

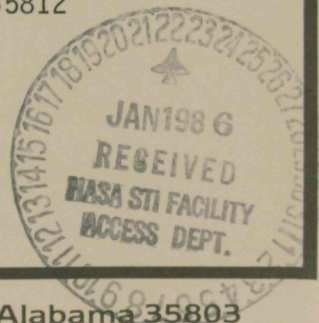
Radiometrics, Inc.

STAR FIELD SIMULATOR FINAL REPORT

October 31, 1985

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Prepared For
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 National Aeronautics and Space Administration
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1 INTRODUCTION

This report covers the efforts of Radiometrics, Inc. for the National Aeronautics and Space Administration (NASA) under Contract Number NAS8-35803 in providing a Star Field Simulator to serve as a source of radiation for the ASTRO Star Tracker.

1.1 Background

The star tracker and simulator are components of a motion compensation test facility located at Marshall Space Flight Center in Huntsville, Alabama. Preflight tests and simulations using various levels of guide stars will be performed in the test facility to establish performance of the motion compensation system before being used in a flight environment.

The ASTRO Star Tracker operates over a wide dynamic range of irradiance corresponding to visual stellar magnitudes of -0.8 to 8. A minimum of three simulated guide stars with variable magnitudes are needed to fully test the Star Tracker performance under simulated mission conditions.

1.2 Objectives

The objectives of this effort were to design and build a star field simulator that would:

- Provide sources of collimated light to simulate natural guide stars
- Provide three simulated stars arranged in a triangular pattern within the field of view of the tracker with angular separations of approximately 30 arc seconds
- Provide independent magnitude adjustment for each star from -0.8 to 8 visual magnitude
- Provide separate monitors for each simulated star's brightness that can be calibrated in visual stellar magnitude
- Provide a collimated beam approximately 8 inches in diameter with a beam divergence of 4 microradian
- Have the light sources and collimator mounted in separate packages with fiber optics cables connecting the sources to the collimator.

2 DESCRIPTION

2.1 Light Source

The Star Field Simulator has three independent light sources mounted in an enclosure separated mechanically from the collimator unit to divide the mass of the equipment and remove the heating effects from the area of the collimator optics. Figure 1 is a photograph of the Control Unit. The power supply and lamps are contained in this package.

Each source consists of a tungsten lamp, color temperature correcting filter, condenser lens, LCD display and a neutral density filter wheel. Lamp voltage is varied with a multi-turn control mounted on the front panel. The electrical control provides a range of adjustment equivalent to approximately a 10 to 1 change in brightness of the simulated stars. Three neutral density attenuating filters and one open position are provided by the manually operated filter wheels. The filter wheels provide transmittances of 0.001, 0.01, 0.1 and 1. The combined effects of the electrical adjustment and the attenuating filters produce an output adjustment corresponding to visual star magnitudes of -0.8 to 8.

