there is sufficient contrast.

Figure 4-29 was taken across the mountains in a westerly direction towards the San Gabriel Valley which is covered by overcast. The light horizontal streaks are from the faint glow of city lights, and the bright spots against the mountain are from automobile headlights on a road several miles away.

Figure 4-30 shows the stars in the northern sky, just above the ridge. The constellation Cassiopeia is included in this scene, but it is not readily apparent, probably because lower magnitude stars appear almost as bright as the major stars in this photograph. A shorter exposure time might have brought out a better relationship between the star magnitudes. The black spots are due to dirt particles on the face plate of the tube.

Figures 4-31 and 4-32 were taken at the same location as above, but using Kodacolor II film. Figure 4-31 is the same scene as Figure 4-27. Figure 4-32 is of the planet Venus in the eastern sky. The stars are also clearly visible in this photograph, including the Pleiades group in the constellation Taurus, to the left and above Venus. The size of Venus is distorted by its intensity.

Figures 4-33 and 4-34 were taken in the laboratory of a transparent color chart, to test the ability of the image intensifier camera to record the visible colors as monochromatic shades. Figure 4-35 is a drawing of the chart, which consisted of a viewgraph made from the transparent acetate sheets used by illustrators. In Figure 4-33 the only illumination is from the digital voltmeter, located to



FIGURE 4-23

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light

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FIGURE 4-24

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light



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FIGURE 4-25

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light

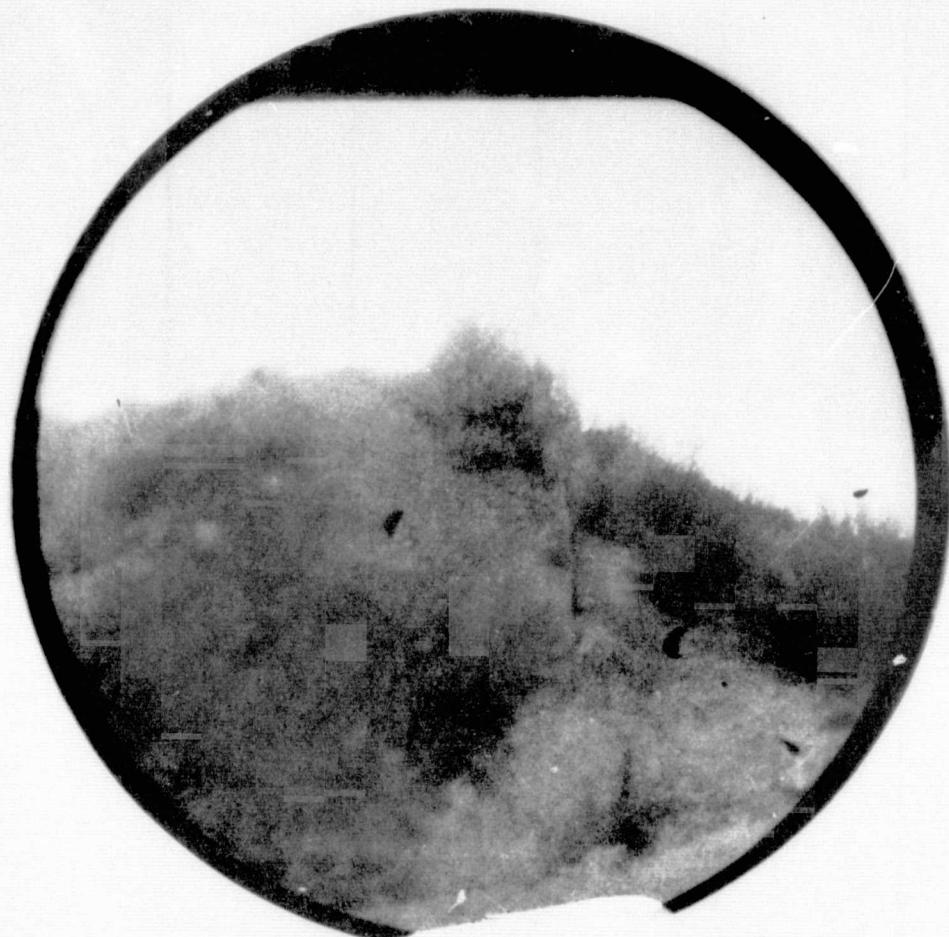


FIGURE 4-26

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light



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FIGURE 4-27

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1/2 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light and City Lights through Overcast in Background



FIGURE 4-28

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1/2 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light



FIGURE 4-29

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1/4 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light and Air Glow through Overcast, and Headlights in Distance



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FIGURE 4-30

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	1/4 second
Film:	Plus X
Iris:	f 1.2
Illumination:	Star Light

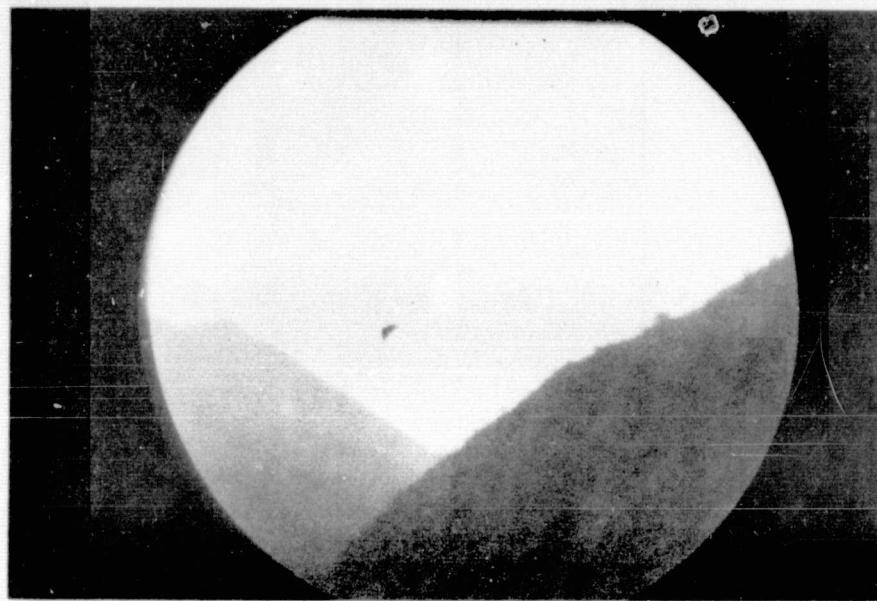
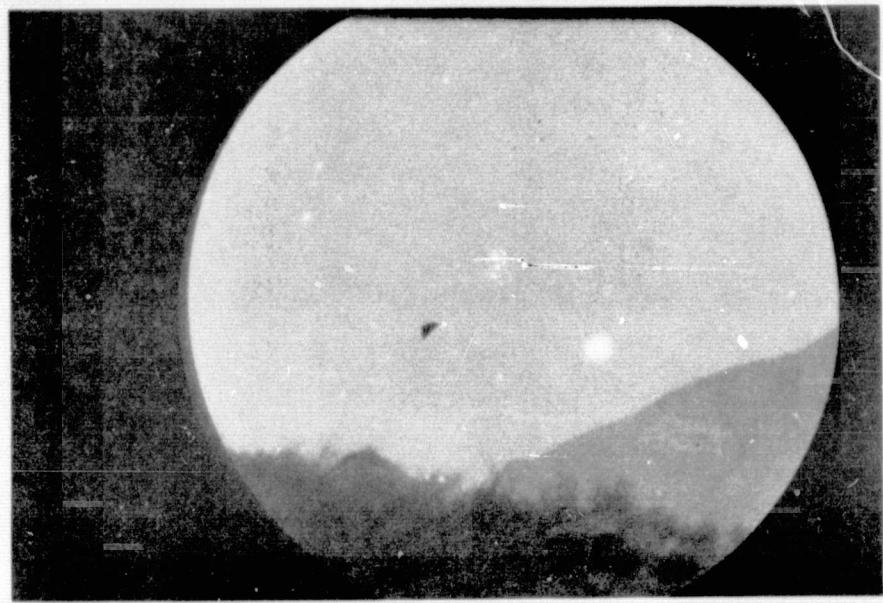


FIGURE 4-31

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	10 seconds
Film:	Kodacolor II
Iris:	f 1.2
Illumination:	Star Light and City Lights through Overcast in Background



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FIGURE 4-32

Photograph Taken With Image Intensifier Camera

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	5 seconds
Film:	Kodacolor II
Iris:	f 1.2
Illumination:	Star Light

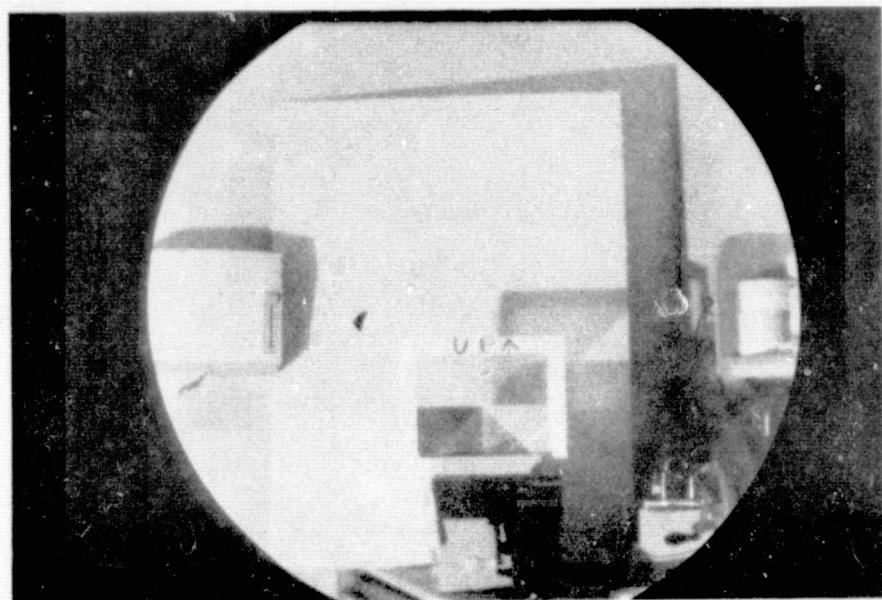


FIGURE 4-33

Photograph of a Front Lighted Transparent Color Chart  
and its Image

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	16 seconds
Film:	Kodacolor II
Iris:	f 1.2
Illumination:	See Figure 4-18

