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DESIGN AND CONSTRUCTION OF A LOW FREQUENCY MTF CAMERA

by

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ABSTRACT

A low frequency Modulation Transfer Function Camera has been designed and constructed. Areal sinusoidal targets are imaged through a cylindrical lens and an objective lens to form transmission sinusoidal images. Modulation is changed by varying the background illumination. The range of available frequencies is from .3 to 30 cycles per millimeter, and the modulations available are 25, 33, 44, 55 and 64%.

ROCHESTER INSTITUTE OF TECHNOLOGY
Department of Photographic Science
and Instrumentation

May 16, 1975

Why does bg illum reduce contrast?
Because density is logarithmic, not a linear function.

INTRODUCTION

The objective of this thesis was to design and construct a low frequency Modulation Transfer Function (MTF) camera. The basic consideration for the design of the camera was to image low frequencies, which allows the study of edge effects due to processing which are inherent at low frequencies. As such, the camera will be especially useful for studying the chemical effects in graphic arts film.

In the past, there have been two methods employed at the Rochester Institute of Technology to measure the MTF of photographic materials: a mathematical generation of the MTF from an edge trace, and contact printing transmission sinusoids onto photographic materials. The MTF camera is designed to image an areal sinusoidal target through a cylindrical lens which will smear the areal object and produce a transmission sinusoid at the film plane. This method of producing a sine-wave pattern on a photographic material avoids some disadvantages that are inherent in the previously mentioned methods of determining MTF. Some of these disadvantages are:

Edge Analysis Method

1. The production and imaging of a high quality edge is difficult.
2. The mathematical procedures are complicated and time consuming.
3. This method relies on the proper determination of the spread function of the photographic material, which in itself is difficult.

Contact Print Method

1. The input modulation can be changed only by using a new test target of different modulation.
2. For a given frequency, two microdensitometer traces are required.

3. The transmission test targets are easily scratched or marred due to normal handling.
4. The diffusion of light through the emulsion of the test target, which is inherent with contact printing, is an uncontrollable parameter.

The camera is now a permanent piece of testing equipment for the Photographic Science Department at the Rochester Institute of Technology.