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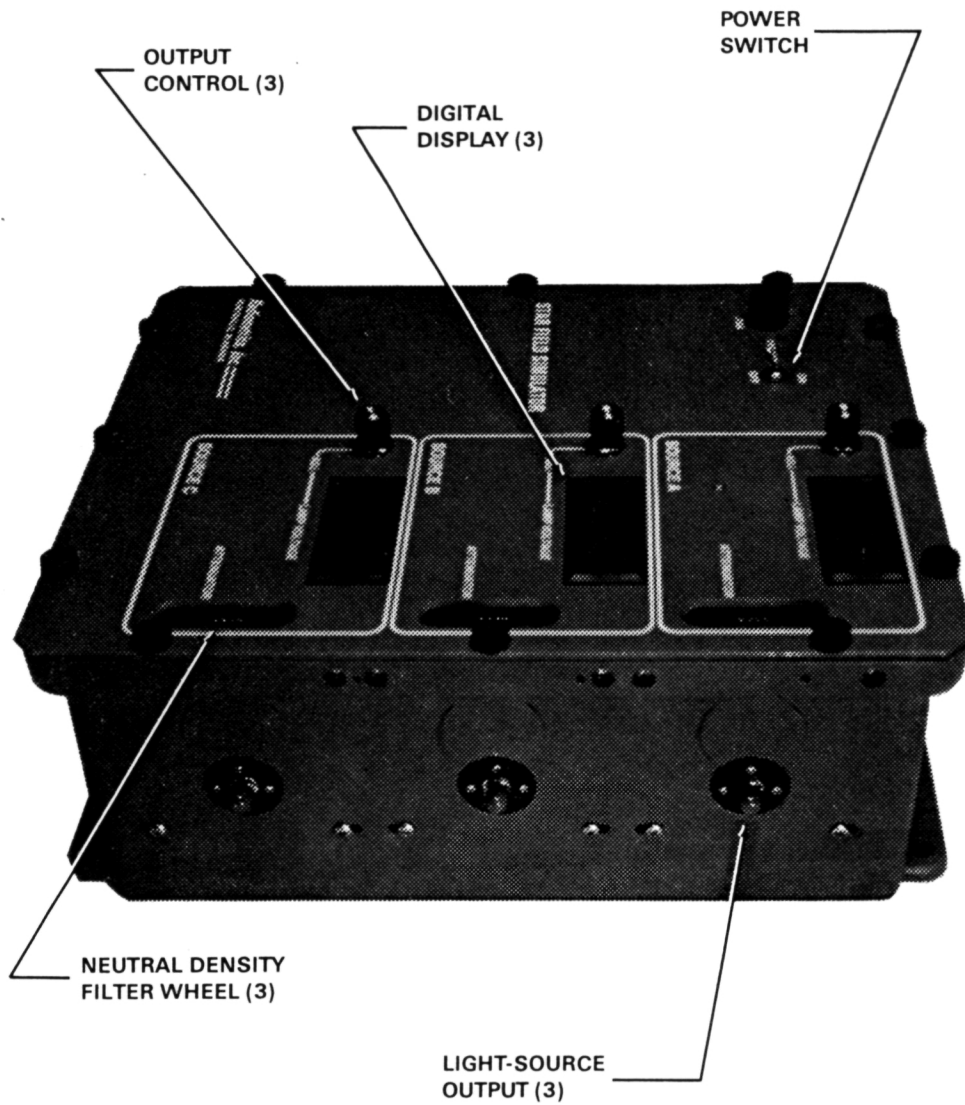


FIGURE 1. STAR FIELD SIMULATOR CONTROL UNIT

The lamps, condenser lenses, attenuating filters and displays are mounted in a common enclosure along with the dc power supply. The enclosure is light tight to prevent stray light from escaping into the room.

2.2 Collimator

Figure 2 is a schematic diagram of the light source and collimator optics. The collimator is a Newtonian configuration with a plane diagonal secondary and an $f/6$ paraboloid primary. The simulated stars are pinholes 5 microns in diameter located in the focal plane of the collimator. One pinhole is on the optical axis, two more are located off axis to form a triangular pattern. The angular separation is approximately 30 arc seconds between pinholes.

2.3 Fiber Optics

Each light source is coupled to the collimator by a fiber optics cable approximately four feet long. The fiber cable has a single fused quartz core 50 microns in diameter. The output end of the fiber is mounted directly behind the pinhole to provide uniform illumination of the 8-inch primary mirror. The fiber cables are terminated at the input end with Amphenol screw-on connectors for convenient attachment to the light source module.