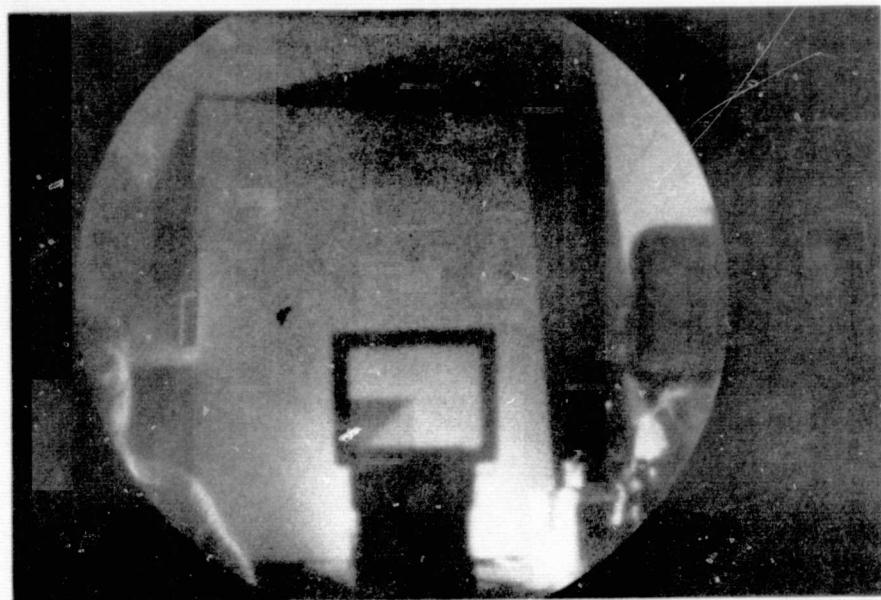


FIGURE 4-34

Photograph of a Rear Lighted  
Transparent Color Chart

Image Intensifier:	ITT
Luminous Gain:	1800
Exposure:	8 seconds
Film:	Kodacolor II
Iris:	f 1.2
Illumination:	Cigarette behind Box which supports the Color Chart

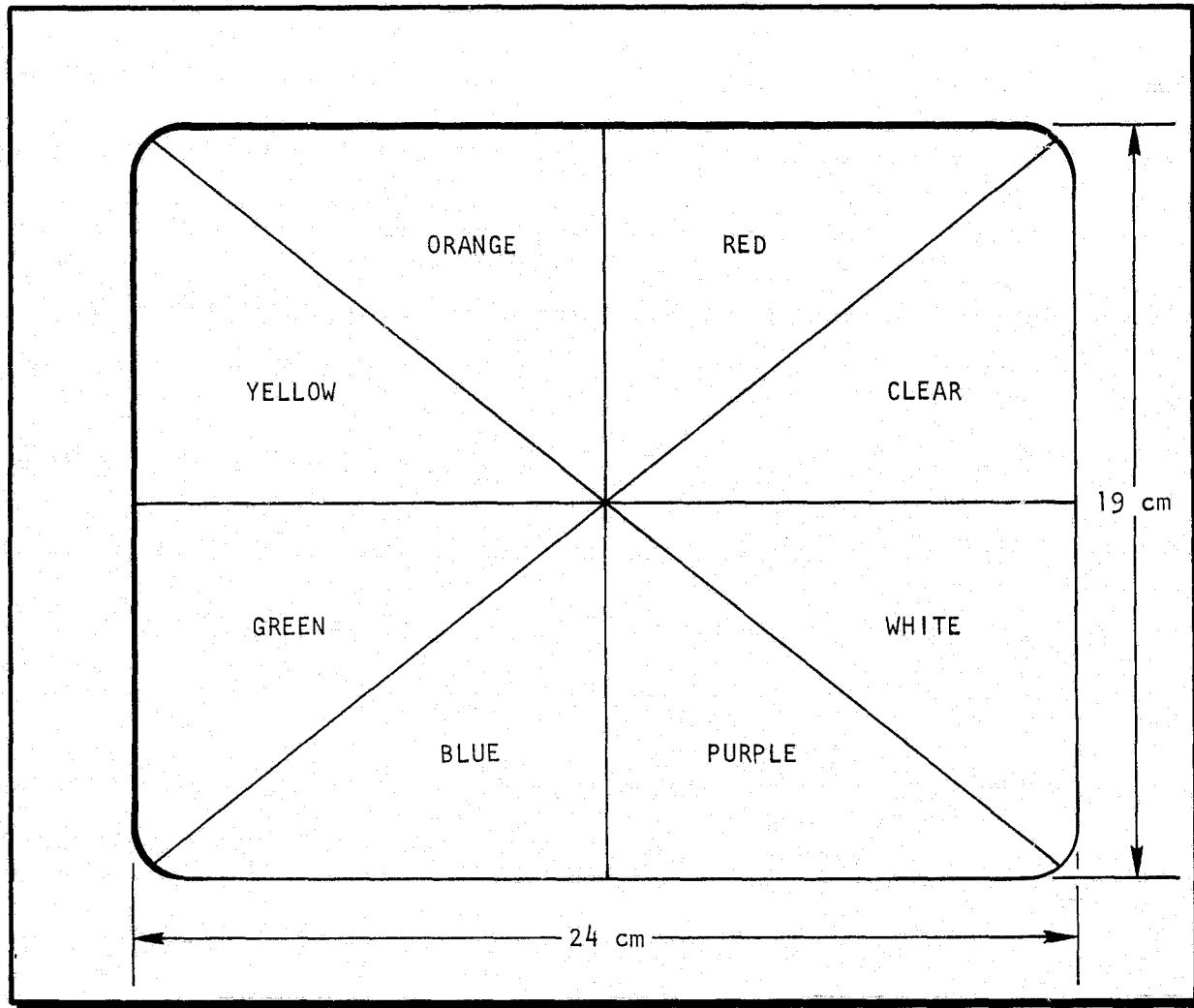


FIGURE 4-35  
Color Transparency Chart for Color Recognition Test

the left of the camera as shown in Figure 4-18. A white screen was placed against the wall behind the chart to reflect light through the pattern. However, Figure 4-33 shows that the pattern was also projected onto the background, so that two images of the chart appear in the photograph, with superposition of one quadrant. Since the spectral response of the tube over the very narrow band of wave lengths which represent the visible spectrum is essentially constant, the different shapes which appear in the photograph must be due to different reflectances and transmissibilities for each of the color segments. These results are sufficient to show that under favorable conditions the image intensifier camera can distinguish most visible colors and present them as monochromatic shades. The main difficulty would appear to be separating red, orange, and yellow.

Another interesting observation from Figure 4-33 is the reversal in shades between the color chart and its projected image on the background. For instance, the white segment reflects most of its light, transmitting very little to the pattern on the background. The clear segment above it reflects virtually no light, transmitting most of it to the background, which appears light in the photograph.

Figure 4-34 is of the same pattern but rearlighted by a cigarette, which is behind the box which supports the pattern. In this scene, only the green and blue segments stand out, while the others are virtually invisible. This is partly due to the fact that much of the energy from the cigarette is infrared, which is not filtered by any of the segments except the green and the blue, giving further proof that the tube is responsive to longer wave lengths well beyond the visible region of the spectrum.

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 CONCLUSIONS

1. The results of the testing are in general agreement with the conclusions of Task 1, Tradeoff Analysis. These results demonstrate that it is possible to take good pictures of real world scenes at very low light levels, which are invisible to the unaided eye, with a proximity focussed image intensifier incorporated in a good quality 35 mm camera, and using ordinary film and processing.
2. Both camera approaches tested proved to be feasible, and will give good results in properly designed configurations. However, for the relay lens approach, a special lens design which places the entrance pupils close to coincidence would be required to obtain the desired results. This is not possible with two standard photographic lenses such as were used in this study.
3. The cassette approach offers several important advantages. It is very compact compared with the relay lens approach, and if the input face plate of a standard intensifier tube design is extended by a few millimeters, camera modifications are not required. Easy conversion between a standard camera and an image intensifier camera is another valuable feature.
4. Compact battery operated power supplies are readily available for image intensifier camera applications if automatic brightness control (ABC) is not needed. Most of the real world photography in this report did not use ABC, but it was necessary to experiment with exposure times to obtain best results. ABC would make it easier to take good pictures, however more development will be required to adequately incorporate ABC in a power supply for the cassette configuration.
5. Both P-11 and P-20 phosphor screens for the image intensifier can be used in the image intensifier camera, but the P-11 is a better choice if photography is more important than viewing. The P-11 phosphor appears to be less grainy, and is a good match with most ordinary photographic films.
6. Either the input or the output side of the proximity focussed tube can be operated at ground potential. In the relay lens approach, it makes no difference. In the cassette configuration, having the film side grounded avoids high voltage problems which can effect the photographic results.
7. Phosphor persistence can be troublesome if the film is advanced immediately after an exposure is made, causing a double exposure. The obvious answer is to wait a few seconds before advancing the film. Phosphor persistence also has the effect of lengthening the exposure time, but not significantly.

8. Ordinary films (Plus X, Tri X, Panatonic X, and Kodacolor II) gave the best results. High speed films such as Kodak 2485 were not found to be necessary, and do not provide as good definition. Color film requires longer exposure, but provides better definition than the black and white films, even though the tube output is monochromatic.

9. Best performance was obtained with medium or low gain settings for the image intensifier tube. Highest gain settings were not necessary, and produced poor definition pictures due to higher noise and tube saturation.

## 5.2 RECOMMENDATIONS

1. The cassette approach shows considerable promise for future flight hardware, and development should be continued. This includes working with the image intensifier manufacturer to make design modifications to the tube which will remove the necessity to modify the camera. Preliminary discussions indicate that this modification will not be difficult.
2. The two new approaches described in Section 3.3 for providing automatic brightness control in the cassette configuration camera should be further evaluated, and the best approach should be built and tested. At the present time the preferred approach is to integrate the screen current and use this to control the exposure time.
3. The power supply should be re-packaged into a compact potted unit which can be incorporated into a camera. It should include automatic brightness control, and electronic shuttering if the study of ABC approaches determines that electronic shuttering is the best way to control exposure.

## **APPENDIX A**

### **Image Intensifier Specification**

APPLICATION		REVISIONS		
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE APPROVED

**UNLESS OTHERWISE SPECIFIED  
DIMENSIONS ARE IN INCHES**

## TOLERANCES

ANG  $\pm 0^\circ 30'$

DEC .XX ± .XXX ±

**CONTRACT NO.**

| DWG NO.

DRAWN

CHIKI

DESIGN

## DESIGN

# **PERKIN-ELMER**

AEROSPACE DIVISION

## IMAGE INTENSIFIER

SIZ

**CODE IDENT NO.**

**26581**

39-0426

SCALE

SHEET 1 of 5

## 1. SCOPE

1.1 This specification establishes the minimum requirements for a Generation II Proximity Focused Image Intensifier Tube, without power supply, referred to herein as the Image Intensifier.

## 2. APPLICABLE DOCUMENTS

2.1 Government Documents. N/A

## 3. REQUIREMENTS

3.1 Type and Configuration. The image intensifier shall use proximity focusing for the electron imaging method and shall incorporate a microchannel plate. Configuration and maximum overall dimensions shall be as shown in Figure 1. Unless otherwise noted, all performance specified herein is based on input illumination from a 2854° K color temperature tungsten lamp.