DESIGN

Optical System

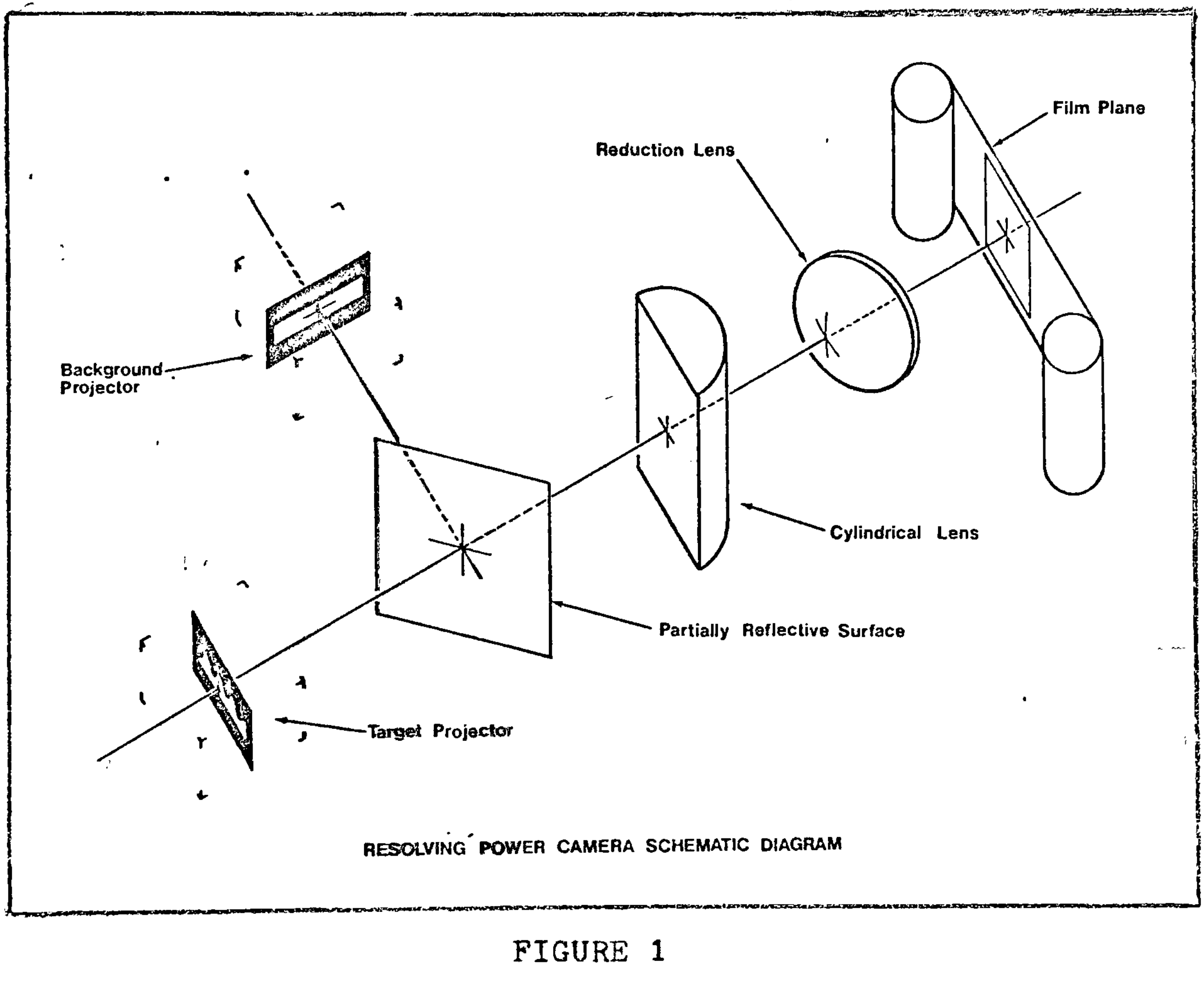

FIGURE 1

There are three optical elements in the system: an objective lens, a cylindrical lens, and a cube beam splitter.

The general orientation of these components are illustrated in Figure 1. The conjugate planes for the objective lens are dependent on the desired magnification, and the magnification is dependent on the range of frequencies to be recorded. The original areal object slides[1] have frequencies ranging from .1 to 10 cycles per millimeter, thereby requiring the magnification to be one-third.since the desired maximum frequency is 30 cycles per millimeter. The following table lists the original frequencies of the variable area targets and the respective frequencies at the film plane.

ORIGINAL FREQUENCY	IMAGE FREQUENCY
.100	.300
.185	.555
.251	.753
.631	1.893
1.000	3.000
1.580	4.740
2.510	7.530
3.980	11.940
6.310	18.930
10.000	30.000

The objective lens is a Schneider Xenon photographic objective of focal length 50 millimeters. At a magnification of one-third, the object conjugate is 200 millimeters and the image conjugate is 66.66 millimeters. A cylindrical lens of focal length 25 millimeters was placed between the object and the objective lens, and its exact placement was calculated as

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[1] Peter S. Hertzmann,"Design and Construction of Sinusoidal Targets for Resolving Power Cameras."

shown in the appendix. The aperture stop in the objective lens limits the field angle in the smearing dimension, and, therefore, for a given object size and magnification, only one f/# can be used. This f/# was determined by ray tracing procedures[2], and was found to be f/9.5.

In the non-smearing dimension, the axial object ray originates on axis at the object, passes through the rim of the aperture stop in the objective lens, and terminates on axis at the image plane. In the smearing dimension, the axial object ray must originate off axis at the extreme dimension of the areal object slide, pass through the rim of the aperture stop in the objective lens, and terminate on axis at the image plane. The proposed ANSI Standard for Determining the MTF of Photographic Materials (January 1974) requires that the objective lens must have an f/# ranging from 3.0 to 3.2. To meet this standard, a field stop was placed in front of the cylindrical lens in the smearing dimension. The field stop is in the form of a slit and is placed where the axial object ray crosses the optical axis. The height of the slit was made to maintain an f/9.5 at the objective lens. This permits the actual aperture in the objective lens to be opened to a larger f/#. Due to the physical size of the cylindrical lens, the largest f/# that can be obtained without vignetting is f/3.4. This does not meet the proposed standard exactly, however, the frequencies to be recorded are low enough that no detrimental effects will be encountered.

