GONIOPHOTOMETER TO MEASURE DIFFUSION CHARACTERISTICS OF REAR PROJECTION SCREENS

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FOREWORD

This research represents a portion of the exploratory development program of the Technical Training Branch, Training Research Division of the Behavioral Sciences Laboratory. The research was documented under Project 1710, "Training, Personnel and Psychological Stress Aspects of Bioastronautics," Task 171007, "Automated Training and Programed Instruction." Dr. Gordon A. Eckstrand was project scientist. Dr. Ross L. Morgan was task scientist. The work was performed in part under Contract AF 33(615)-2348, by the University of Dayton Research Institute, Dayton, Ohio. The work was initiated in December 1964 and completed in October 1965.

Among the many individuals who contributed to this study, particular appreciation is expressed to William J. Hovey of the University of Dayton Research Institute, for the design of the photometer.

This technical report has been reviewed and is approved.

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ABSTRACT

A goniophotometer has been developed for use in measuring the diffusion characteristics of rear projection screen materials. Rear projection screens provide a wide range of possible diffusion characteristics. Similarly, different applications require different characteristics. The goniophotometer will facilitate the selection of screens most suitable for a particular application. Primary components of the device include a light tight chassis, a light source mounted on an arm which can be rotated ± 60°, a holder for screen specimens, a specifically designed photometer, and two interior ambient light panels and associated interior foot candle meters. Schematics, wiring diagrams, and drawings necessary for the fabrication of additional units are included.

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SECTION I

INTRODUCTION

The rear projection screen has proved to be one of the most popular and useful devices in modern visual presentation systems. However, there is very little quantitative diffusion data available describing the rear projection screen materials. As with other elements of a projection system, such as lamps, lenses, and projectors, additional engineering data are needed to write definitive specifications of a new projection system. This lack of performance specifications, especially for rear projection screen materials, poses a special problem in the design and development of new projection systems.

Rear projection screens provide a wide range of possible diffusion characteristics. Similarly, different applications require different characteristics. Thus, if it is possible to develop precise descriptions of the diffusion characteristics of different types of screens, it will be easier to choose the screen most suitable for a particular application. The goniophotometer was developed to measure the diffusion characteristics of different types of rear projection screens and thereby facilitate the specification of screens most suitable for particular applications.

SECTION II

GENERAL DESCRIPTION OF THE GONIOPHOTOMETER

The goniophotometer, figure 1, consists of a baffled, light-tight chassis, 183 by 122 by 50 cm (72 by 48 by 19-1/2 inches), a film strip projector as a light source, a holder for the screen specimens, a specially designed photometer, an arm which can be turned ± 60 degrees on which the projector is mounted, and two ambient light panels. One of the unusual characteristics of this goniophotometer is that the light source is enclosed in a light-tight chassis to control the ambient light falling on the back of the screen. Another unusual characteristic is that the light source, rather than the sensing head, is rotated. This provides for precise control and mechanical stability. In a practical situation, bend angle is a composite of projection angle and viewing angle and varies from point to point on the screen. In the laboratory, this is usually simplified. Systems rotating the sensing head approximate a situation in which the viewer observes the center of the screen from different angles; i.e., the projection angle is held normal while the viewing angle is varied. Rotating the light source, as is done here, approximates a viewer seated in front of a screen observing different points on the screen, i.e., the viewing angle is held normal while the projection angle is varied. In both situations, projecting onto the coated side of the screen minimizes specular reflection as a factor. One of the early investigations planned using the goniophotometer is the study of the comparability of the two methods of measurement. How does the light loss resulting from a 30-degree projection angle compare to the loss resulting from a 30-degree viewing angle and various combinations of 15-degree projection angles and 15-degree viewing angles?

The 6.35 by 10.15 cm (2-1/2 by 4 inch) screen specimen is inserted in a holder, figure 2, mounted at the center front of the chassis. The photometer is mounted 2.85 cm (1-1/8 inches) away from the screen specimen outside the chassis. For normal testing the photometer remains stationary, but provisions have been made for moving the photometer laterally across the screen. The projector is rotated on a radius of 69.85 cm (27-1/2 inches) to establish the bend angles, figure 3. This is accomplished by a rigid aluminum arm that is pivoted on the test sample plane. In this way, the light beam from the source, although rotated through various bend angles, remains centered on the same point of the test screen specimen.

For studies requiring ambient light behind the screen, light sources and light sensors are included within the chassis. The a.c. voltage to the system is stabilized by employing a constant voltage transformer.