3.1.1 Format Size. The useful screen and photocathode diameter shall be either 18mm or 25mm.

3.1.2 Input Window. The input window shall be circular with a flat, planar surface. The window material shall be either fiber optics or planar 7056 glass.

Figure 1

Maximum Overall Dimensions

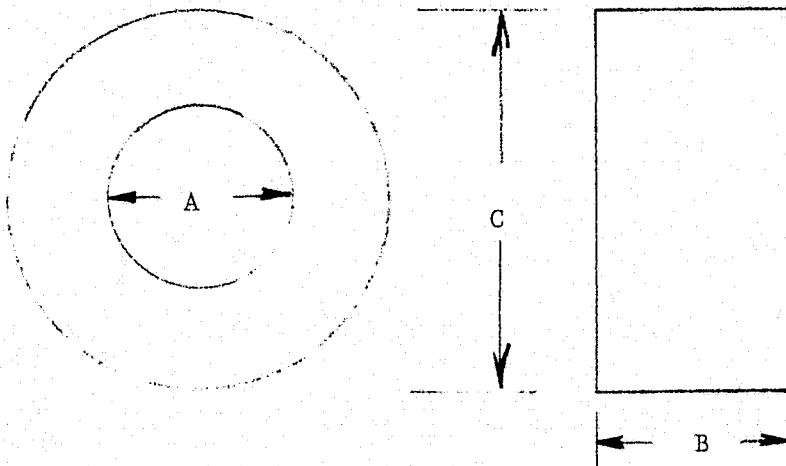


Image Intensifier Size	A	B	C
18mm	18mm	1.0 in.	1.5 in.
25mm	25mm	1.0 in.	2.0 in.

SIZE <b>A</b>	CODE IDENT NO. <b>26581</b>	39-0426
SCALE		SHEET 2 of 5

3.1.3 Output Window. The output window shall be circular with a flat, planar surface. The window material shall be fiber optics. 180° inversion of the image is permissible.

3.1.4 Photocathode. The photocathode shall be a multialkali type with a minimum luminous sensitivity of 200  $\mu\text{A/lm}$ . The minimum radiant response at the respective wavelengths shall be as follows:

<u>Wavelength</u>	<u>Min. Radiant Response</u>
800 nm	12 mA/W
850 nm	5 mA/W
900 nm	1 mA/W

3.1.5 Phosphor. A P-11 response characteristic is preferred. However, a P-20 response characteristic is also acceptable.

3.1.6 Cathode and Screen Blemishes. The cathode and screen blemishes shall not exceed in number or size those specified in Table I for each of the defined areas.

Size of Blemishes Observed at Output Screen	Number of Blemishes		
	Area A	Area B	Area C
Greater than 0.015"	0	0	0
0.010" to 0.015"	0	0	2
0.007" to 0.010"	0	3	5
0.003" to 0.007"	1	18	18

Area A is defined as the area within a circle 30% of the total useful diameter, concentric with the major axis of the tube.

Area B is defined as the area bounded by a circle 30% of the useful diameter and a circle 80% of the useful diameter, both of which are concentric with the major axis of the tube.

Area C is defined as the area bounded by a circle 80% of the useful diameter and a circle 100% of the useful diameter, both of which are concentric with the major axis of the tube.

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Table 1 ORIGINAL PAGE IS POOR

SIZE <b>A</b>	CODE IDENT NO. <b>26581</b>	39-0426
SCALE		SHEET 3 of 5

3.1.7 Luminous Gain. The ratio of the output brightness of the phosphor in foot-lamberts to the input illumination of the photocathode in foot-candles shall be 10,000 ft-L/ft-C minimum, for inputs up to  $4 \times 10^{-5}$  ft.-C, and with full voltage applied to the image intensifier.

3.1.8 Output Brightness. The output brightness, for maximum input illumination, and with voltages set for full gain, shall be between 2 foot-lamberts and 6 foot-lamberts.

3.1.9 Output Brightness Uniformity. For a uniform light input, the output screen brightness shall be uniform within  $\pm 10\%$  of the average value.

3.1.10 Limiting Resolution. The minimum limiting resolution shall be 25 line pairs/mm.

3.1.11 Magnification. The input to output optical magnification of the image intensifier shall be  $1 \pm 0.005$ .

3.1.12 Distortion. There shall be no barrel, pincushion, or "S" distortion.

3.1.13 Equivalent Background Input. With no input illumination, the maximum measured output background shall be equivalent to an input to the image intensifier of  $4 \times 10^{-11}$  lumens/cm<sup>2</sup>.

3.1.14 Maximum Input Illumination. The life characteristics of the image intensifier shall not be adversely affected by continuous operation at a maximum input level of  $2 \times 10^{-4}$  foot-candles. Room lighting or point light sources for short periods shall not damage the image intensifier.

3.1.15 Environmental Requirements. The image intensifier shall have an operating temperature range of -18°C to +38°C, and a storage temperature range of -54°C to +68°C. The image intensifier must withstand shock and vibration equivalent to normal laboratory handling.

3.1.16 Life. At an input illumination of  $2 \times 10^{-4}$  foot-candles, with maximum voltages applied to the image intensifier, the minimum life shall be 1,000 hours.

3.1.17 Power Requirements.

Operating Voltages (Maximum)

Cathode	300 VDC
Microchannel plate	1000 VDC
Anode	5000 VDC

Operating Current (Nominal)

	18mm Tube	25mm Tube
Cathode	$5 \times 10^{-10}$ Amp.	$10^{-9}$ Amp.
Microchannel plate	$6 \times 10^{-6}$ Amp.	$12 \times 10^{-6}$ Amp.
Anode	$3 \times 10^{-6}$ Amp.	$5 \times 10^{-6}$ Amp.

SIZE <b>A</b>	CODE IDENT NO. <b>26581</b>	39-0426
SCALE		SHEET 4 of 5

3.1.18 Control Capabilities. The image intensifier can be used with a power supply (not part of this specification) which provides automatic brightness control, remote gain control, and gating capability.

3.1.19 Construction. The image intensifier shall be encapsulated or otherwise protected in a suitable high dielectric strength potting material. Electrical leadwires, if used, shall be suitably insulated, and shall be a minimum of four inches long. Either the photocathode or the anode can be connected to ground.

3.1.20 Identification and Marking. The image intensifier shall be legibly marked with the following minimum information:

- a. Manufacturers name or trademark
- b. Manufacturers part number
- c. Manufacturers serial number

#### 4. QUALITY ASSURANCE PROVISIONS

4.1 Data. Performance measurements and calculations made by the manufacturer in determining compliance with this specification shall be submitted to Perkin-Elmer with the delivery of the image intensifier.

4.2 Certification. A letter of compliance shall accompany delivery of the image intensifier, certifying that the requirements of this document have been complied with, and stating the manufacturer's part name, part number, and serial number, and the Perkin-Elmer purchase order number.

#### 5. PREPARATION FOR DELIVERY

5.1 Packaging and Packing. The image intensifier shall be packaged in such a manner as to prevent damage during shipment and storage, and packed to assure acceptance and safe delivery by common carrier.

5.2 Marking for Shipment and Storage. All interior and exterior containers shall be legibly marked with the quantity, item name, and manufacturer's part number, Buyer's name, address, and purchase order number and destination.

#### 6. NOTES

6.1 Intended Use. The image intensifier supplied to this specification is intended for use in a developmental spaceborne camera system.

6.2 Ordering Data. Procurement documents shall specify the following:

- a. Title, number, and revision letter of this specification.
- b. Vendor submission of test data and certification of compliance to this specification.

SIZE <b>A</b>	CODE IDENT NO. <b>26581</b>	39-0426
SCALE		SHEET 5 of 5

Exceptions to Perkin-Elmer Specification 39-0426, No Revision

for Proximity Focused Channel Intensifier Tube, 18 mm & 25 mm

The Perkin-Elmer specification 39-0426 is acceptable except as modified below.

- A) Figure 1 - change C dimensions to read 1.750 inches for the 18 mm size and 2.050 inches for the 25 mm size.
- B) Para. 3.1.3, Output Window - revise the sentence to read "... fiber optics with no inversion of the image."
- C) Para. 3.1.4, Photocathode - change minimum radiant response at 900 nm to read 0.5 mA/W.
- D) Para. 3.1.7, Luminous Gain - insert after "minimum" the words "for P-20 output phosphor, 2800 ft-L/ft-c. minimum for P-11 output phosphor,"
- E) Para. 3.1.8, Output Brightness - revise sentence to read "... foot-lamberts for P-20 output and 0.5 foot-lamberts for P-11 output (see para. 3.1.14)."
- F) Para. 3.1.9, Output Brightness Uniformity - change " $\pm 10\%$ " to read " $\pm 20\%$ ".
- G) Para. 3.1.10, Limiting Resolution - change "25" to read "22-24".
- H) Para. 3.1.14, Maximum Input Illumination - substitute the following paragraphs:

The life characteristics of the image intensifier shall not be adversely affected by continuous operation on fixed voltage power supplies at a maximum input level of  $2 \times 10^{-4}$  ft-c. for exposures in the order of seconds.

Room lighting and point light sources are to be avoided. With proper ABC and bright source protection provisions in the power supplies, accidental short duration exposures to the above sources shall not damage the image intensifier.

- I) Para. 3.1.15, Environmental Requirements - change "68°C." to read "+49°C."
- J) Para. 3.1.16, Life - revise sentence to read "The following shall be considered as a design goal: at an input illumination of  $1 \times 10^{-6}$  foot-candles, with voltages applied to the image intensifier to provide 3/4 of the rated luminous gain, no more than 50% loss in luminous gain may occur in 1,000 hours of operation."
- K) Para. 3.1.17, Power Requirements - change cathode voltage to 200 and micro-channel plate voltage to 900.

.../...

P-E Request P-386  
ITT Quotation F5-1069  
3/14/75

Page 2

- L) Para. 3.1.17, Power Requirements - revise the operating current table to read as follows:

	<u>18 mm Tube</u>	<u>25 mm Tube</u>
CATHODE	$5 \times 10^{-12}$ Amp.	$10-11$ Amp.
MICROCHANNEL PLATE	$3 \times 10^{-6}$ Amp.	$5 \times 10^{-6}$ Amp.
ANODE	$3 \times 10^{-9}$ Amp.	$5 \times 10^{-9}$ Amp.

**APPENDIX B**

**Manufacturer's Data For**

**Image Intensifier Tubes**

7-6317

Perkin-Elmer



Galileo Park, Sturbridge, Massachusetts 01518, (617) 347-9191

### IMAGE INTENSIFIER DATA SUMMARY

Test Date: 5-6-75

Tube Type: 9025 - 2121  
Tube S/N: 440

Cathode Type: S-20  
Input Window: F.O.  
Phosphor Type: P-20  
Output Substrate: F.O.