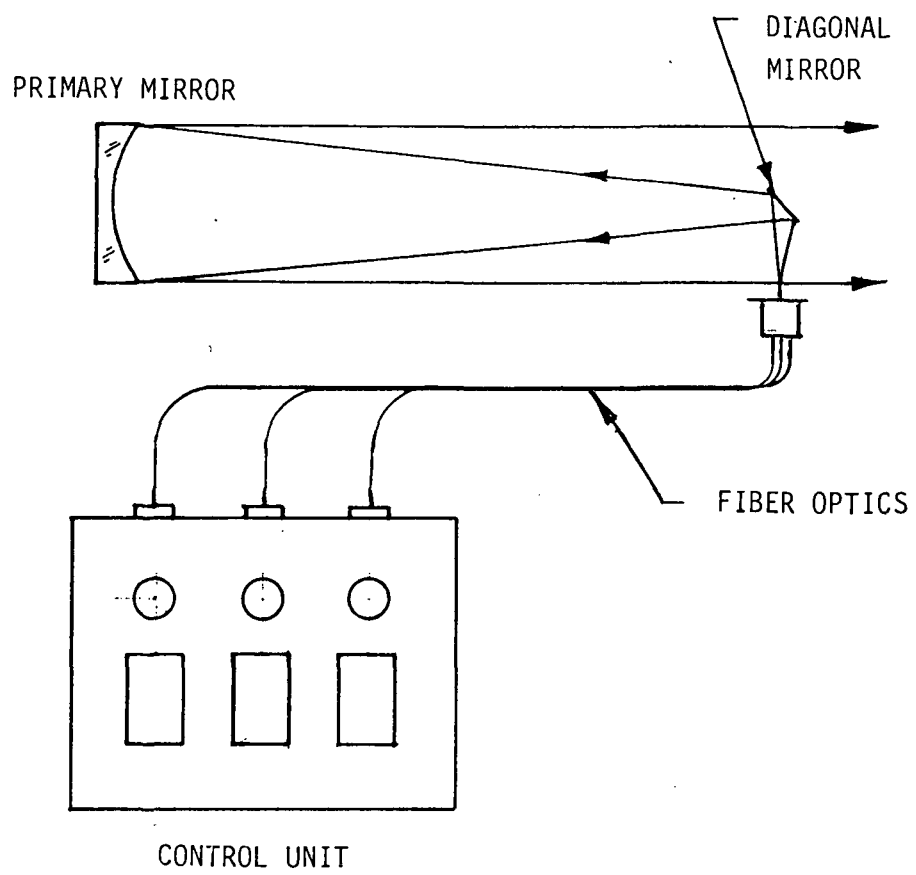


Figure 2. Schematic diagram of simulator.

2.4 Output Control

Star magnitude adjustment is provided by multi-turn controls located on the Control Unit. Each lamp has a separate control and LCD display that permits precise settings of the collimator light output. Calibration data consisting of simulated star magnitude versus display reading is provided with the simulator. Tables 1 through 3 contain the calibration data supplied with the instrument.

Figure 3 is an electrical schematic of the simulator showing the lamps, dc power supply, multi-turn controls and the digital voltmeter modules. All the electrical components are located in the light source unit.

3 TECHNICAL DISCUSSION

3.1 Initial Requirements

Initially the Star Field Simulator was designed to produce a collimated beam of light with an angular divergence of one milliradian or less. The simulator's objective was an $f/2.2$ achromat 110 millimeters in diameter. The polished ends of the fiber optics interconnecting cables were positioned in the focal plane of the objective lens to provide the simulated star illumination. The fiber optics cables were single fiber fused

TABLE 1. SOURCE A CALIBRATION DATA.

DATE 3-20-85

VOLTS	OPEN	ND1	ND2	ND3
4.96	6.6	9.1	11.6	14.1
4.5	7.1	9.6	12.1	14.6
4.0	7.6	10.1	12.6	15.1
3.5	8.2	10.7	13.2	15.7
3.0	8.9	11.4	13.9	16.4
2.5	9.9	12.4	14.9	17.4
2.0	11.3	13.8	16.3	18.8

TABLE 2. SOURCE B CALIBRATION DATA.

VOLTS	OPEN	ND1	ND2	ND3
4.97	7.7	10.2	12.7	15.2
4.5	8.1	10.6	13.1	15.6
4.0	8.6	11.1	13.6	16.1
3.5	9.2	11.7	14.2	16.7
3.0	9.9	12.4	14.9	17.4
2.5	10.7	13.2	15.7	18.2
2.0	11.9	14.4	16.9	19.4

TABLE 3. SOURCE C CALIBRATION DATA.