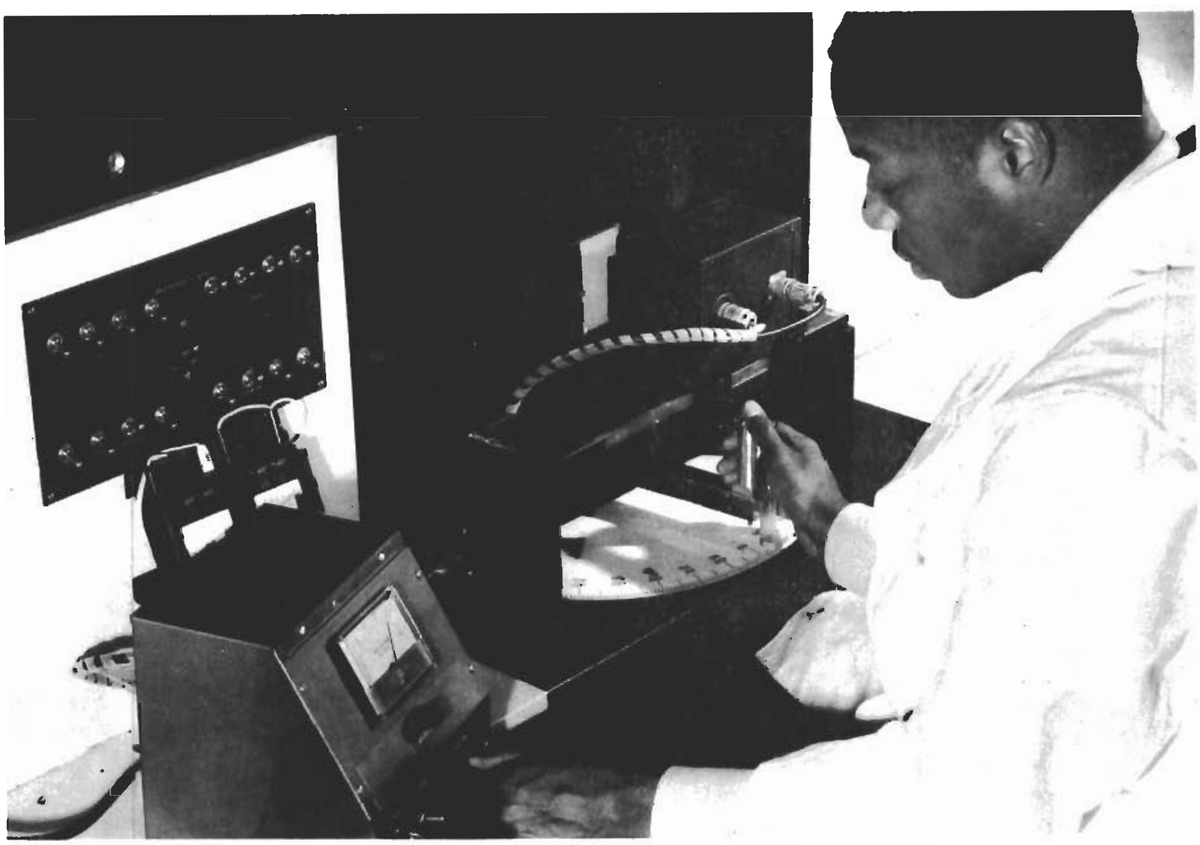


Figure 1. Front View of Goniophotometer

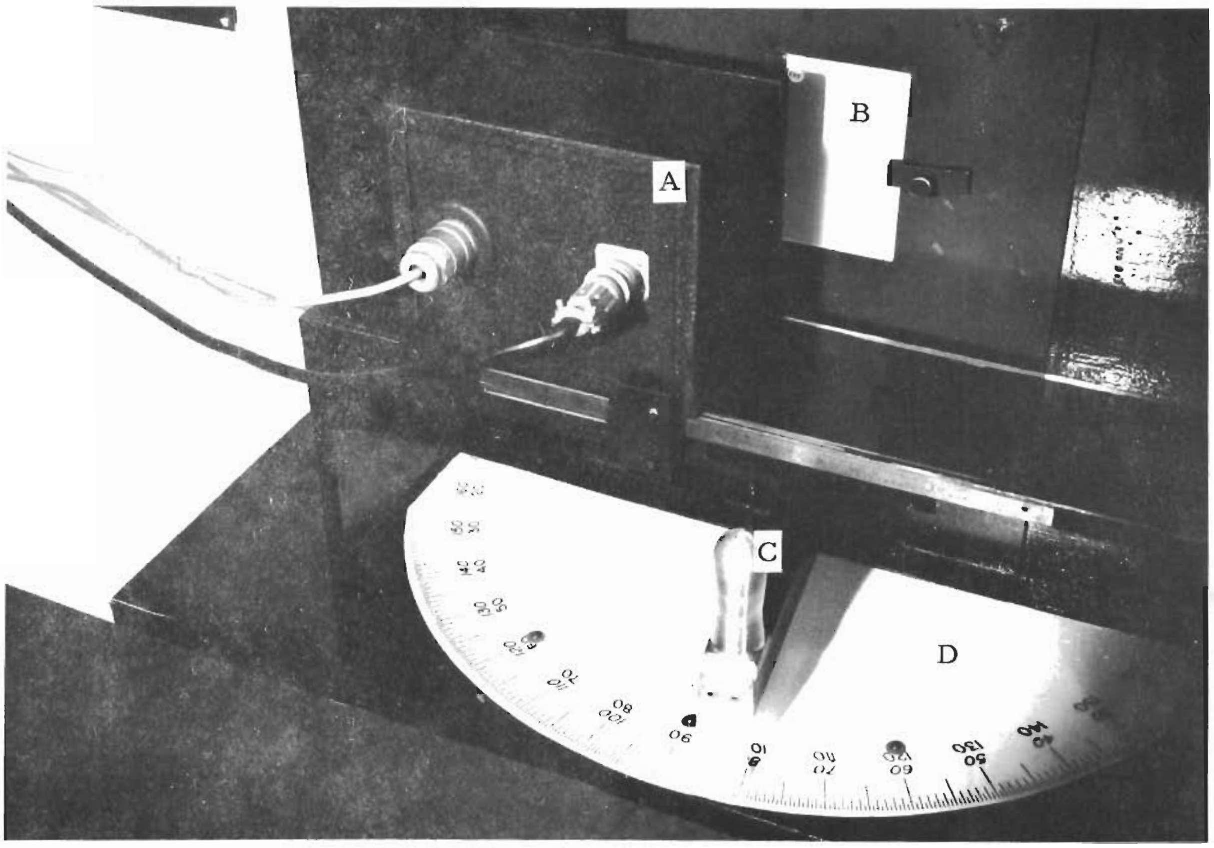


Figure 2. Closeup View of
(A) Photometer Photohead
(B) Screen Specimen
(C) Light Source Control Handle
(D) Protractor

(As shown, A has been moved to left to provide access to B.)