Cathode Luminous Response: 204 micrcamp/2854 K. Lumen

Cathode Radiant Response @ 450 nm : 44 ma/watt

Cathode Radiant Response @ 800 nm : 14 ma/watt

Luminous Gain @ 300, 800, 5000 volts = 15,000 ft-1/ft-s  
Radiant Gain @ 300, 800, 5000 volts = 5,850 watts/watt

Photon Gain @ 300, 800, 5000 volts = 8,300 photons/photon  
@ 450 nm (input)

Detection Threshold =  $5.7 \times 10^{-14}$  watts/cm<sup>2</sup>

Resolution: 25 lp/mm

Uniformity: 1.5:1

Spots, Blemishes: OK

#### Maximum Operating Voltages

9000 series V (A - CEMA OUTPUT) = 5000 volts

Tubes only V (CEMA OUT - CEMA IN) = 800 volts

V (CEMA INPUT - CATHODE) = 300 volts

8000 series V (ANODE - CATHODE) = N/A volts

Tubes only

**SEE BACK FOR FURTHER DETAILS**

## ADDITIONAL SPECIFICATIONS PER SALES ORDER

### PARAMETER

### SPECIFICATION

### ACTUAL

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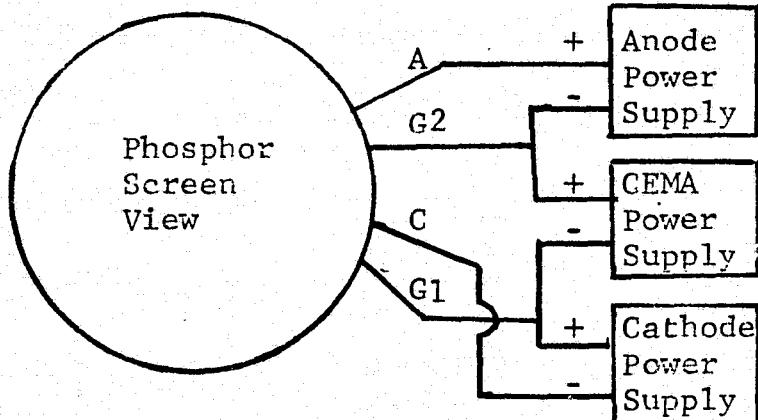
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### Power Supply Connections

#### 9000 Series Tubes

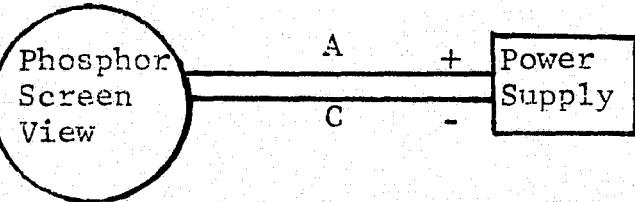


$V$  (A - CEMA output)  
 $I = 1 \times 10^{-7}$  amp/cm<sup>2</sup> (max)

$V$  (CEMA out - CEMA in)  
 $I = 2.5 \times 10^{-6}$  amp/cm<sup>2</sup> (max)

$V$  (CEMA input - cathode)  
 $I = 2 \times 10^{-10}$  amp/cm<sup>2</sup> (max)

#### 8000 Series Tubes

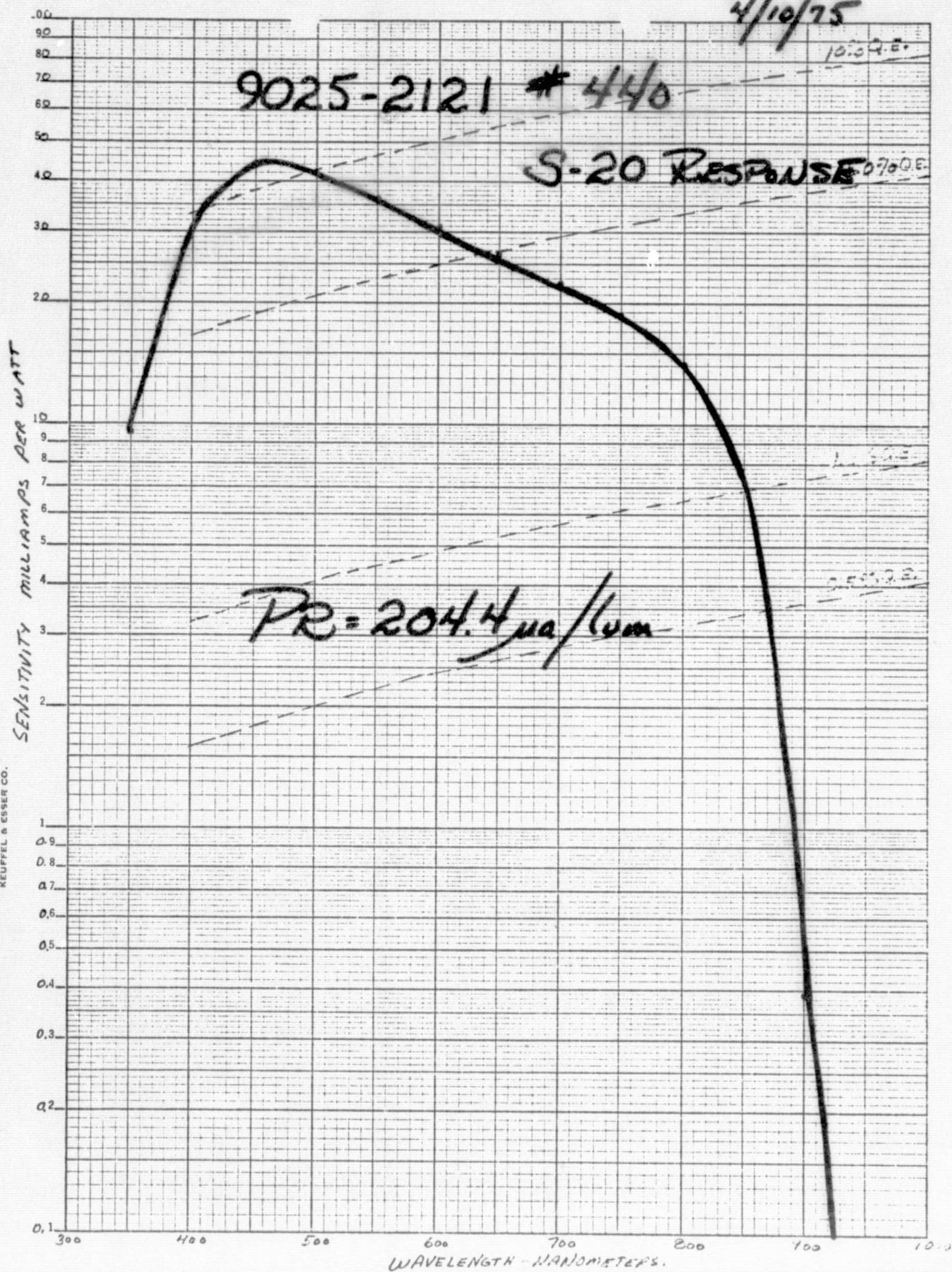


$V$  (Anode - Cathode)  
 $I = 1 \times 10^{-7}$  amp/cm<sup>2</sup> (max)

Note: Maximum currents are determined by the area of the cathode actually illuminated.

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100,000

9025-2121 S/N 440

8

7

6

5

4

3

2

10,000

8

7

6

5

4

3

2

1,000

8

7

6

5

4

3

2

100

8

7

6

5

4

3

2

10

Luminous Gain  
ft.-l / ft.-c

AG 6012  
AEG STIFTUNG  
ELEKTRONIK  
DIVISION  
KREUZBERG  
FRG

V(CEMA) - VOLTS

$V_A = 5000$  VOLTS

$V_K = 300$  VOLTS

300

400

500

600

700

800

900

Galileo Park, Sturbridge, Massachusetts 01518. (617) 347-9191

IMAGE INTENSIFIER DATA SUMMARY

Test Date: 11-10-75  
Sales Order No.: 7-6870

Perkin-Elmer

Tube Type: 9025 - 2122  
Tube S/N: 453

Cathode Type: S-20  
Input Window: F.O.  
Phosphor Type: P-11  
Output Substrate: F.O.

Cathode Luminous Response: 279 microamps/lumen (2854°K)

Cathode Radiant Response @ 550nm: 48 mA/watt

Cathode Radiant Response @ 800nm: 23 mA/watt

Luminous Gain @ 300, 600, 5000 volts = 1059 ft-L/ft-c  
Radiant Gain @ 300, 600, 5000 volts = 748 watts/watt

Photon Gain @ 300, 600, 5000 volts = 657 photons/photon  
@ 550nm (input)

Detection Threshold =  $2.3 \times 10^{-13}$  watts/cm<sup>2</sup> @ 550 nm (input)

Uniformity: 1.6 : 1 Resolution: 20 1p/mm (limiting)

Spots, Blemishes: 1-20 mil dia black spot at edge.

Maximum Operating Voltages

9000 series V (A - CEMA OUTPUT) = 5000 volts  
Tubes only V (CEMA OUT - CEMA IN) = 600 volts  
V (CEMA INPUT - CATHODE) = 300 volts

8000 series V (ANODE - CATHODE) = N/A volts  
Tubes only

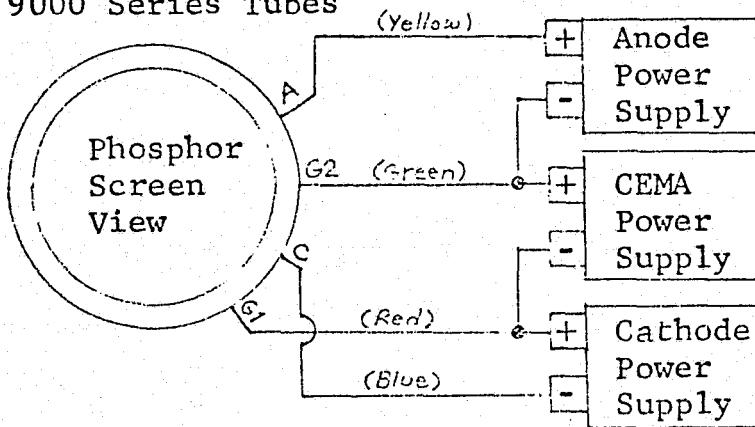
SEE BACK FOR FURTHER DETAILS

# ADDITIONAL SPECIFICATIONS PER CUSTOMER REQUIREMENTS

PARAMETER	SPECIFICATION	ACTUAL

## Power Supply Connections

### 9000 Series Tubes

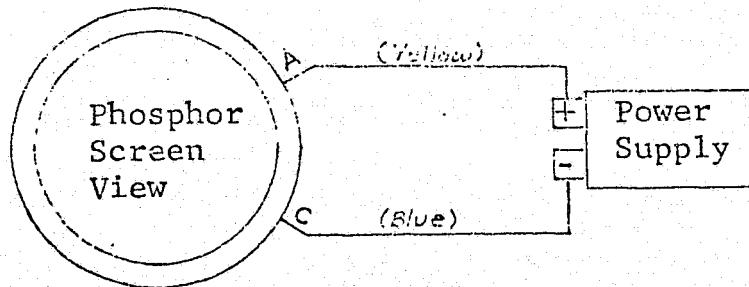


$V$  (A - CEMA output)  
 $I = 1 \times 10^{-7}$  amp/cm<sup>2</sup> (max)

$V$  (CEMA out - CEMA in)  
 $I = 2.5 \times 10^{-6}$  amp/cm<sup>2</sup> (max)

$V$  (CEMA input - cathode)  
 $I = 2 \times 10^{-10}$  amp/cm<sup>2</sup> (max)

### 8000 Series Tubes



$V$  (Anode - Cathode)  
 $I = 1 \times 10^{-7}$  amp/cm<sup>2</sup> (max)

- Notes:
1. Maximum currents are determined by the area of the cathode actually illuminated.
  2. Actual system ground should be chosen based on specific application. Suggestions:

- A. Grounded Anode - to be used when direct contact to the output fiber optics is required. MAKE SURE CEMA and CATHODE POWER SUPPLIES HAVE ADEQUATE HIGH VOLTAGE ISOLATIONS.
- B. Grounded G2 - simplest method when direct contact to either tube face is not required. Cathode voltage can be supplied by a battery with at least 1,000 volt insulation to ground.
- C. Grounded Cathode - to be used when direct or near direct contact to input window is required.