VOLTS	OPEN	ND1	ND2	ND3
4.96	6.4	8.9	11.4	13.9
4.5	6.9	9.4	11.9	14.4
4.0	7.4	9.9	12.4	14.9
3.5	8.0	10.5	13.0	15.5
3.0	8.6	11.1	13.6	16.1
2.5	9.5	12.0	14.5	17.0
2.0	10.7	13.2	15.7	18.2

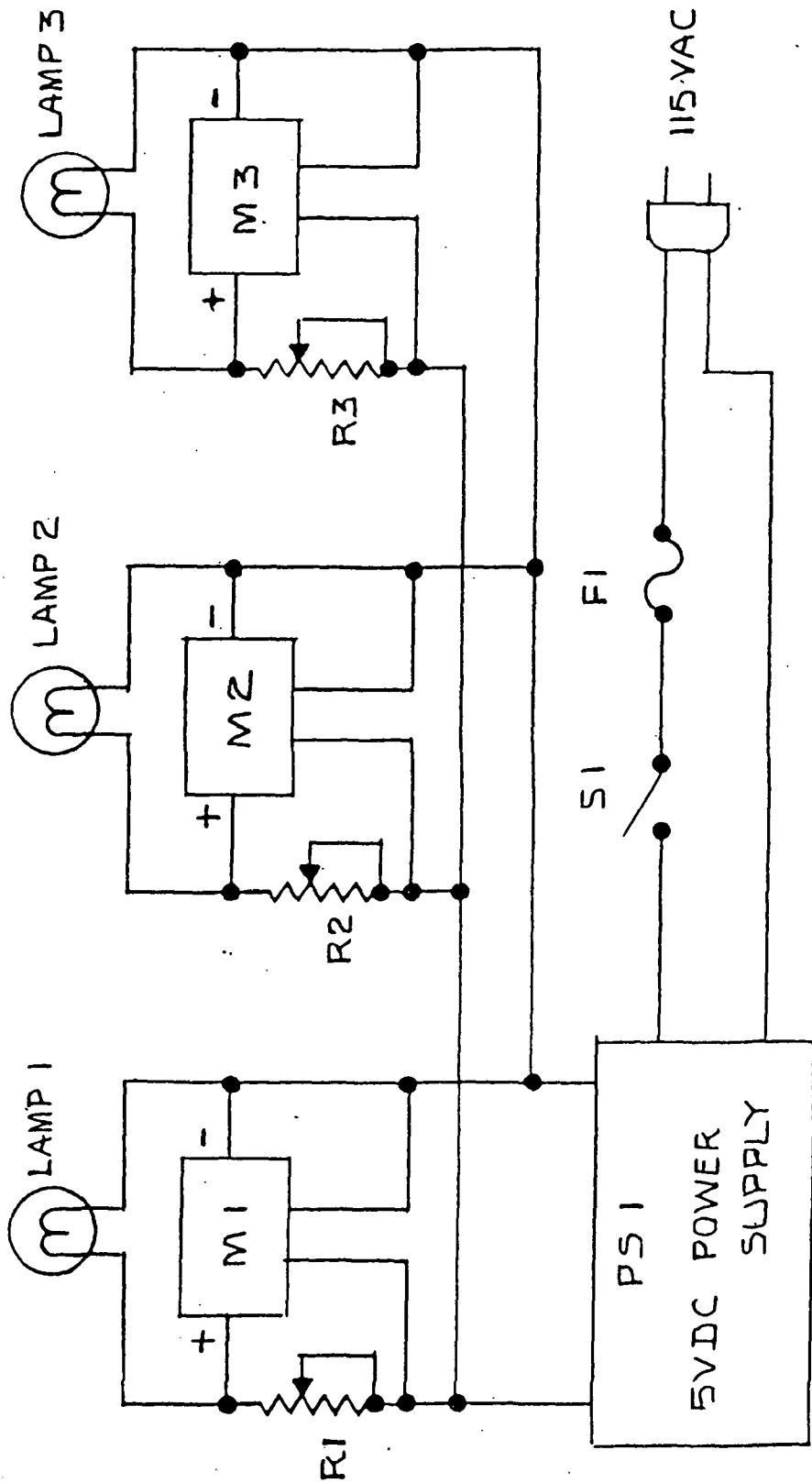


Figure 3. Electrical schematic diagram.