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2 Warren J. Smith, Modern Optical Engineering (McGraw-Hill, Inc., 1966), pp. 17-48.

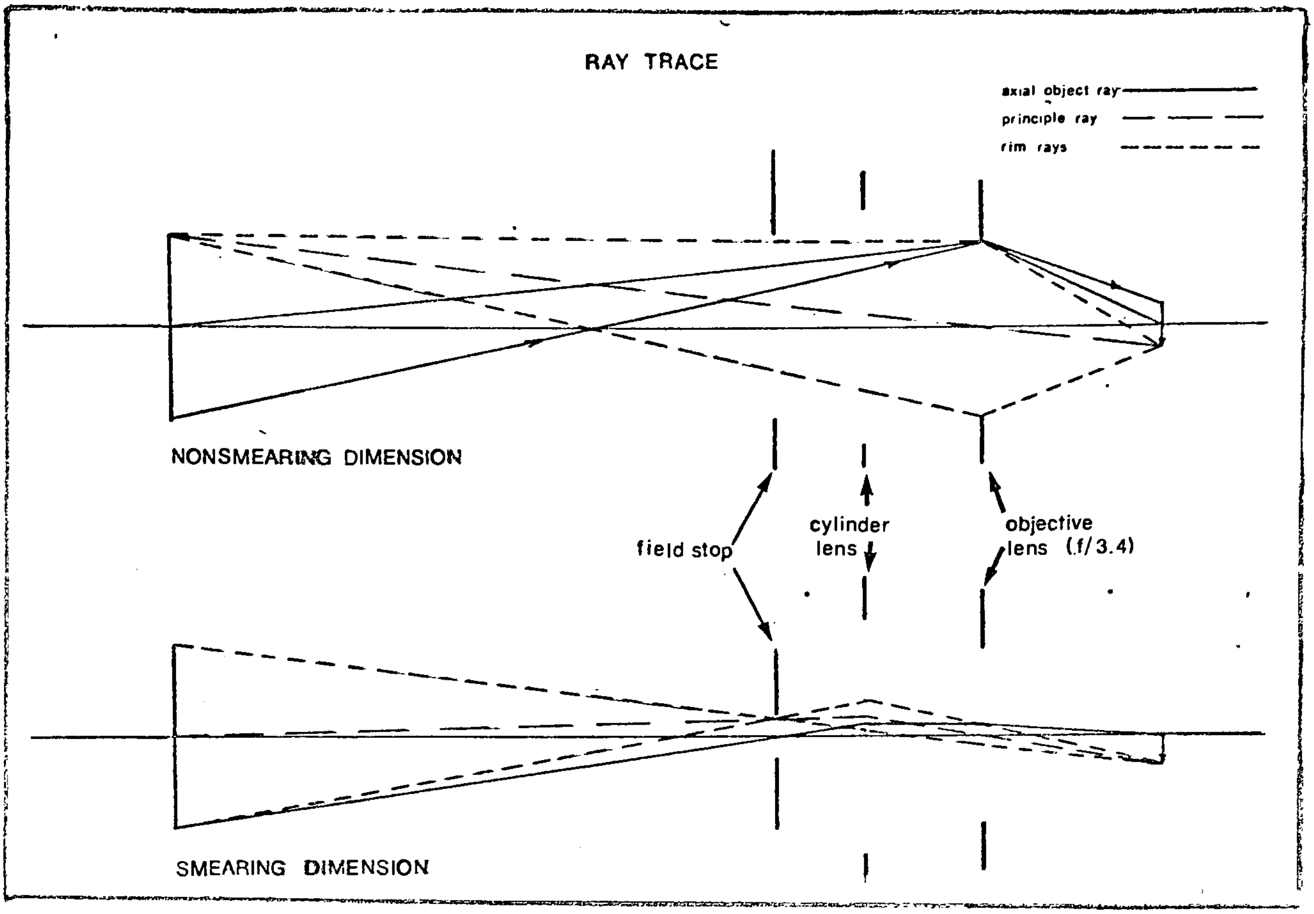
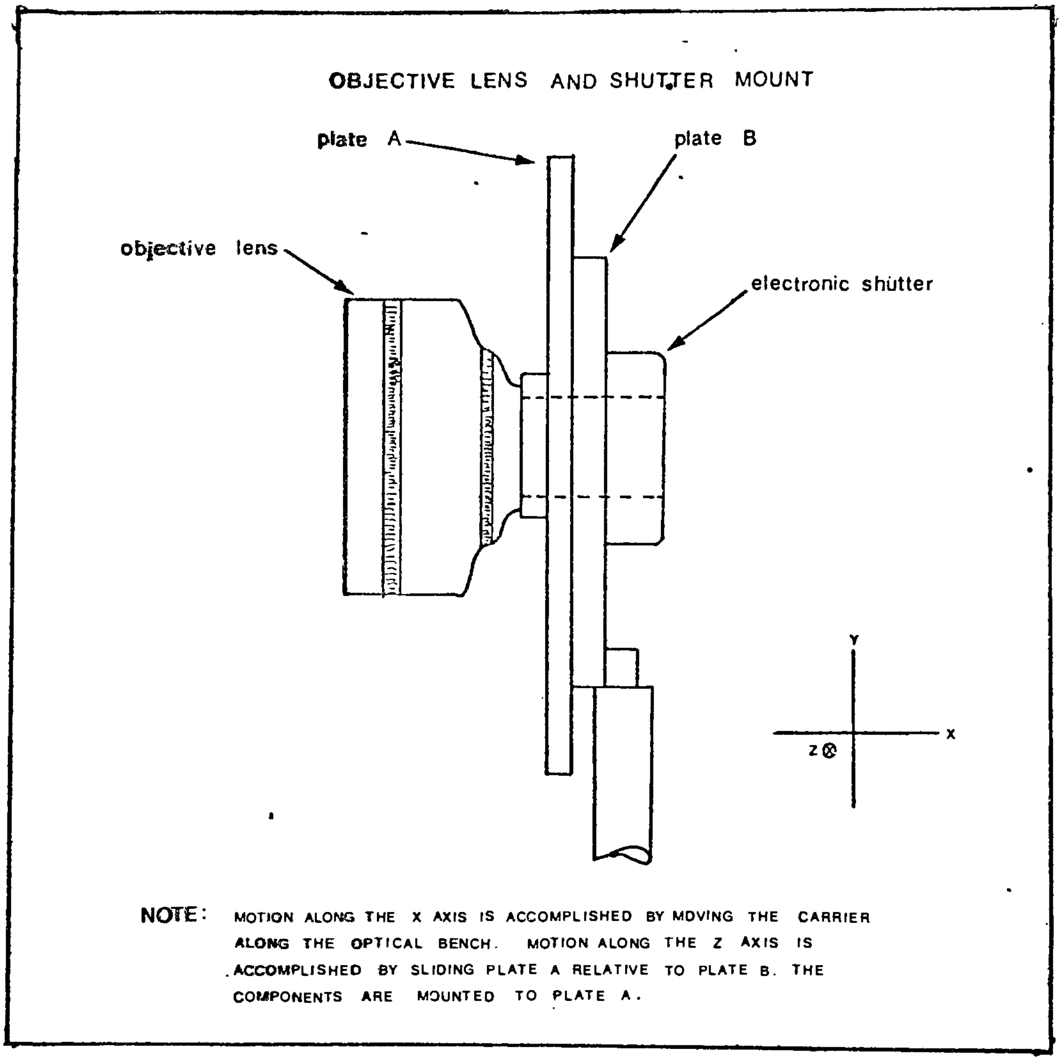