TUBE TYPE: 9025-2122

SERIAL: 453

DATE: 11-10-75

GAIN vs CEMTA VOLTAGE

LUMINOUS GAIN - ft-L/2854 K ft-C

SLM-LOGARITHMIC  
4 CYCLES X 70 DIVISIONS

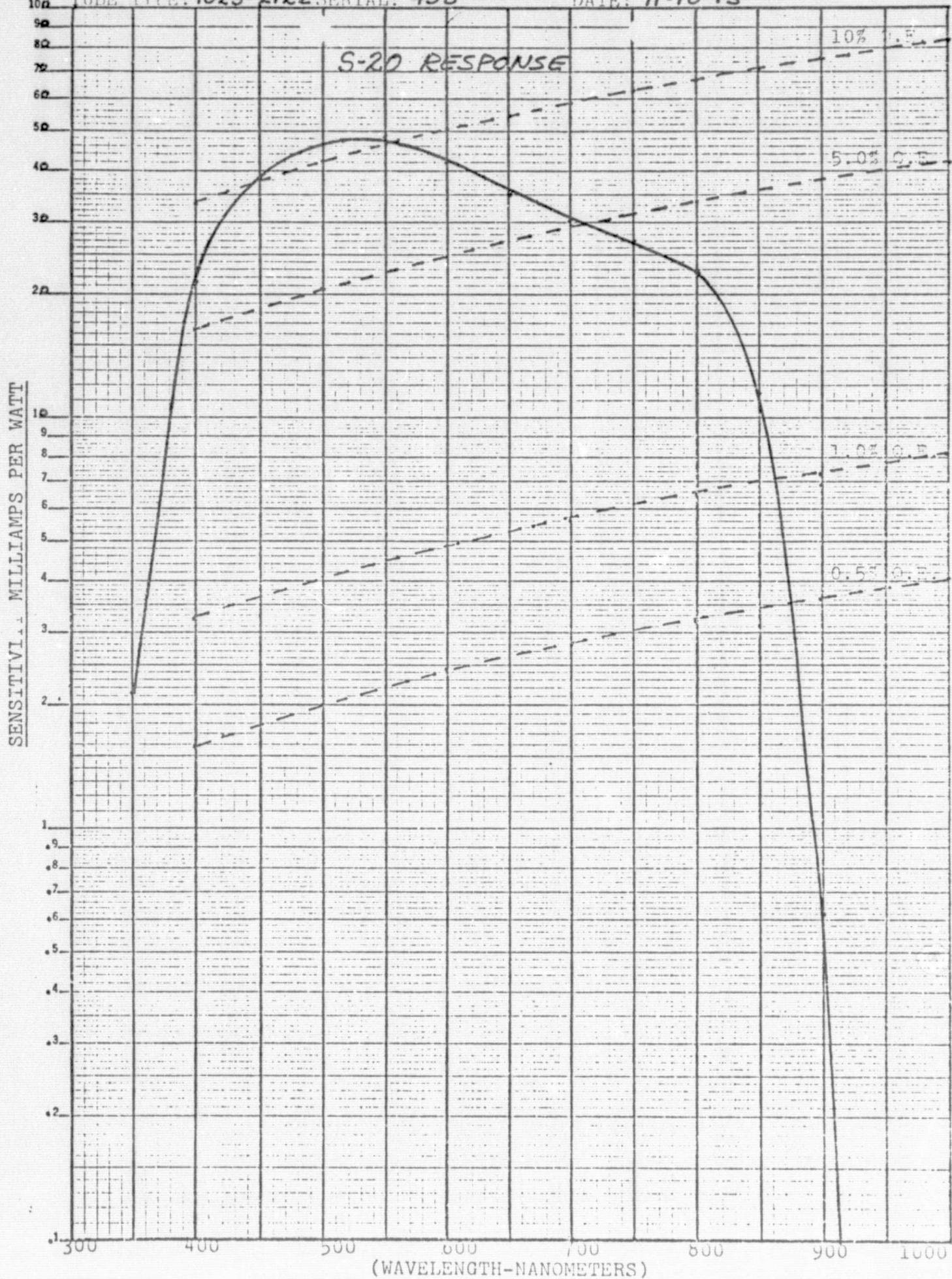
Made in U.S.A.  
KEUFFEL & ESSER CO.

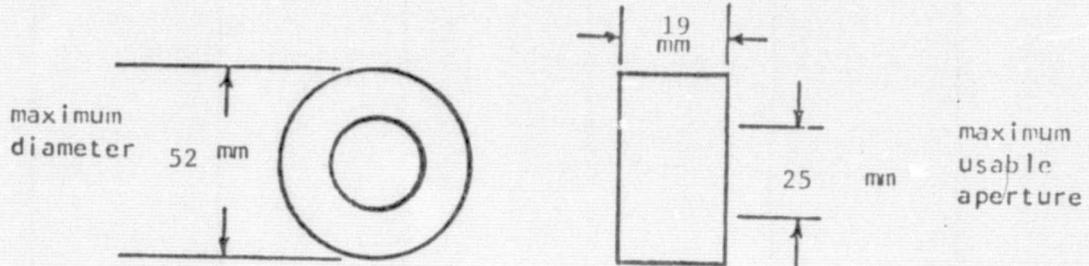
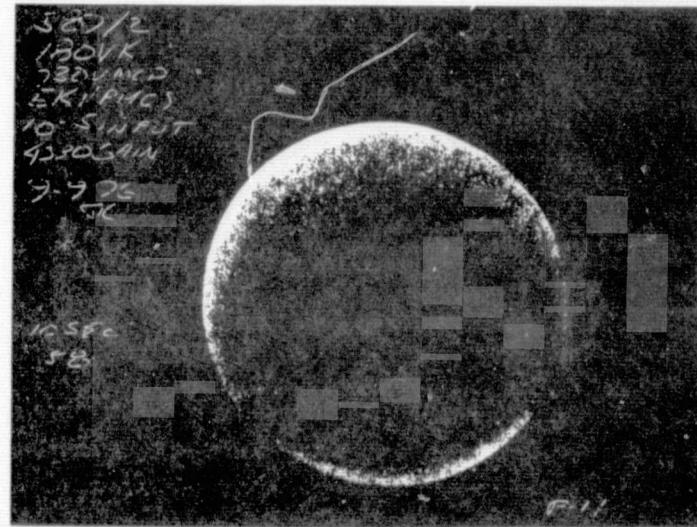
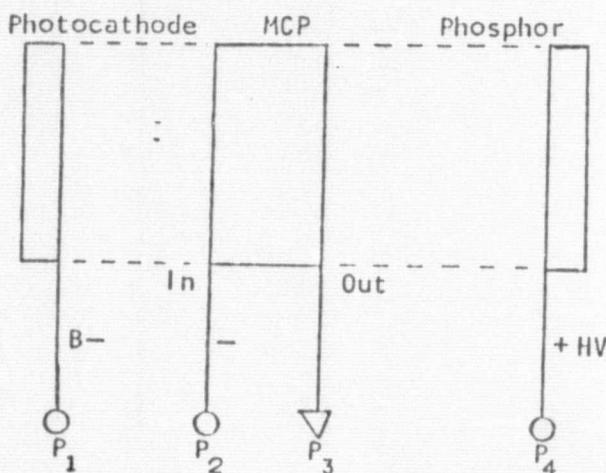
300 400 500 600 700 800  
MAD - POTENTIAL VOLTS

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TUBE TYPE: 9025-2122 SERIAL: 453

DATE: 11-10-75



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CAUTIONFOR DC (CONTINUOUS) OPERATION, INPUT  
ILLUMINATOR VOLTAGE MUST BE TURNED DOWNELECTRO-OPTICAL PRODUCTS DIVISION  
TUBE and SENSOR LABORATORIES  
3700 East Pontiac Street  
Fort Wayne, Indiana 46811  
Telephone 219-423-4341 TWX 810 332-1413— CHANNEL INTENSIFIER TUBE —TYPE F4112SERIAL NO. 587/2DATE 9/10/761.0 OUTLINE DRAWING2.0 ELECTRICAL SCHEMATIC3.0 PIN CONNECTIONS

PIN	COLOR	ELEMENT
1	Black	Photocathode (neg.)
2	Red	MCP Input (neg.)
3	Orange	MCP Output (ground)
4	Yellow	Phosphor (positive)