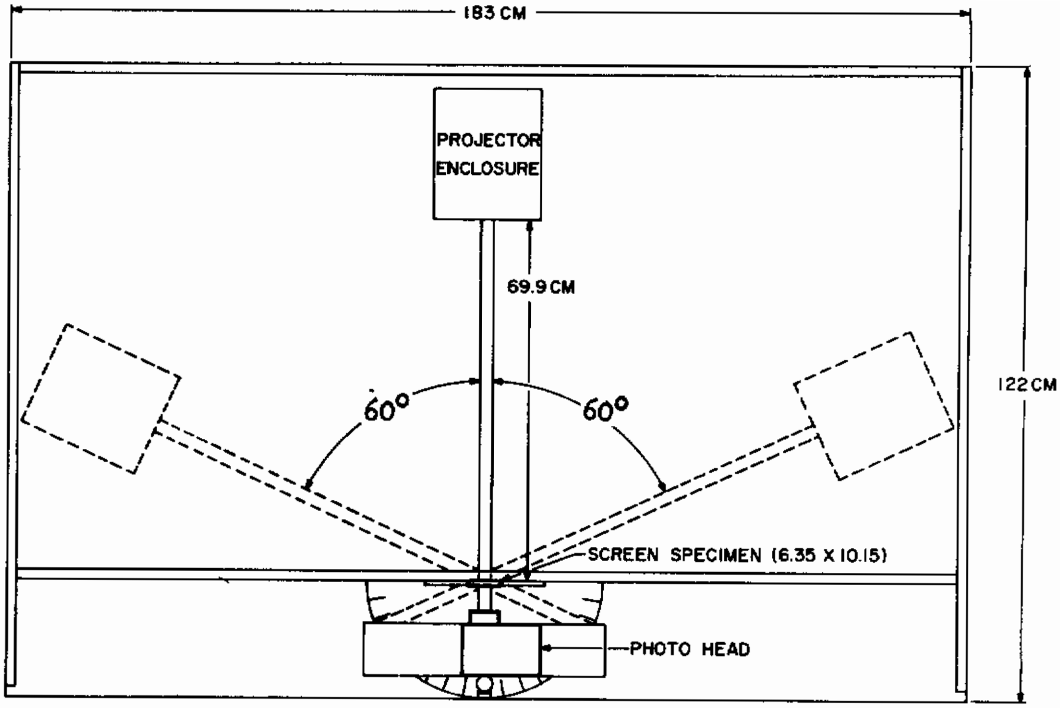


Figure 3. Top View of Goniophotometer Showing Range of Projector Movement

SECTION III

PHOTOMETER

The photometer is a special purpose light meter designed and built by the University of Dayton Research Institute for use in this goniophotometer system. The unit is designed for stable operation while reading a brightness range of 1.2 to 3600 foot lamberts.

The photometer is composed of two subunits, a photohead, and a power supply. The photohead, fig. 2, contains a 929 photo tube as the light sensing device and a 960 cps rotating-wheel light chopper. This light chopper produces an a.c. output signal whose magnitude is proportional to the light input. This feature makes the system immune to many of the stray light leakage and electrical drift problems of a d.c. system. In addition, the photohead contains a Wratten 106 filter in the optical system which, in conjunction with the S-4 response of the 929 photo tube, yields an overall spectral response that closely approximates that of the average human eye.

The power supply chassis, figure 4, contains the photo tube voltage supply and output signal amplifier as well as the system controls and indicators. The photohead and power supply are electrically connected by means of two shielded cables, one supplying power for the light chopper and the other for the photo tube.

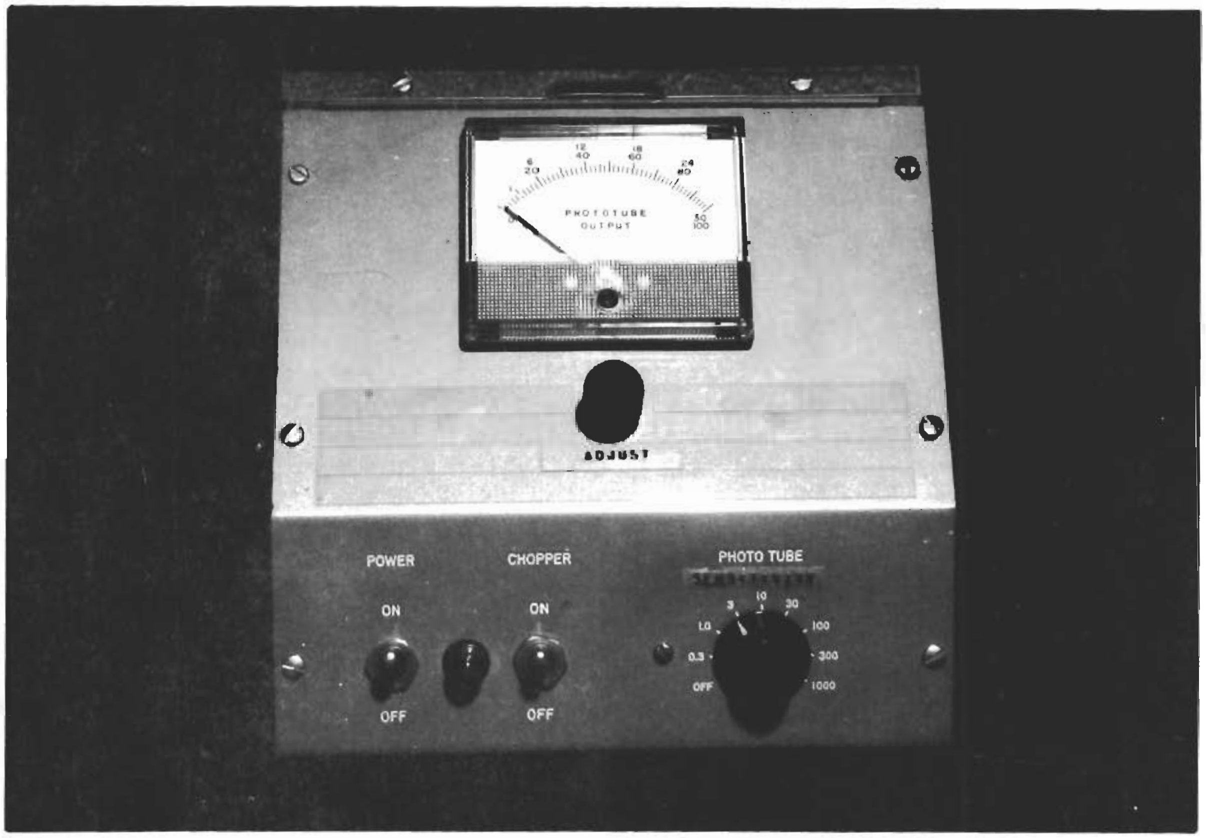


Figure 4. Photometer Power Supply

The control panel on the power supply chassis contains the output meter, two toggle switches, one nine-range rotary switch, an indicator light, and one potentiometer knob. The output meter is calibrated for relative magnitudes of 0 to 100 (or 0 to 30 using the top scale) using the rotary switch sensitivity setting which most nearly corresponds to the existing brightness level. The ranges are divided into a 1-3-10 arrangement to allow the use of the more accurate areas of the indicating meter. The sensitivity settings and maximum measurable brightness levels are listed in table I. Detailed operating instructions and a correction table to normalize data obtained from different sensitivity settings are given in appendix I. The meter does not read in absolute units, but rather in terms of relative ratios.