quartz cores 50 microns in diameter. The core diameter and the objective lens produced a theoretical beam divergence of approximately 0.2 milliradian. This configuration was assembled, tested and delivered to MSFC for evaluation and check out with the star tracker. After receiving the simulator MSFC learned that the ASTRO Star Tracker was extremely sensitive to image spot diameters and the simulator's image of 0.2 milliradian was much too large to serve as guide stars if maximum performance was required of the star tracker.

A new specification was generated by MSFC that called for an 8-inch diameter collimator with a beam divergence of 0.85 arc second for the simulated stars. The Contract with Radiometrics was modified to include these specifications plus the addition of color temperature correcting filters to simulate source temperatures between 5000 and 7000 degrees Kelvin.

3.2 Final Configuration

The original refractive collimator was replaced with an 8-inch diameter reflective system consisting of a plane mirror and a paraboloid arranged in a Newtonian telescope configuration. The light sources in the focal plane of the collimator were changed from the output ends of single 50 micron fibers to 5 micron pinholes illuminated by the fibers. Each lamp assembly required a condensing lens to concentrate more light onto the fiber optics

cable. To shift the lamp's spectrum toward blue wavelengths, color temperature correcting filters were used between the lamps and the fiber optics cable.

4 CALIBRATION

4.1 Equipment and Facilities Required

The following equipment is needed to calibrate the the Star Field Simulator. Calibration should be performed in a room where ambient lighting can be reduced to near darkness to reduce the background light contribution to the readings.

1. One tungsten lamp, 12 watt, 12 volts or equivalent with electrical socket and mount.
2. One regulated AC or DC power supply capable of producing 1 ampere at 12 volts.
3. One positive lens with a focal length of approximately 250mm. (f-number not critical).
4. One lens holder to accommodate the lens selected.
5. One iris diaphragm or aperture with an opening of 3 to 6 millimeters in diameter.
6. One calibrated photopic detector, UDT, PIN-10AP or equivalent.
7. One 2.2 megohm resistor.
8. One digital voltmeter, Beckman, Model 3030 or equivalent.
9. One high sensitivity photometer, EG&G Model 585 with photopic filter or equivalent.
10. One neutral density filter with optical density of 2.0.

11. One workbench or table approximately 8 feet long.
12. A source of 115 vac, 60 Hz power with at least four 3-wire receptacles.
13. One 6-foot tape measure.

4.2 Procedure

4.2.1 Radiometer Photopic Calibration

1. Set up the calibrated photodiode and related test equipment as shown in Figure 4.
2. Turn on the lamp and set the voltage to 12 volts.
3. Set the voltmeter to read 200 millivolts full scale.
4. Read and record the voltmeter reading.
5. Remove the photodiode and set up the EG&G Model 585 Radiometer with photopic adapter's input aperture positioned at the focal plane of the auxiliary lens L1.
6. Record the Model 585 photometer reading.