FIGURE 2

A ray trace diagram is shown in figure 2, and a ray trace table is shown in the appendix. The calculations do not include any compensation for the beam splitter, but it was calculated that the beam splitter required the object to be moved 13.68 millimeters away from the first optical element. This calculation is also shown in the appendix.

The objective lens was tested for resolution and aberrations. The resolution far exceeded the necessary requirements for imaging frequencies in the range previously mentioned, and the lens had very minimal aberrations.

An electronic shutter was mounted in conjunction with the objective lens. The two components were mounted so that adjustment in three dimensions is possible to aid in alignment. Further, the cylindrical lens and the slit field stop are mounted together. These two components are mounted so that rotational alignment is also possible. These mounts are illustrated in figures 3 and 4, respectively.


OBJECTIVE LENS AND SHUTTER MOUNT

NOTE: MOTION ALONG THE X AXIS IS ACCOMPLISHED BY MOVING THE CARRIER ALONG THE OPTICAL BENCH. MOTION ALONG THE Z AXIS IS ACCOMPLISHED BY SLIDING PLATE A RELATIVE TO PLATE B. THE COMPONENTS ARE MOUNTED TO PLATE A.

FIGURE 3

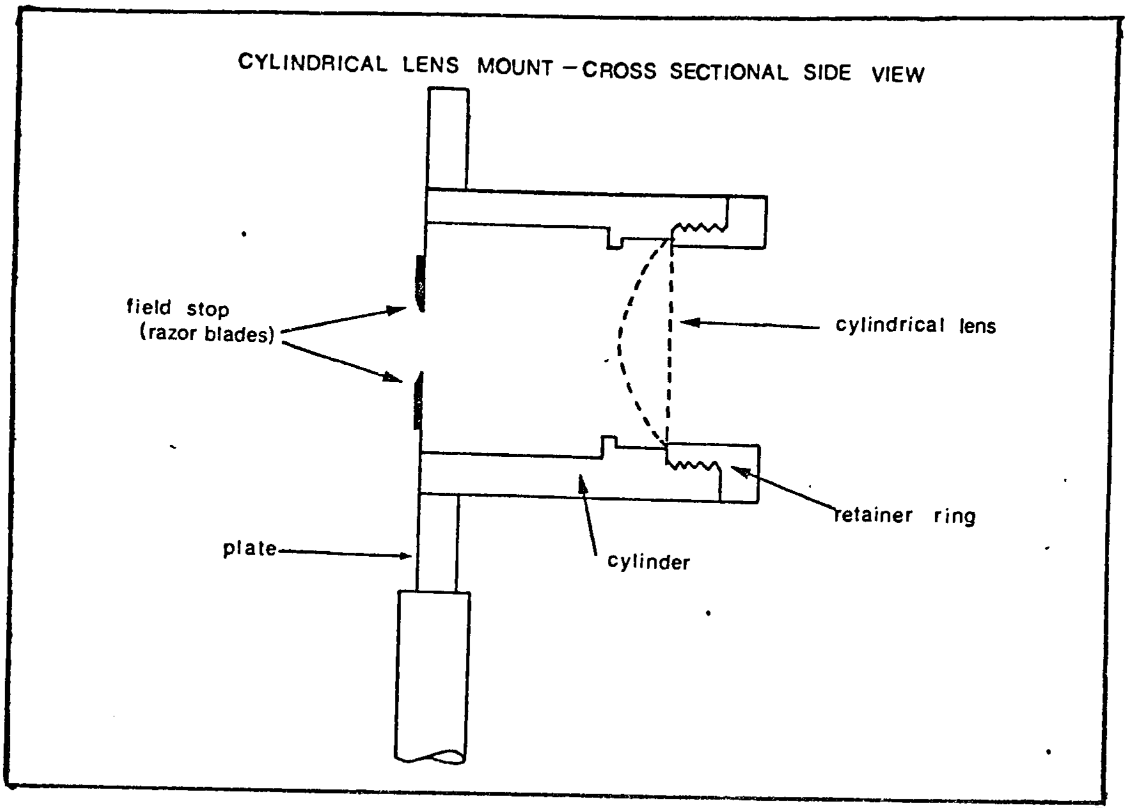


FIGURE 4

Illumination

The previously mentioned proposed ANSI standard calls for a light source of color temperature 3000K ± 250K. The light sources chosen are General Electric, CAR, 150 watt, 3100K projector lamps. These lamps were chosen for several reasons:

1 The filament shape is rectangular and approximates the shape of the object.
2 The color temperature is within the range suggested by the proposed ANSI standard.
3 The lamp fits the system with minimum modifications.
4 The luminance is sufficient to cover a wide range of film speeds.

The lamps are mounted in two GAF 1680 slide projectors, which also house the object slides. The object projector holds the object slides, and the backgroun~~g~~d projector acts to control the modulation at the film plane. The lamps are cooled by snail-type exhaust fans that are mounted external to the entire camera to minimize vibrations.

The modulation slides[3] render 25, 33, 44, 55, or 64% modulation at the image plane. Requirements for proper adjustment of illumination for use of the modulation slides were maintained. A copy of the operating manual for the Sinusoidal Areal Targets and the accompanying modulation slides is enclosed in the appendix.