TABLE I. Sensitivity Setting vs Maximum Measurable Brightness

Sensitivity Setting	Maximum Brightness (Ft Lamberts)
0.3	3600.0
1.0	1200.0
3.0	360.0
10.0	120.0
30.0	36.0
100.0	12.0
300.0	3.6
1000.0	1.2

The FULL-SCALE ADJUST control is adjusted to allow a setting of 100 per cent for any light level. This affords normalized data and the direct reading of the percentage of peak of on-axis brightness available at any specified bend angle.

The mechanics of the light aperture in the photometer provides a 36-degree view angle. The photometer is mounted 2.85 cm (1-1/8 inches) from the screen specimen. This results in the photometer receiving light from a screen area approximately 1.9 cm (3/4 inch) in diameter.

SECTION IV

SPECIMEN ILLUMINATION SOURCE

The specimen illumination source is a film strip projector enclosed in a housing to control stray light from the projection bulb. This projector uses a CAR 150 watt true focus bulb with an internal reflector, a 3-inch f/3.0 lens, and includes remote control of film advance. A Graflex "Compact" projector was selected, since it is small yet gives a satisfactory light distribution. Any other projector with these characteristics, particularly the uniform light distribution, could be used in this goniophotometer.

As shown in figure 3, the projector is mounted on an arm which rotates to give bend angles up to ±60 degrees. Figure 2 shows the control handle and protractor used to set the projector at the desired bend angle. Using this photometer and projector setup, the quantity of light passing through the center of the screen can be measured for various bend angles. The photometer can be moved laterally across the screen to facilitate measurement of contrast ratio within a projected image.

The distance from the center of the projector lens to the screen is 69.85 cm (27-1/2 inches). For this distance the projected image is approximately 19 by 25.4 cm (7-1/2 by 10 inches). Since the test screen is 10.16 by 6.35 cm (4 by 2-1/2 inches) only the central uniformly illuminated position is utilized. The rotating arm is pivoted within 0.32 cm (1/8 inch) of the plane of the screen. Thus, the light beam from the source, although rotated through various bend angles, remains centered on the same point of the test screen specimen.

SECTION V

COSINE LAW APPLIED TO INCIDENT ILLUMINATION

When screen specimens are tested at different bend angles, there are two reasons for the change in light transmission. The first is due to the diffusion characteristics of the screen, while the second is caused by the variation in screen illumination due to the change in incident angle of the light beam. The first one is the only one of interest in determining screen specifications. The second one is due to the geometry of the system and is independent of the type of screen used.

With reference to this second or geometric characteristic, when a beam of light is perpendicular to a surface, the area illuminated is minimal and, hence, the illumination on any point is maximal. As shown in figure 5, the length of the projected image, and thus the area increases depending on the angle of incidence. This increase in area causes a decrease in illumination at any given point. Thus, since gain is defined as light output divided by light input, if the input to the screen is incorrectly assumed to be constant for different incident angles, the computed values of gain will be in error. This geometric variation in illumination can be corrected using Lambert's Cosine Law which states that the illumination on a surface is decreased in proportion to the cosine of the angle of incidence.

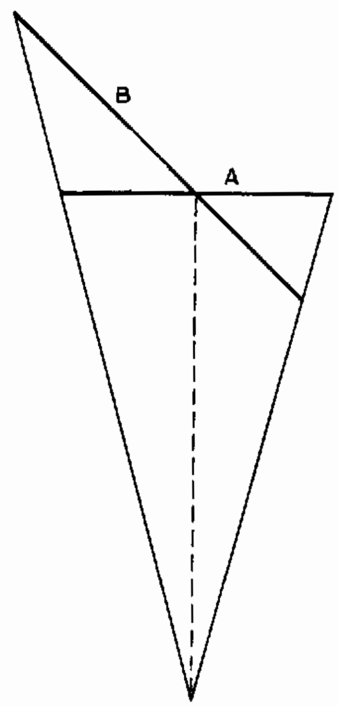


Figure 5. Projected Image Width for Light Beam Normal to the Surface (A) and for an unknown Incident Angle (B).

This variation in illumination is most significant for wide angle, low gain, screens. Figure 6 is a plot of data from a wide angle screen showing the data both before and after the cosine correction has been applied. The cosine correction is almost insignificant for high gain screens because of the small angles involved.

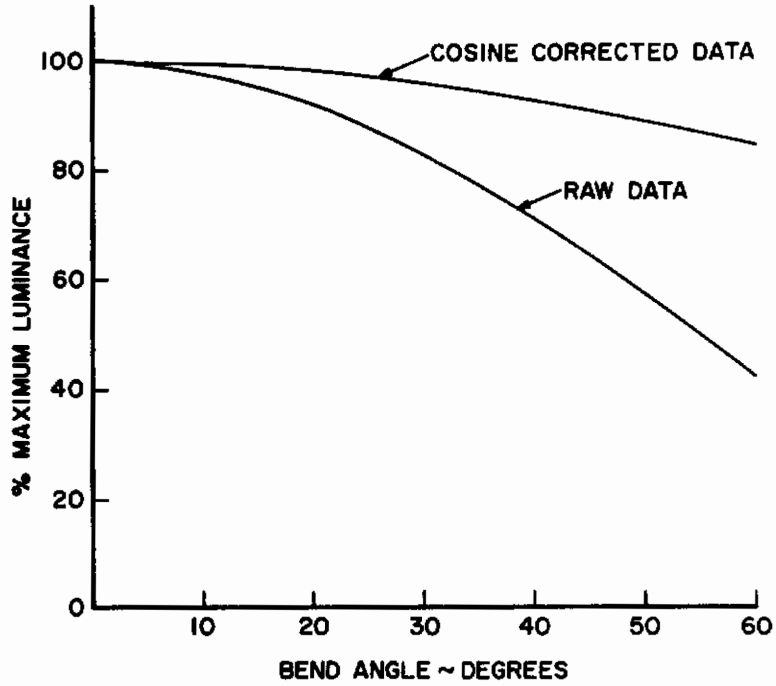


Figure 6. Sample Curve With and Without Cosine Correction

SECTION VI

AMBIENT LIGHT SOURCE

Some of the studies to be conducted with the goniophotometer in the evaluation of rear projection screens will require various amounts of light behind the screen. These studies will be related to the amount and location of stray light within enclosed systems, such as, individual study stations, the more complex group presentation systems where the projection systems are located in separate rooms, and to systems in which the projection area cannot be completely enclosed for light control.