5.0 CATHODE SENSITIVITY254 μa/lumen4.0 TYPICAL OPERATING VOLTAGES

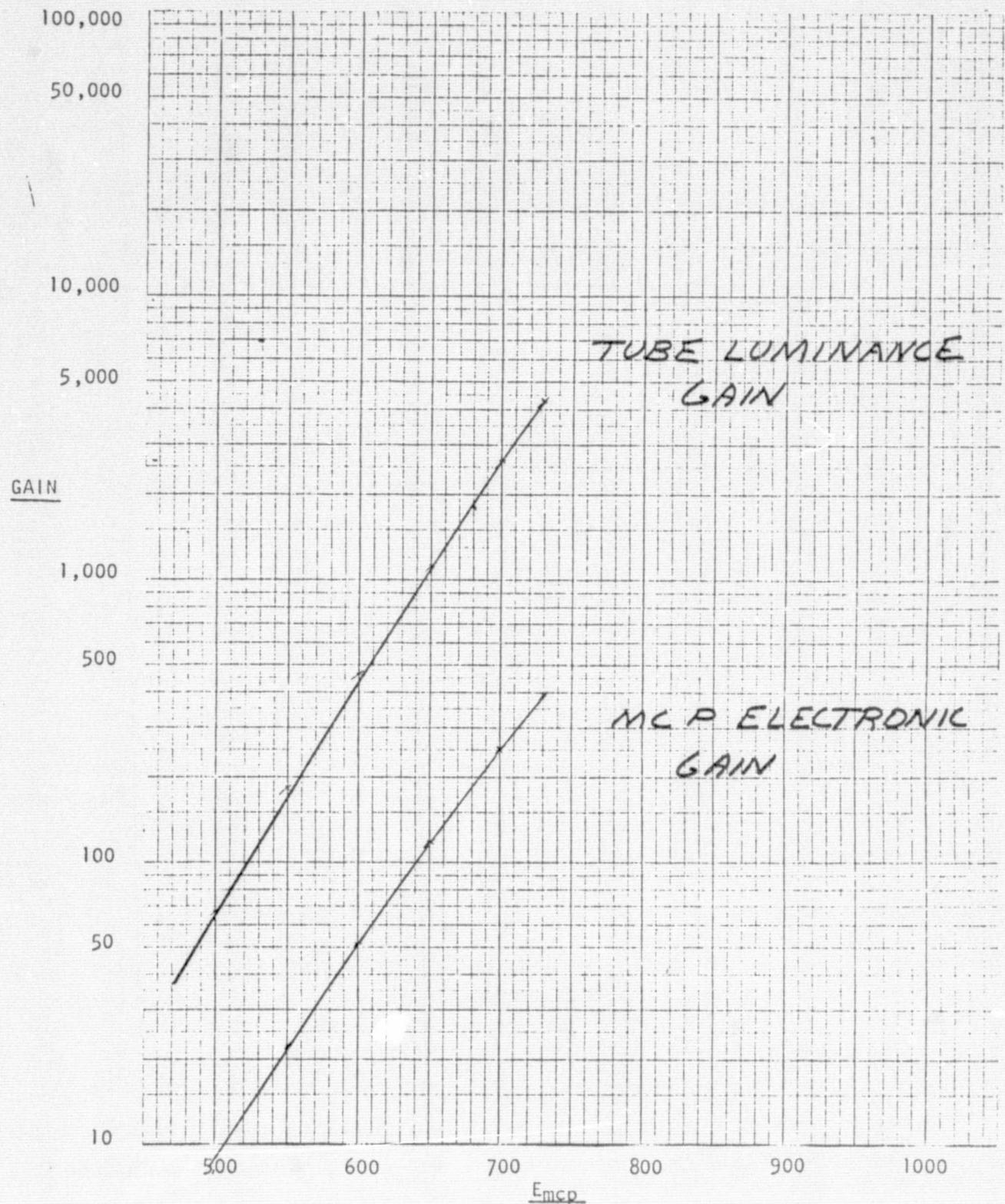
Cathode-to-MCP input	<u>180</u>	volts
MCP input to MCP output	<u>708</u>	volts
MCP output to phosphor	<u>5000</u>	volts

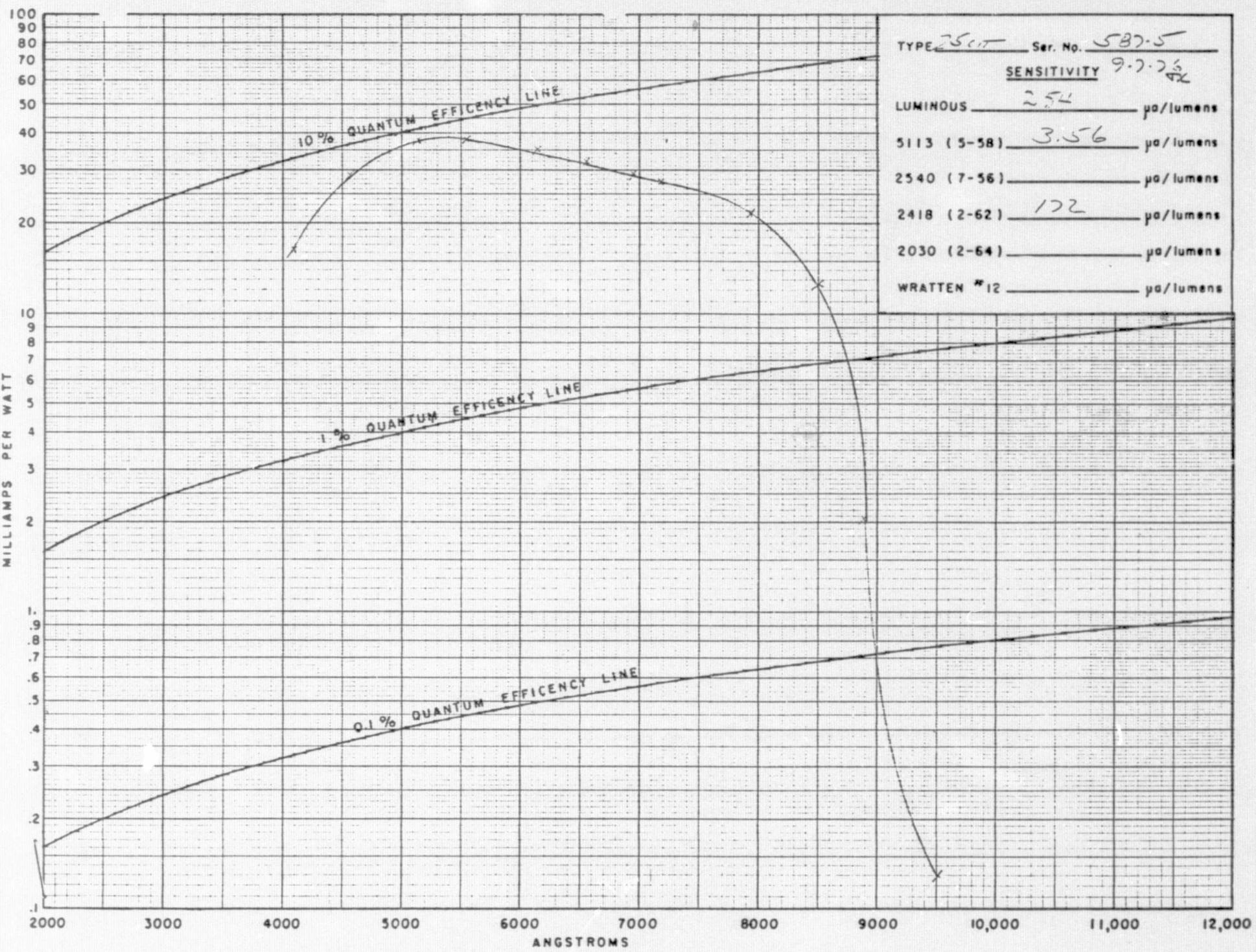
7.0 TUBE LUMINOUS GAIN30006.0 RESOLUTION22 linepairs/mm\*8.0 EQUIVALENT BACKGROUND INPUT $3 \times 10^{-12}$  @ 3K Gain lumen/cm<sup>2</sup>

\* Voltages for 3K Gain

-GAIN CHARACTERISTICS-

Tube Number: 587/2 Date: 9/10/76  
MCP Number: 560-20-012 Resolution: 22 1p/mm  
Conductivity:  $5.4 \times 10^{-6}$  amps. Cathode Sensitivity: 254 ua/l  
at 500 volts at .005 lumens  
Phosphor: P-11 Photocathode: S-20





## **APPENDIX C**

**Analysis of Image**

**Illumination By**

**Relay Lenses**

## APPENDIX C

### ANALYSIS OF IMAGE ILLUMINATION BY RELAY LENSES

#### INTRODUCTION

The following analysis was prepared by Mr. Earle B. Browne, Supervisor, Technical Staff, of the Optical Technology Division of Perkin-Elmer. It first derives the case for a simple lens, Equation 9 in this analysis. For an object at infinity ( $m = 0$ ) this becomes Equation 3 in Section 4.3 of the Task 1 report.

The second analysis considers the more complicated but also more realistic case of a combination of complex thick lenses. The derivation is then solved numerically for two combinations, designated 1 and 2 in this analysis. The numerical solution for combination 1 (two 55 mm, f/1.2 lenses for 35 mm format) results in an I/B of .045. For combination 2 (55 mm and 25 mm lenses for 16 mm format) I/B equals .042, which is not a significant difference. Thus it can be assumed that the illumination at the film plane for the brassboard design for 16 mm format would be about the same as for the brassboard designed for 35 mm format.

#### 1. CASE FOR A SIMPLE LENS

Consider the diagram in Fig. 1. A light-emitting area, A, is imaged at A' by a lens, L, the object distance being r and the image distance, r'. We wish to determine the illuminance (flux per unit area) at A', knowing the luminance (flux per unit area per unit solid angle) at A.

If B is the luminance at A, then it is clear from inspection that the illuminance at A' will be

$$I = B \Omega \frac{A}{A'} \quad (1)$$

where  $\Omega$  is the solid angle of the lens entrance pupil as seen from A.

Now,

$$\Omega = \frac{\pi D^2}{4 r^2} \quad (2)$$

and

$$\frac{A'}{A} = \frac{(r')^2}{(r)^2} = m^2, \text{ the magnification} \quad (3)$$

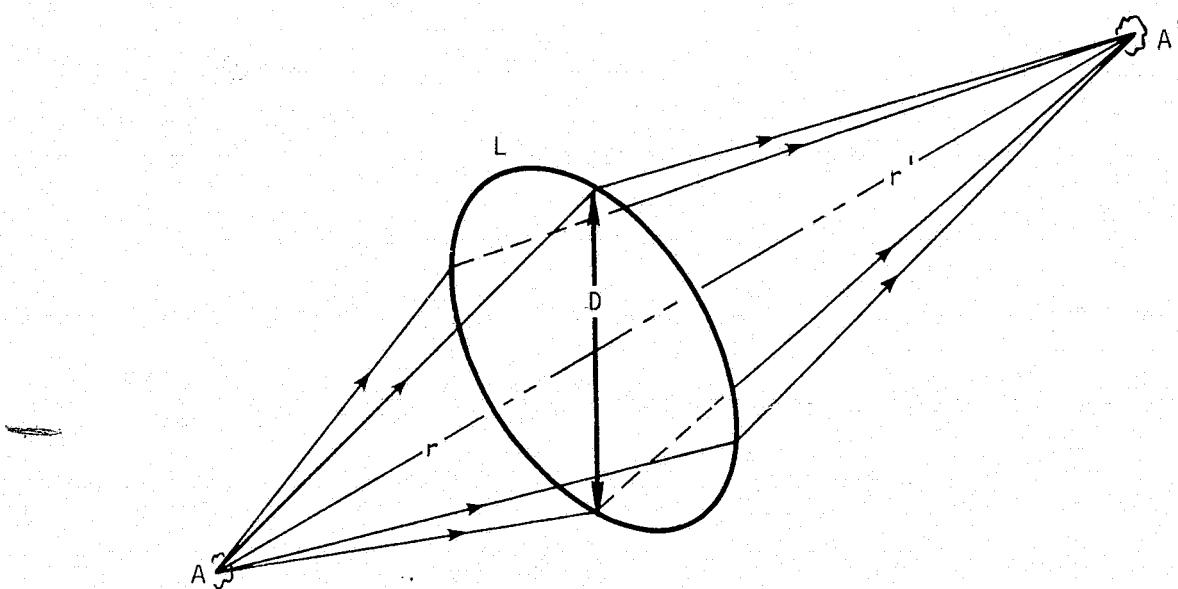


FIGURE 1

## REPRODUCIBILITY OF THE OPTICAL IMAGE

(A) PAGE IS POOR

so that

$$I = \frac{\pi D^2 B}{4 m r^2} \quad (4)$$

From the lens formula

$$\frac{1}{r} + \frac{1}{r'} = \frac{1}{f} \quad (5)$$

where  $f$  is the lens focal length. Hence, from (5) and (3) we obtain

$$r = f \frac{1+m}{m} \quad (6)$$

yielding, after substitution in (4)

$$I = \frac{\pi D^2 B}{4f^2(1+m)^2} \quad (7)$$

Now

$$\frac{f}{D} = N \quad (8)$$

where  $N$  is the relative aperture of the lens. Thus, we finally obtain

$$I = \frac{\pi B T}{4N^2(1+m)^2} \quad (9)$$

the factor  $T$  having been included to account for the lens transmissivity.