Film Plane

A Hi-Precision Ball Slide, built by Automation Gages, Rochester, New York, was used as the basis for the film plane assembly. This particular assembly was chosen due to its ease of motion and because its back plate is extremely flat. A hinged platen was made and fastened to this finished surface. In the platen, two spring loaded clips are used to guide the film for proper registration while loading. A recessed slit was cut on the finished surface, and an aperture was cut in the stationary member. The film and the finished surface are stationary relative to each other, but they slide past the aperture in the stationary member. Due to

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[3] Peter S. Hertzmann, "Design and Construction of Sinusoidal Targets for Resolving Power Cameras."

the physical thickness of the film plane assembly, the aperture was cut on a bevel. The largest image produced on the film plane is 10 X 10 millimeters, and only nine images are made on one piece of film. (Seven frequency slides and two step tablet slides.) The dimensions of the film plane assembly easily accommodates a 10 X 10 millimeter image size and a spacing between images of five millimeters.

With the aforementioned dimensions, the required movement of the film plane between exposures is fifteen millimeters. The motionof the film plane is accomplished by a Bodine Type K Reversible Instrument Gearmotor, Model 717. The gearmotor is attached to a lead screw which passes through a thread mounted on the film plane assembly. Thus, as the motor turns, the film plane is advanced along the lead screw.

A dynamic braking circuit was used to stop the motor at the desired positions between exposures. The braking circuit is a capacitor discharge type, and the electrical schematic in figure 5 illustrates this circuit. The capacitor was determined by increasing the capacitor size until the motor just stopped with no rotational drift.

There are three microswitches used with the film plane assembly to make the operation almost fully automatic: one to activate the braking circuit of the motor, and the other two to disconnect the slide tray advance in the projector. This is necessary only at the last exposure of the series. Two normally open push-button switches are used at each end of