$$i = \underline{\hspace{2cm}} \text{ amps.}$$

7. Calculate the calibration factor for the Model 585 photometer using the expression

$$K = \frac{i R_1}{2.73 V_P}$$

$$= \frac{0.366 i R_1}{V_P} \text{ amps/fc.}$$

Substituting 2.2×10^6 ohms for R_1 produces

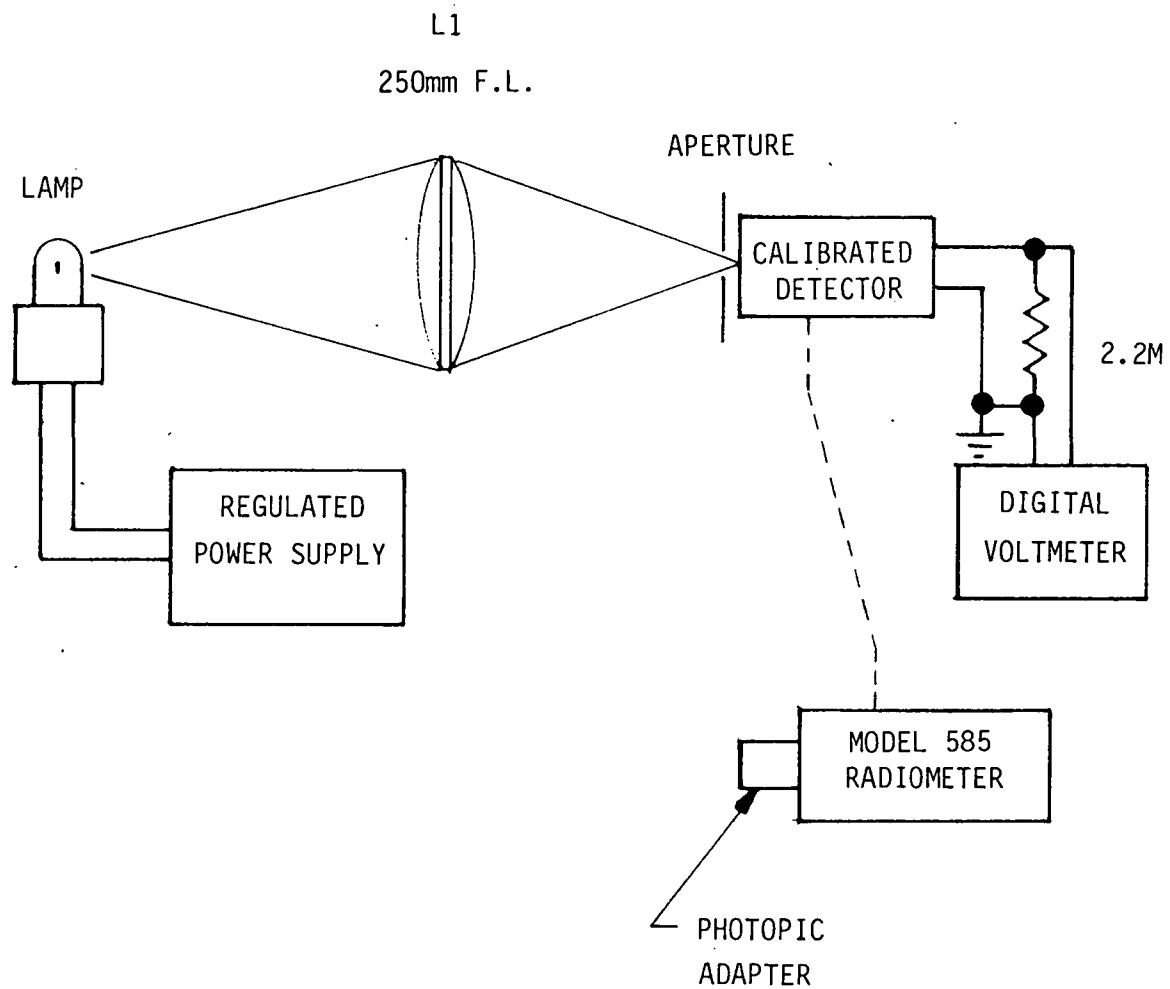


Figure 4. Photopic calibration of radiometer.

$$K = \frac{8.05 \times 10^5 i}{V_P} \quad \text{amps/ft.}$$

Illuminance is related to the Model 585 current reading, i_1 by the expression

$$E_V = \frac{i_1}{K} \quad \text{lumen/ft}^2$$

or equivalently

$$= \frac{10.76 i_1}{K} \quad \text{lumen/m}^2.$$

Express E_V in visual stellar magnitude by using a zero magnitude star having an illuminance E_{V0} of 2.65×10^{-6} lumen/m² as a reference. (Ref. RCA Electro Optics Handbook, p66). Illuminance produced by the collimator can be expressed in terms of visual stellar magnitude using the expression

$$m = -2.5 \log \frac{E_V}{E_{V0}}$$

where m is the visual magnitude corresponding to E_V .