For this reason two ambient light sources were included within the chassis. Each source consists of 15 light bulbs arranged in three banks of five as indicated in figure 7. A shield keeps the light from falling directly on the test screen and thus only scattered or highly diffuse light falls on the back of the test screen.

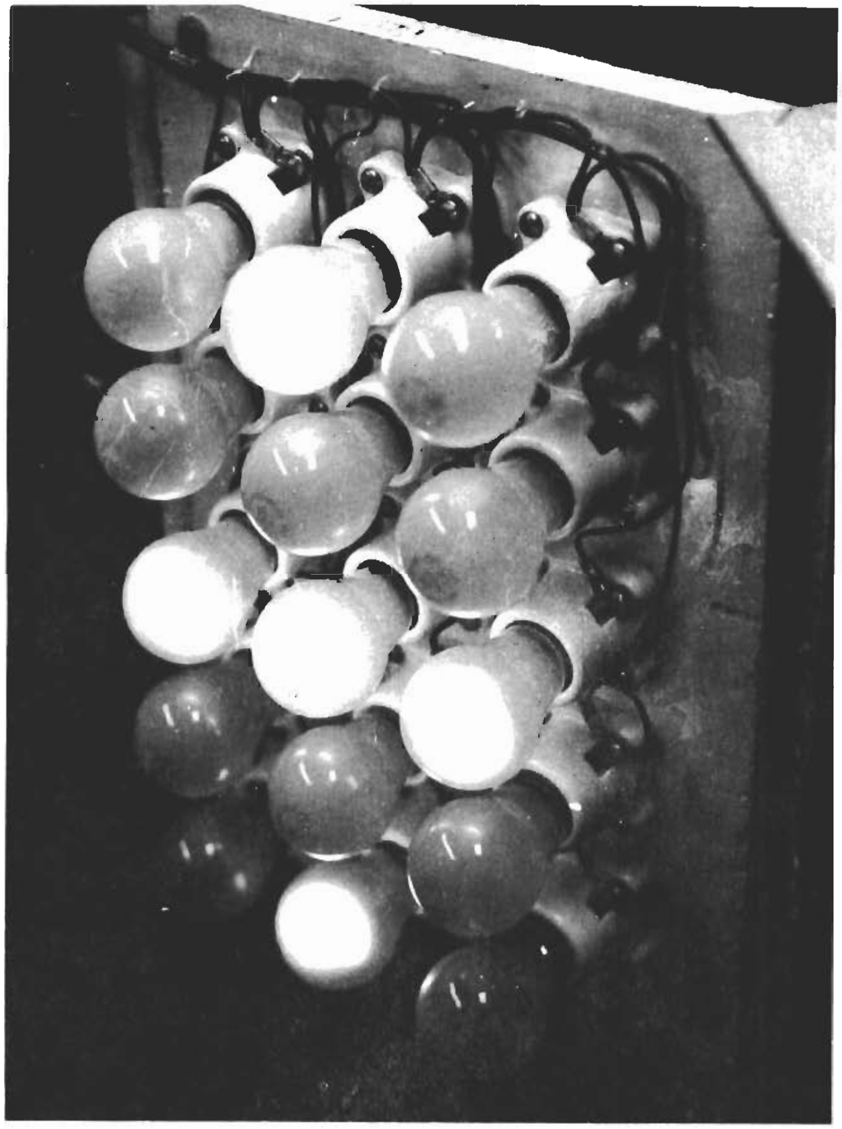


Figure 7. Ambient Light Source (Switches number 1 and 4 are closed).

The system was designed to be capable of simulating a wide variety of ambient light levels behind the rear projection screens. Thus, the ambient light level produced by the two light sources was designed to be changeable in the following ways:

(1) The light sources are wired using a binary system. Using different combinations of the four switches any number of lights from one to fifteen can be illuminated in each light source. They have been arranged in the order shown in figure 8 to give a uniform ambient light distribution even when the number of lights is varied.

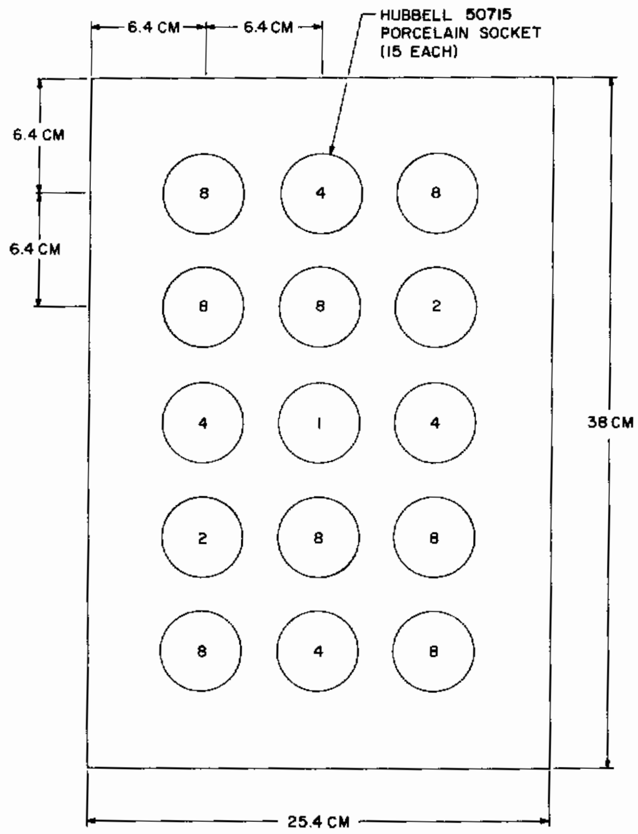


Figure 8. **Light Bank Spacing and Order of Illumination (the socket number indicates the switch which controls the lamp).**

(2) The input voltage to the light sources can be changed by means of a variable autotransformer to increase or decrease the lamp illumination.

(3) The inside surface of the chassis is black and thus reflects very little light. Reflecting surfaces can be inserted on the back and sides to reflect more light.