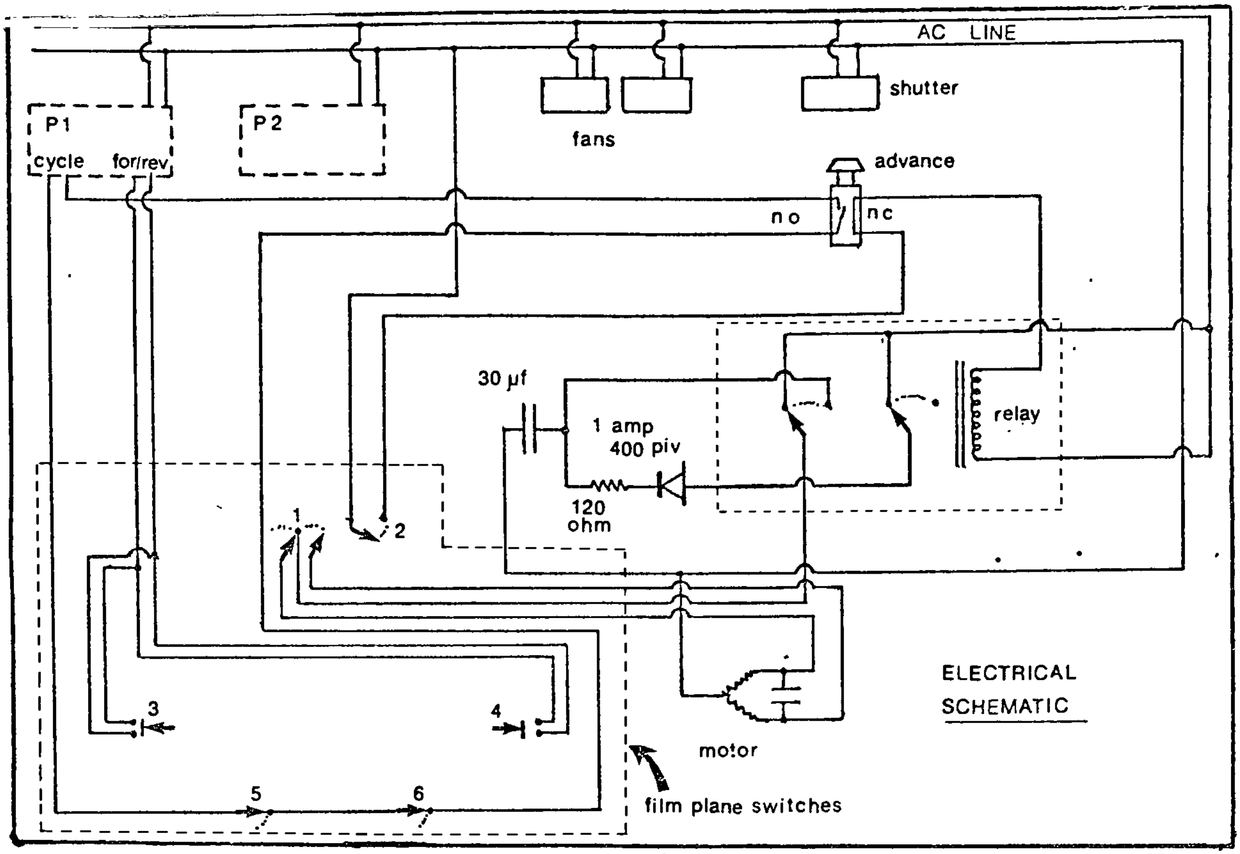

FIGURE 5

1 Single-pole-double-throw toggle switch to reverse motor
2 Normally open microswitch to stop motor
3&4 Normally open pushbutton switches to reverse projector
5&6 Normally closed microswitches to disconnect slide cycle

the film plane travel such that, when activated, they will reverse the direction of the slide tray in the projector. A single-pole-double-throw toggle switch reverses the direction of the motor. After the last exposure has been made, (at which point the slide cycle circuit has been disconnected via the aforementioned microswitch) the advance button on the control panel is manually pushed. The film plane assembly will begin to advance and will depress the push-button switch to reverse the direction of the slide tray in the projector. The film plane assembly will continue to advance until it activates the single-pole-double-throw toggle switch which will reverse the direction of the motor. The film plane assembly will then return to the first position in the new direction. This entire assembly is illustrated in figures 6, 7, and 8.