8. Set up the equipment as shown in Figure 5. Use a diagonal mirror and an 8-inch or larger primary mirror with known reflectivities.
9. Turn on the Control Unit and radiometer and allow 5 to 10 minutes for the equipment to stabilize.
10. Set the Source A ND filter wheel to the OPEN position.
11. Set the Source A electrical control to maximum.

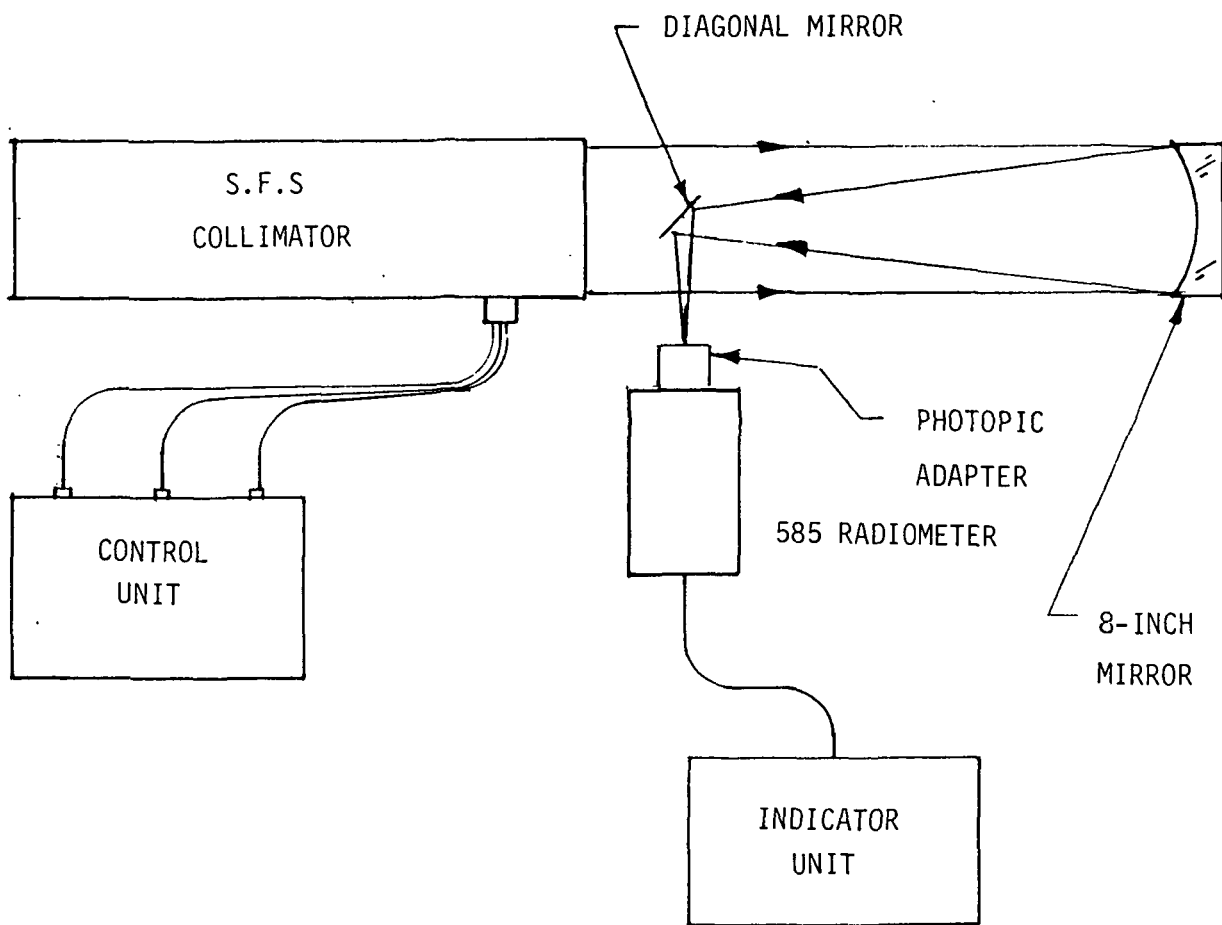


Figure 5. Collimator output calibration.