(4) The type of lamps can be changed to increase or decrease the total illumination.

Two Gossen foot-candle meters are included in the chassis to measure the level of interior ambient light. One is placed above the screen. The second is on the back wall, slightly off center.

The ambient light sources are wired on a separate circuit from the remainder of the goniophotometer for the purpose of obtaining a better voltage regulation. (See figure 11 in Appendix III.)

A small exhaust fan provides circulation to remove the heat from the projector and the ambient light sources.

APPENDIX I

PHOTOMETER OPERATING INSTRUCTIONS

An amber light is connected to the main ON-OFF switch and indicates that the power is ON. The CHOPPER switch controls the light chopper in the photohead. The FULL-SCALE ADJUST control is a potentiometer which allows a setting of 100 per cent for any light level. The nine-position selector switch labeled PHOTO TUBE SENSITIVITY is essentially a sensitivity range selecting switch.

To successfully operate the photometer, follow the ten steps listed below:

1. All switches on OFF.

2. FULL-SCALE ADJUST and PHOTO TUBE SENSITIVITY knobs at full counterclockwise.

3. Plug into 115v, 60-cycle outlet.

4. Power switch ON.

   NOTE: Allow 15 minutes to warm up if critical measurements are required; otherwise, allow 30 seconds.

5. Chopper switch ON. Allow 5 seconds for speed to stabilize.

6. Insert the test screen specimen in the specimen holder. Place photohead in position to measure light aperture directly in front of center of screen specimen. Adjust the light source to the 90-degree position so the full-scale lighting conditions exist.

7. Slowly rotate the PHOTO TUBE SENSITIVITY switch through increasing ranges until a meter reading greater than 30 (0 - 100 scale) is obtained. If the meter reading exceeds 100, back up until reading is between 30 and 100.

8. Calibrate the meter by turning the FULL-SCALE ADJUST knob in a clockwise direction until the meter reads exactly 100.

9. The instrument is now adjusted for the base line conditions (screen and light source at normal angle equals 100%).

   CAUTION: To avoid a change in calibration, do not change the FULL-SCALE ADJUST knob position until ready to recalibrate for the next screen specimen.

10. Perform the experiment as required; each meter reading represents a percentage of the base line value. If the meter drops below a reading of 30 or exceeds 100, change the PHOTO TUBE SENSITIVITY switch one step. Table II contains a listing of the correction factors for the eight reading ranges of the PHOTO TUBE SENSITIVITY switch. All meter readings are taken from the 0 - 100 scale. The 0 - 30 scale is used for approximations only.

TABLE II. Correction Table to Normalize Data Obtained from Different PHOTO TUBE SENSITIVITY Settings

100% Sensitivity Setting

Reading Sensitivity Setting	1000	300	100	30	10	3	1	0.3
1000	1.00	0.30	0.10	0.030	0.01	0.0030	0.001	0.0003
300	3.33	1.00	0.33	0.10	0.033	0.01	0.0033	0.001
100	10.0	3.00	1.00	0.30	0.10	0.030	0.01	0.0030
30	33.3	10.0	3.33	1.00	0.33	0.10	0.033	0.01
10	100	30.0	10.0	3.00	1.00	0.30	0.10	0.030
3	333	100	33.3	10.0	3.33	1.00	0.33	0.10
1	1000	300	100	30.0	10.0	3.00	1.00	0.30
0.3	3333	1000	333	100	33.3	10.0	3.33	1.00

Table II is used to normalize data that are obtained from different range settings during a given experiment. The table is used in the following manner:

(1) Enter the table by going to the column that is headed by the sensitivity setting for which the original 100% calibration point was established.

(2) Go down that column to the row that is labeled by the sensitivity setting in effect when the reading was taken. This locates the correction factor.

(3) Multiply the instrument reading (0 - 100 scale) by the correction factor obtained in step 2. This corrected reading represents the per cent of light present relative to the original 100 per cent level.

A representative data sheet is presented below to provide an example of the use of Table II. In the illustration, calibrating the device by setting the normal axis reading to 100% required the use of sensitivity setting 3.0. As the light source was rotated to -35 degrees, it was necessary to increase the sensitivity to a setting of 10. Further rotation required a further change to 30. At this level, a final reading of 43 was obtained. Entering Table II in the column labeled 3 and going down to the row labeled 30 indicates a correction factor of 0.10. Thus, the reading represents a light level that is 0.10 x 43 or 4.3% of the original reference level. Carrying the example further, the cosine correction for this angle (60 degrees) is 2.000. The corrected light level at a 60-degree bend angle for this screen specimen is 8.6% of that obtained on the normal axis. It will be noted that a similar value was also obtained at 60-degree rotation in the opposite direction.

GONIOPHOTOMETER DATA SHEET-MRHTM

Sample No. 680 Material [illegible]

Technician J. [illegible] Date 12-2-65

Plot No. ______ Noise Level ______

half st.: 67½°-112½°

Bend	Ang.	Reading	Sensitiv. Set	Factor	% Output	Cosine Correct.	Cor. Out.		
30	-60	43	[illegible]	.10	4.30	2.000	2.60		
35	-55	[illegible]	[illegible]	.10	[illegible]	1.743	[illegible]		
40	-50	[illegible]	30.0	.10	[illegible]	1.556	[illegible]		
45	-45	59	10.0	.10	[illegible]	1.414	[illegible]		
50	-40	76	10.0	.20	16.20	1.305	[illegible]		
55	-35	[illegible]	10.0	.20	23.40	1.221	[illegible]		
60	-30	21	3.0	1.0	[illegible]	1.155	[illegible]		
65	-25	43	3.0	1.0	43.00	1.103	[illegible]		
70	-20	[illegible]	3.0	1.0	57.00	1.064	[illegible]		
75	-15	[illegible]	3.0	1.0	72.00	1.035	[illegible]		
80	-10	87	3.0	1.0	[illegible]	1.015	[illegible]		
85	-5	[illegible]	[illegible]	[illegible]	[illegible]	1.004	[illegible]		
90	-0	100	3.0	1.0	100.00	1.000	100		AV.
95	+5	[illegible]	3.0	1.0	[illegible]	1.004	[illegible]	96.38	96.38
100	+10	87	3.0	1.0	[illegible]	1.015	82.31	88.31	88.31
105	+15	73	3.0	1.0	73.00	1.035	[illegible]	74.52	75.04
110	+20	[illegible]	3.0	1.0	[illegible]	1.064	[illegible]	61.71	61.71
115	+25	44	3.0	1.0	44.00	1.103	48.53	47.43	47.98
120	+30	32	3.0	1.0	32.00	1.155	36.96	35.81	36.38
125	+35	[illegible]	10.0	.20	23.40	1.221	28.57	28.57	28.57
130	+40	56	10.0	.30	[illegible]	1.305	[illegible]	21.92	21.92
135	+45	[illegible]	10.0	.20	12.00	1.414	16.97	16.54	16.75
140	+50	[illegible]	30.0	.10	2.70	1.556	[illegible]	13.38	13.46
145	+55	62	30.0	.10	6.20	1.743	[illegible]	10.81	10.81
150	+60	43	30.0	.10	4.30	2.000	2.60	2.60	8.60