For an object at infinity (ordinary photographic situation),  $m = 0$ , and the quantity in parentheses becomes unity, yielding the familiar formula for cameras.

When the lens,  $L$ , becomes a combination of lenses, then it is useful to note that the relative aperture,  $N$ , is that corresponding to the effective aperture and focal length of the lens combination. Also, that the distances  $r$  and  $r'$  are the distances to the principal planes of the combination.

In particular, when  $L$  consists of two objectives "back-to-back" (collimated light between), the effective focal length (and relative aperture) of the

combination depends upon the separation,  $d$ , between the second principal plane of the first lens and the first principal plane of the second. Hence, the illumination depends upon the separation. However, the magnification,  $m$ , in this particular case, is independent of the separation, and is simply the ratio of the focal lengths.

## 2. CASE FOR A RELAY COMPOSED OF TWO COMPLEX LENSES

When an image is formed by a combination of thick lenses, instead of the "thin" lens assumed in the prior discussion, the situation is more complicated. The relative aperture which would be applicable for this case is a mathematical combination of the parameters of the two lenses - the location of their principal planes and pupils.

Figure 2 shows the arrangement in schematic form.

$P_{1a}$ ,  $P_{2a}$ ,  $P_{1b}$ ,  $P_{2b}$  are the first and second principal planes of the lenses (a) and (b);  $EP_b$  is the entrance pupil plane (image of the aperture stop as seen from the object space) of lens (b);  $d$  is the physical separation between the two exterior glass surfaces as shown.  $f_{1a}$  is the front focal length of lens (a), which locates the object position. It will be noted that the principal planes of the lenses are shown "crossed", which is a common situation.

The basic equation for the illumination at the final image plane is the same as before (Equation (1) with the transmission factor  $T$  added),

$$I = B T \Omega \frac{A}{A'} \quad (10)$$

and we must now determine the appropriate values of  $\Omega$  and  $A/A'$ .

The solid angle of collection,  $\Omega$ , is

$$\Omega = \frac{\pi}{4} \omega^2 \quad (11)$$

where  $\omega$  is the plane angle subtended by the entrance pupil of the lens combination (entrance pupil of lens (b) as imaged by lens (a)), or

$$\omega = \frac{EP'}{r} \quad (12)$$

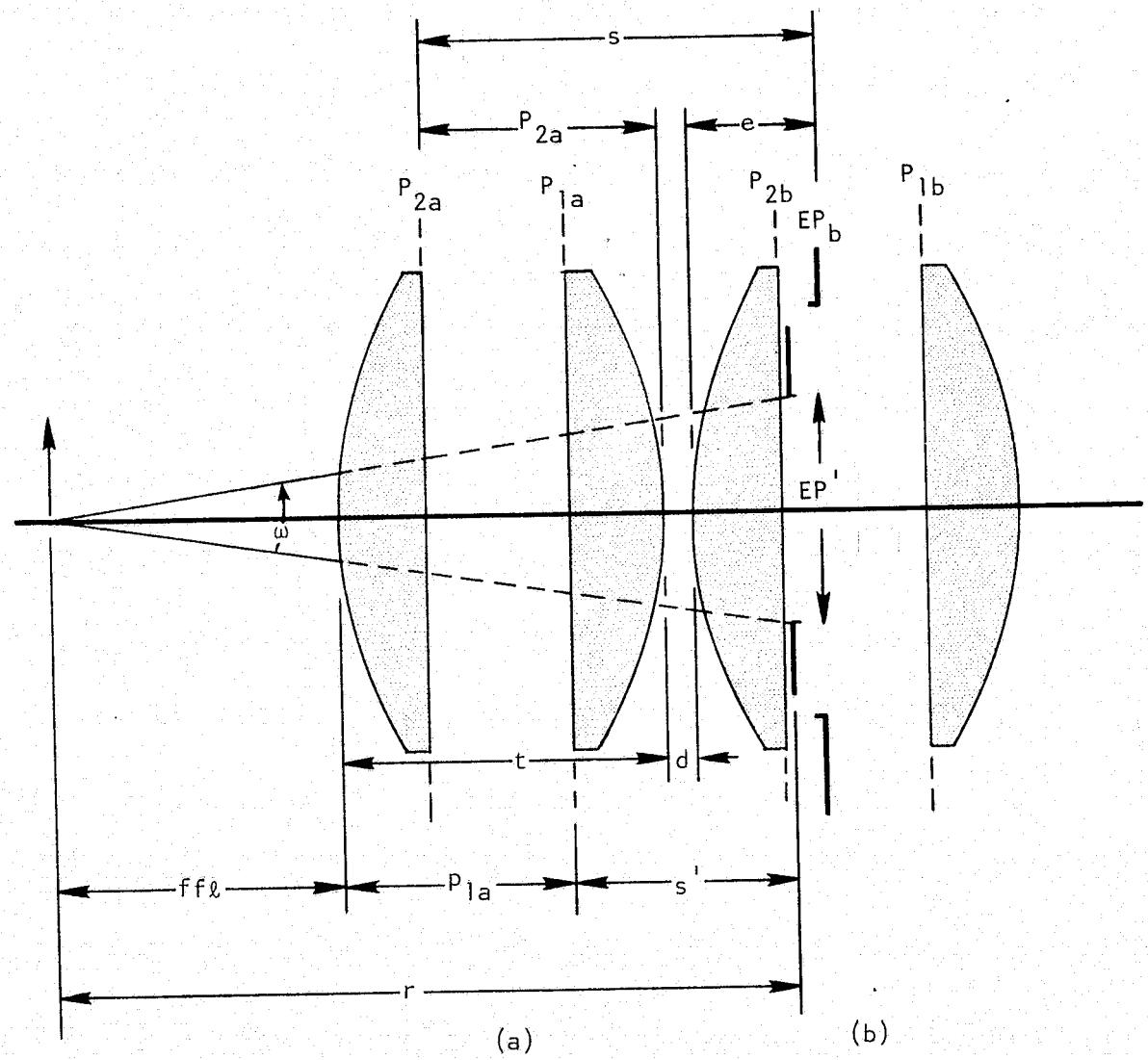
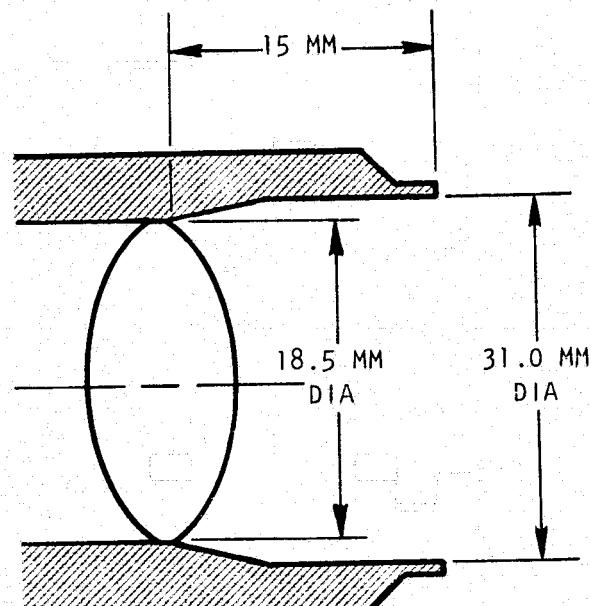
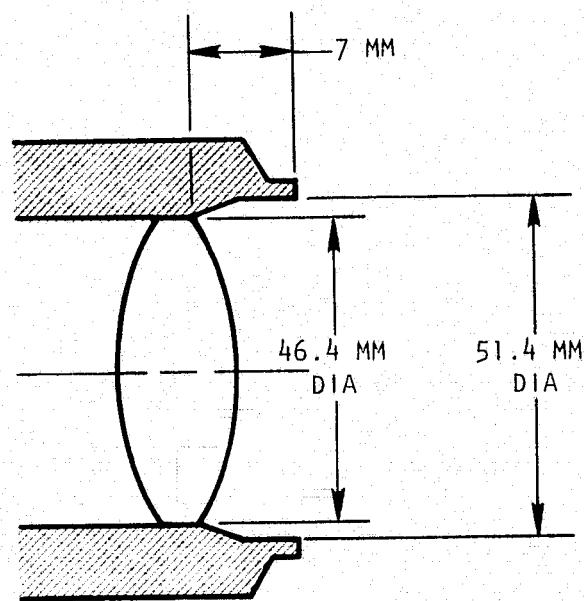


FIGURE 2



25 MM, f1.4 DAC LENS



55 MM, f1.2 NIKON LENS

FIGURE 3

where

$$EP' = EP_b \frac{s'}{s} \quad (13)$$

and

$$\frac{1}{s'} = \frac{1}{f_a} + \frac{1}{s} \quad (14)$$

From the figure,

$$s = e + d + P_{2a}$$

and

$$r = f f_1 + P_{1a} + s'$$

and

$$\frac{A}{A'} = \frac{f_a^2}{f_b^2} \quad (15)$$

In a practical case, the simplest procedure is probably to physically measure  $w$  on an optical bench and then apply Equation (10) directly.

Table 1 shows numerical results for two hypothetical combinations of a relay composed of two complex lenses.