12. Record the digital display and Model 585 radiometer readings.
13. Using the electrical control reduce the display reading to 4.50 and record the radiometer and display readings.
14. Continue to reduce the display reading in 0.5 volt steps until the display reads 2.00. Record the display and radiometer readings at each step.
15. Repeat Steps 10 through 14 using Sources B and C.

4.2.2 Neutral Density Filter Calibration

1. Using the equipment setup in Figure 5, set the filter wheel of Source A to OPEN.
2. Record the radiometer reading, i_0 .
3. Set the ND filter wheel of Source A to 1.0 and record the radiometer reading, $i_{1.0}$.
4. Calculate the optical transmittance of the ND 1.0 filter by using the expression

$$T_{1.0} = \frac{i_{1.0}}{i_0}.$$

5. Set the ND filter wheel to 2.0 and record the radiometer reading, $i_{2.0}$. Calculate the optical transmittance of the ND 2.0 filter by the same method used in Step 4.
6. Set the ND filter wheel to 3.0 and record the radiometer reading. Calculate the optical transmittance of the ND 3.0 filter as in Steps 4 and 5.
7. Set the Source A electrical control for a minimum reading on the display.
8. Repeat Steps 1 through 7 using Sources B and C.

5 CONCLUSIONS AND RECOMMENDATIONS

The Star Field Simulator in its final configuration met all the design objectives, except for the maximum brightness of -0.8 visual magnitude. When the collimator diameter was increased to 8 inches and the beam divergence reduced from 0.2 milliradian to 4 microradian, the losses associated with transferring light from the lamp to the collimator were too great to reach the desired upper limit of brightness. By using the most powerful lamps available, within the current capacity of the power supply, and adding condenser lenses to the light sources, the goal of -0.8 visual magnitude was still not achieved.

Two approaches are available for a relatively simple solution to this problem.

1. Replace the present power supply with one that has a higher current capacity. With more power available the lamps may be changed to increase light output. This is straight forward, but the result is more heat dissipated inside the Control Unit.
2. Replace the lamps with a commercially available point source assembly supplied by Oriel Corporation which has the lamp, condenser optics and a focusing lens included in

a small package. The point source produces a concentrated spot of light with high brightness that can be efficiently coupled to the fiber optics cable. The present power supply capacity is adequate to operate three point sources. The present lamp and condenser assembly would need to be replaced with the point source assembly.

The second approach is preferable because light transfer to the fiber cables is efficient and the heat dissipated by the power supply and lamps within the Control Unit is held to present levels.

6 EQUIPMENT PARTS LIST

TABLE 4. MAJOR COMPONENT PARTS LIST

ITEM	QTY	DESCRIPTION	MFG	P/N
1	3	Resistor, Variable, 100 ohms	Bourns	3540S-1-101
2	3	Digital Panel Meter	Texmate	PM-35X
3	1	DC Power Supply, 5V, 1.2A	Condor	AS-1.2/OVP
4	3	Lamp, Tungsten	Sylvania	7335
5	1	Fuse Holder	Littlefuse	342012A
6	1	Switch	C&K	U11P3HZQ
7	3	Connectors, Fiber Optic	Amphenol	9051105005
8	3	Connectors, Fiber Optic	Amphenol	9051205000
9	1	Mirror, Diagonal	Edmund	D32135
10	1	Mirror, Paraboloid, f/6	Edmund	D32129
11	3	Lens, Condenser	Rolyn	11.0013
12	3	Filters, Color Temp,	Mel.Griot	FG-3
13	3	Pinholes, 5um	Mel.Griot	04PIP003