APPENDIX II

DETAILED SKETCHES OF GONIOPHOTOMETER

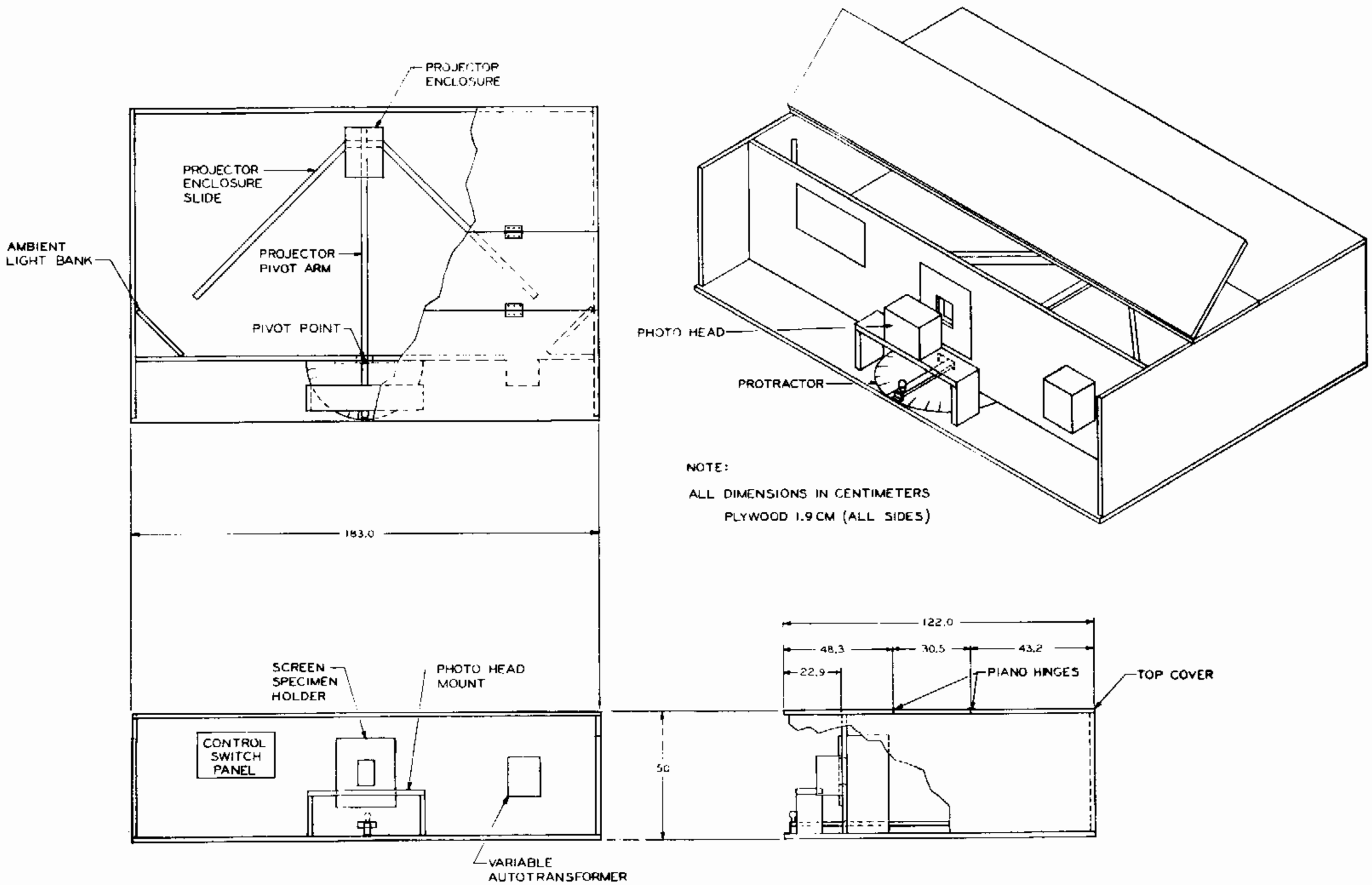


Figure 9. Front, Side, Top, and Overall Views of Goniophotometer

APPENDIX III

SCHEMATICS OF THE PHOTOMETER AND GONIOPHOTOMETER

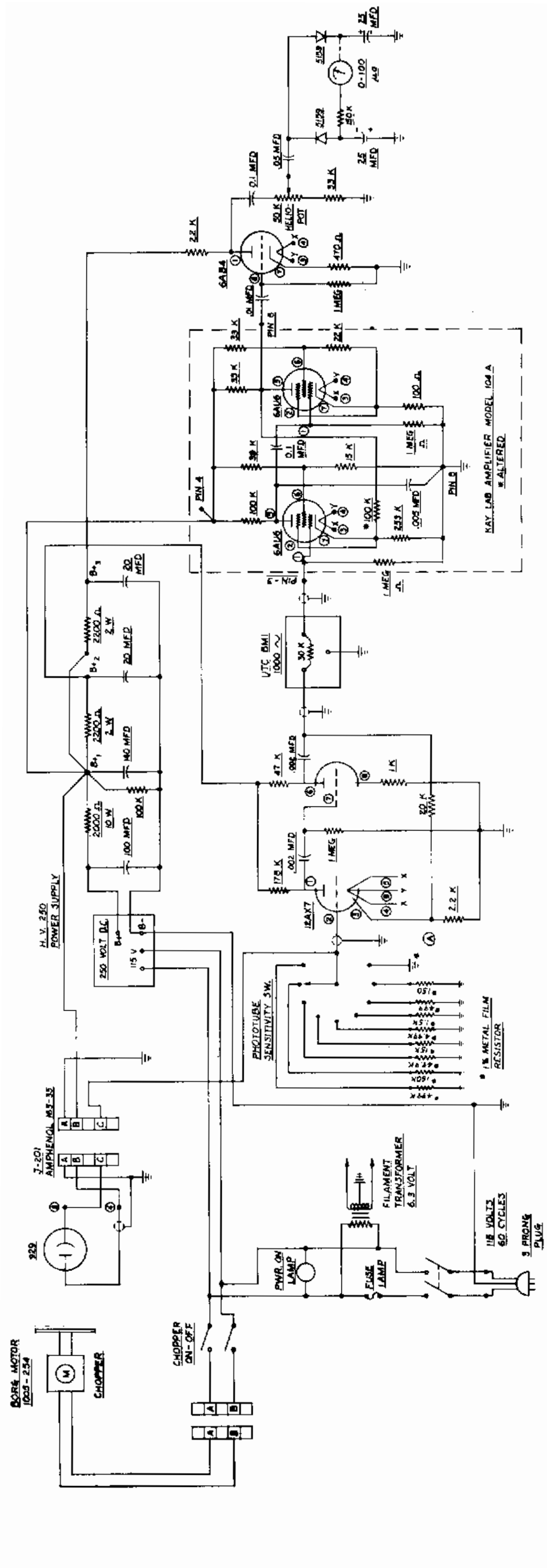
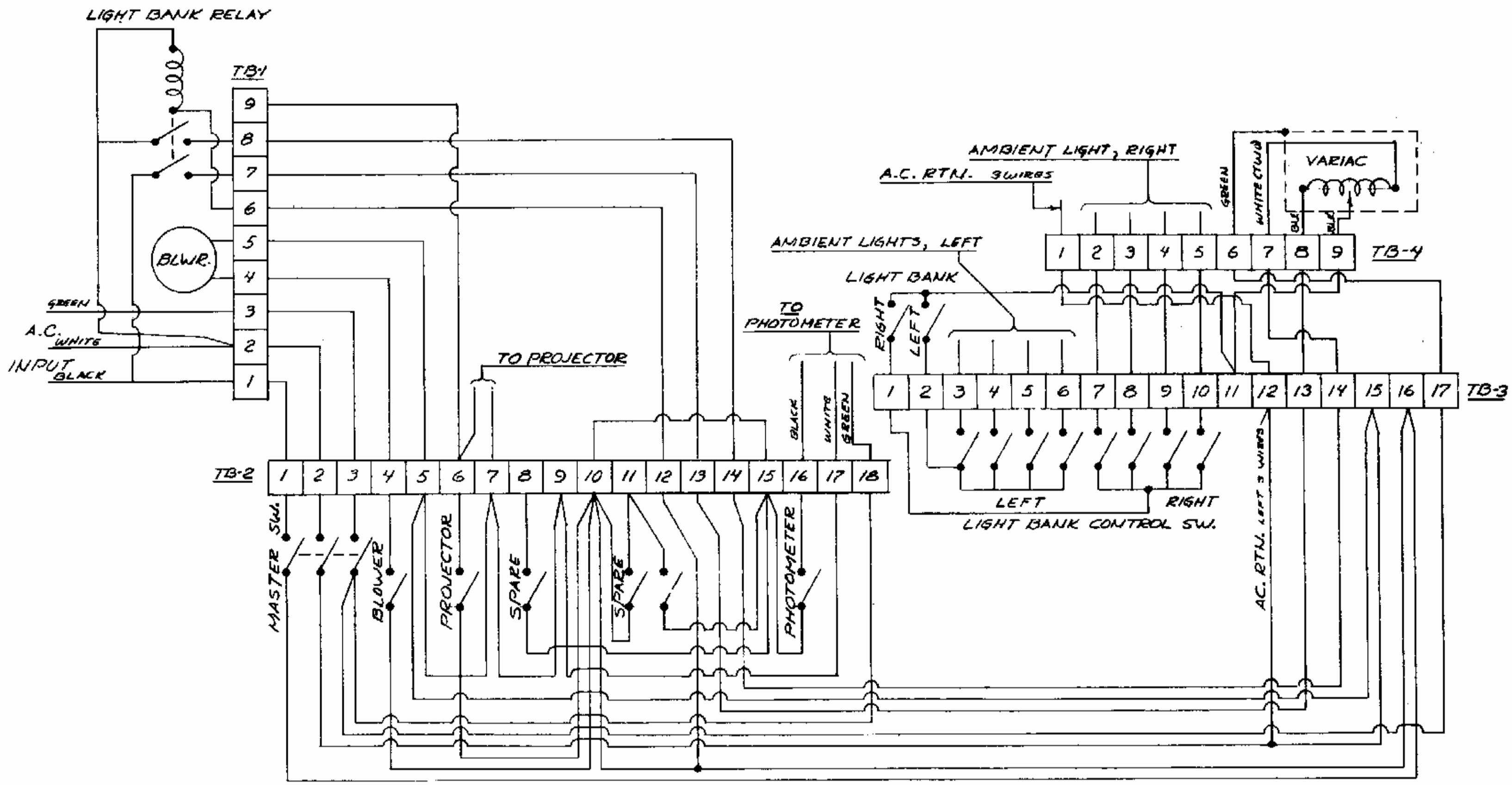


Figure 10. Photometer Wiring Diagram



NOTE: Each light control switch controls 1, 2, 4 or 8 lamps.

Figure 11. Goniophotometer Wiring Diagram

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13. ABSTRACT

A goniophotometer has been developed for use in measuring the diffusion characteristics of rear projection screen materials. Rear projection screens provide a wide range of possible diffusion characteristics. Similarly, different applications require different characteristics. The goniophotometer will facilitate the selection of screens most suitable for a particular application. Primary components of the device include a light tight chassis, a light source mounted on an arm which can be rotated ±60°, a holder for screen specimens, a specifically designed photometer, and two interior ambient light panels and associated interior foot candle meters. Schematics, wiring diagrams, and drawings necessary for the fabrication of additional units are included.

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