E.B. Brown  
6/3/75

TABLE 1  
FOR TWO HYPOTHETICAL COMBINATIONS OF A RELAY COMPOSED  
OF TWO COMPLEX LENSES

Let the parameters be (referring to Figures 2 and 3):

	Combination (for 35 mm format)	Combination (for 16 mm format)
$f_a$	55 mm	55 mm
$f_b$	55 mm	25 mm
$ff_1$	43 mm	43 mm
$P_{1a}$	12 mm	12 mm
$P_{2a}$	22 mm	22 mm
$d$	10 mm	10 mm
$EP_b$	46 mm	18 mm
$e$	15 mm	7 mm
$T$	0.60	0.60
then		
$s$	47 mm	39 mm
$s'$	25.3 mm	23 mm
$r$	80.3 mm	78 mm
$EP'$	24.8 mm	10.6 mm
$\omega$	0.308 rad	0.136 rad
$\Omega$	0.075 sr	0.0145 sr
$A/A'$	1.0	4.84
$I/B$	0.045	0.042

## **APPENDIX D**

### **Test and Calibration Plan**

Contract Number NAS9-14401  
Perkin-Elmer Aerospace Division SPO 30348

TEST AND CALIBRATION PLAN  
FOR AN IMAGE INTENSIFIER/IMAGE CONVERTER CAMERA

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

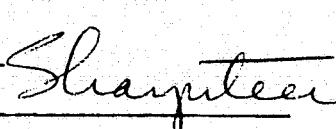
Lyndon B. Johnson Space Center  
Houston, Texas 77058

MAY 1975

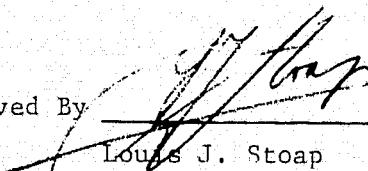
Prepared By

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James T. Sharpsteen  
Project Manager

Approved By

  
Louis J. Stoap  
Manager  
Photo-Mechanical Programs

## TEST AND CALIBRATION PLAN

### 1.0 Purpose

The purpose of this plan is to establish an approach and procedure outline for testing the brassboard for an image intensifier camera system being developed by Perkin-Elmer for NASA/Johnson Space Center.

### 2.0 Discussion

The purpose of the brassboard is to provide a vehicle for testing approaches, performance predictions, and conclusions arrived at in the trade-off analysis, Task 1 of the study. Since the design does not have strictly defined performance goals, this is not an acceptance test. Instead, it is intended to provide an approach to a testing program which will establish optimum combinations of variables for achieving best performance, as well as a means to test results and conclusions that were arrived at through analysis. Because of unknowns, the test plan is flexible, so that its direction can be changed or modified if necessary as results are obtained.

The test program will consist of two parts, laboratory test, and field test. Tests in the laboratory will allow separation of input and system variables, both for measuring performance, and for determining optimum combinations. Tests in the field, using typical scenes under typical conditions, are the only way to determine the real capabilities of the system.

As an approach to planning the laboratory tests, Table 1 examines the variables that can be manipulated singularly and in combinations. Three are scene variables, while the other three are system variables. Obviously tests of all combinations is neither necessary nor practical.

### LUMINANCE

The first and most significant scene variable is luminance, since this is related directly to the primary purpose of the camera. The test luminance will range from the goal for minimum scene level to the maximum recommended intermittent light level for the image intensifier,  $10^{-9}$  to  $10^{-5}$  candela/cm<sup>2</sup> ( $3 \times 10^{-6}$  to  $3 \times 10^{-2}$  foot-lamberts). Tests under variable luminance levels will provide an opportunity for system calibrations, as well as for determination of optimum combinations of exposure times and intensifier gains.

Results will be evaluated both by photometry and film. Photometric measurements will be by photodiode and brightness spot meter. Film density will be determined with the Perkin-Elmer Microdensitometer. Film type will not be a variable unless test results indicate that the type chosen by analysis does not perform as well as expected and that another type might be better suited.

Illumination will be broadband, determined by the output of the ten inch luminance standard. An opal glass window at the three inch opening will establish a uniform brightness at a known object position. Combinations of uniform neutral density filters and a step filter will establish light levels for input to the brassboard. The Microdensitometer will establish film densities and "shades of gray" for combinations of luminance values and system variables, from which will be established optimum settings for the tests which follow.

Table I  
RELATION OF TEST VARIABLES TO TEST PLAN

Variables	SCENE			SYSTEM		
	Luminance	Spectrum	Geometry and Contrast	Exposure	$I^2$ Gain	Film
Achieved By:	Neutral Density Filters	Spectral Filters	Test Patterns and Targets	a. Camera Shutter b. $I^2$ Gating	Varying Screen Voltage	Selecting Optimum Film
Objective of Test:	Calibration & Useable Operating Range	Verify Spectral Range	Distortion and Limiting Resolution	Compare Methods and Determine Optimum Values	Determine Optimum for Various Conditions	Verify Choice of Film
Anticipated Test Range:	$10^{-9}$ to $10^{-5}$ Candela/cm <sup>2</sup> ( $3 \times 10^{-6}$ to $3 \times 10^{-2}$ foot-lambert)	350nm min. 930nm max.	max. 25 lp/mm	.001 to 5 sec.	1 Decade (max. to 1/10 max.)	1 Type Only
Test Equipment and Material Required:	Luminance Std. Opal Glass N.D. Filters Step Filter	Same; Plus Spectral Filters	Luminance Std. and Light Box, Targets and Grid	a. None b. Gated Power Supply	Variable Voltage Power Supply	Kodak 2485 Film
Evaluation Method:	a. Photometry b. Film (Density)	a. Photometry b. Film (Density)	a. Film (Distortion) b. Film (Resolution)	Film (Density)	a. Photometry b. Film (Density) c. Film (Resolution)	Observe General Performance in Tests with Film
Instrumentation:	a. Sensor b. Micro-densitometer	a. Sensor b. Micro-densitometer	a. Visual Evaluation b. Micro-densitometer	a. Visual Evaluation b. Micro-densitometer	a. Sensor b. Micro-densitometer	a. Visual Evaluation b. Micro-densitometer

## SPECTRUM

The variable luminance tests, in abbreviated form, will be repeated for two narrow frequency bands, close to the expected extremes of wave length over which the image intensifier is expected to perform (350 and 930 nanometers). This test will roughly establish the limits of useful wave length for the brassboard.

## GEOMETRY AND CONTRAST

Distortion and resolution will be measured by photographing illuminated test patterns and targets. Resolution will be measured by inserting targets in series with the neutral density filters in the set up for luminance tests. Variables will include luminance level and high and low contrast targets. Results will be measured on the film both by visual examination and with the Microdensitometer. Because the three inch opening in the luminance standard will have a diameter on the film of about 1/3 of the available field of the 25mm image intensifier, the set up for luminance tests will not be suitable for determining distortion. Since precise control of luminance will not be required for this measurement, an 8" x 10" light box with suitable attenuation will be used to illuminate a glass test grid. Distortion will be determined from the film, using the Microdensitometer.

## FIELD PHOTOGRAPHY

The results of the laboratory tests will be used to determine the best combination of system variables for tests in the field. Field test plans will be kept flexible, and will be varied as required as results are obtained, in line with the developmental nature of the program. Night scenes will include photographs of the heavens, as well as terrestrial scenes under various conditions of natural illumination.

### 3.0 Equipment and Instrumentation

Luminance Standard      Photo Research Corporation  
(10" sphere-3" opening)

Brightness Spot Meter      Photo Research Corporation

Microdensitometer      Perkin-Elmer Corporation  
Model 1010A

Photo-Diode

Precision  
Neutral Density  
Filters (3), 50mm Squ. Glass  
Densities: 1.0, 2.0, 4.0  
(0.1% transmission accuracy at 550nm)

Step Neutral  
Density Filter  
21 steps; Densities:  
.05 to 3.05

Interference Filters (2)  
Approximately 400 nm  
and 850 nm center frequencies.  
50mm Squ. Glass

Optical Bench

Test Targets (2)  
(USAF Tri Bar)  
High contrast and low contrast

Light Box "8" x "10"

Test Pattern  
(grid)

Film, type 2485      Kodak

## 4.0 Procedure

### A. Luminance

1. Set-up the luminance standard at one end of the optical bench, on axis with the bench.
2. Set the luminance standard for 39.0 foot-lamberts (its lowest calibrated value).
3. With the brightness spot meter at the position on the bench to be occupied by the brassboard (no less than 2 feet from the luminance standard), measure the output of the luminance standard.
4. Place the opal glass in front of the opening of the luminance standard, and increase the output of the standard until the same reading is obtained as in step 3.
5. Attenuate the output of the luminance standard with neutral density filters, in steps of approximately one decade from  $3 \times 10^{-6}$  to  $3 \times 10^{-2}$  foot-lamberts. With a photodiode installed at the film plane in the camera, make a measurement at each luminance level with full gain on the image intensifier tube. Repeat at several lower gain values down to one-tenth maximum gain. Use this data to construct system calibration curves (output versus scene luminance for each gain setting).
6. Set up the brassboard on the optical bench, focus the lens, and expose film for each input light level of step 5. The tube gain and shutter exposure time should be varied at each level if necessary to give optimum results. The analysis from the Task 1 report plus the data from step 5 should help in finding the best gain setting for each condition. The step filter should also be used at least once at each luminance level to assist in establishing best combination of gain and exposure values.
7. Develop film for maximum speed, (exposure Index 8000), in accordance with Kodak instructions.
8. Make density measurements on the film using the Microdensitometer.
9. Evaluate performance, and establish guide lines for determining optimum combinations of image intensifier gain and camera exposure for different luminance levels.

### B. Spectrum

1. During step A-6 above, repeat exposures at maximum luminance using interference filters to roughly establish the upper and lower cutoff wavelengths for the system. The interference filters should be selected in conjunction with the spectral curve for the lamp.
2. Repeat B-1 above at reduced luminance values (down to minimum value for which meaningful results are obtained).

3. Develop film.
4. Make density measurements.
5. Determine approximate cutoff wavelengths for useful system performance.

#### C. Resolution

1. During step A-6, repeat exposures at maximum and minimum luminance with high and low contrast USAF targets in place after the N.D. filters. For each combination of luminance and contrast, make one exposure at maximum gain/minimum exposure, and another at minimum gain/maximum exposure.
2. Develop film.
3. Determine resolution by visual evaluation, and with the Microdensitometer.
4. Evaluate resolving capabilities of the system for combinations of variables (luminance/gain/exposure), and compare with the analytical predictions of Task 1.

#### D. Distortion

1. Using the brightness spot meter for correlating luminance levels, set up the light box with N.D. filters and the test grid.
2. Photograph the grid, using full gain, and with exposure time compatible with the light level from the box.
3. Develop the film.
4. Analyze system distortion using the Microdensitometer.

#### E. Exposure Control

1. During tests where exposure time is a variable, make some tests both with the shutter and with screen voltage gating. Compare results.