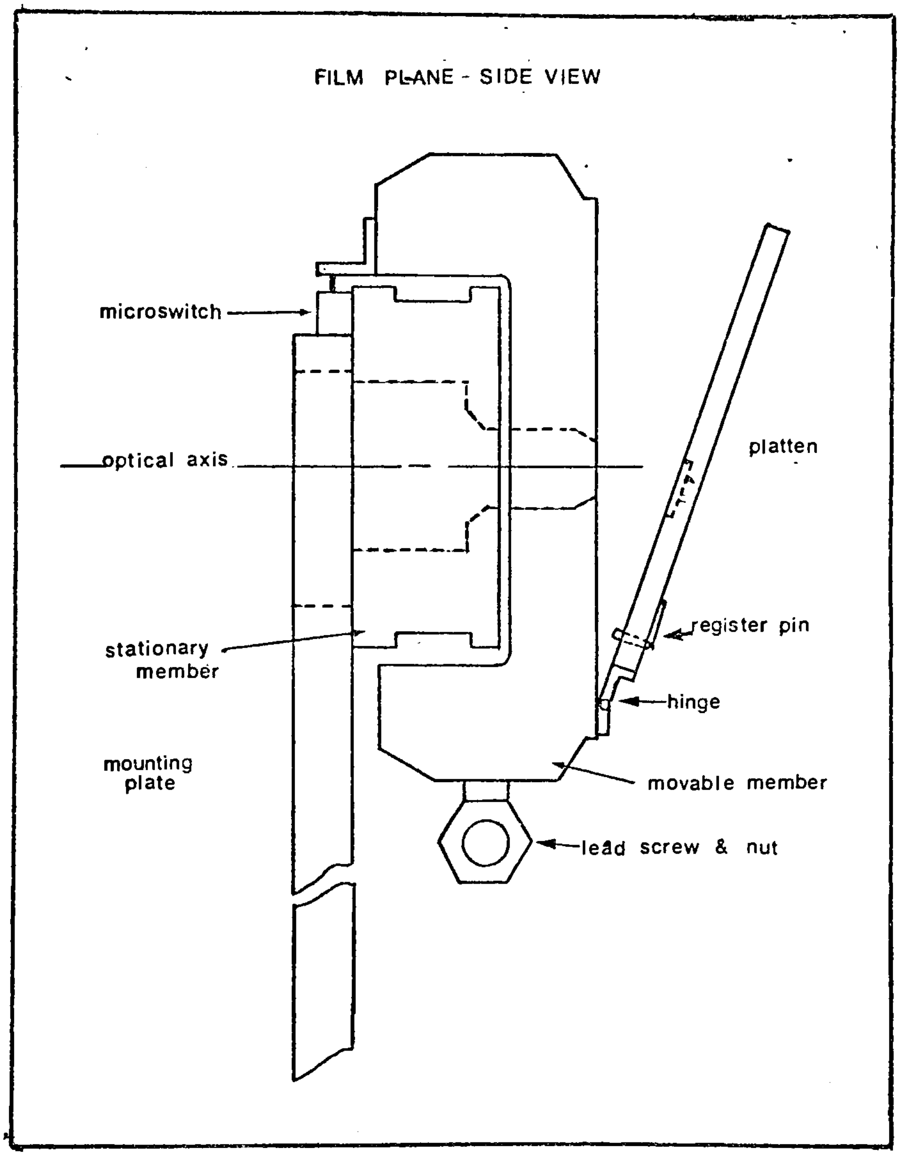

FIGURE 6

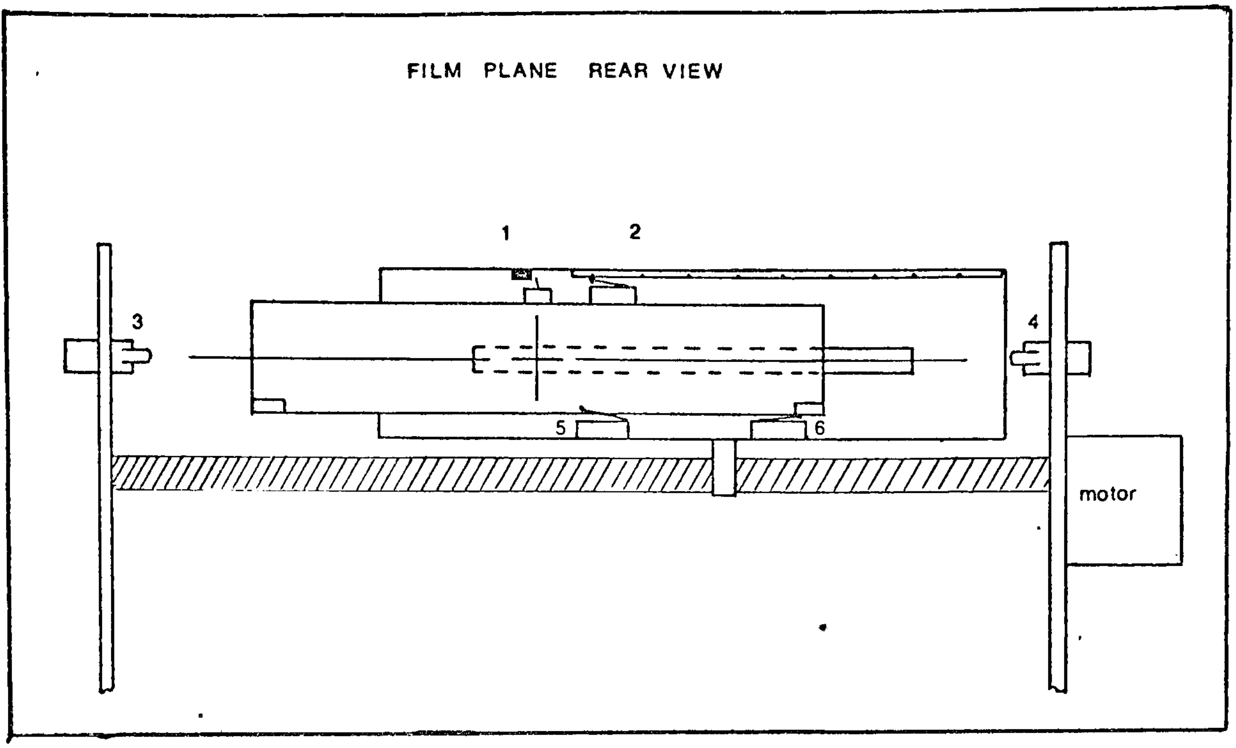

FIGURE 7

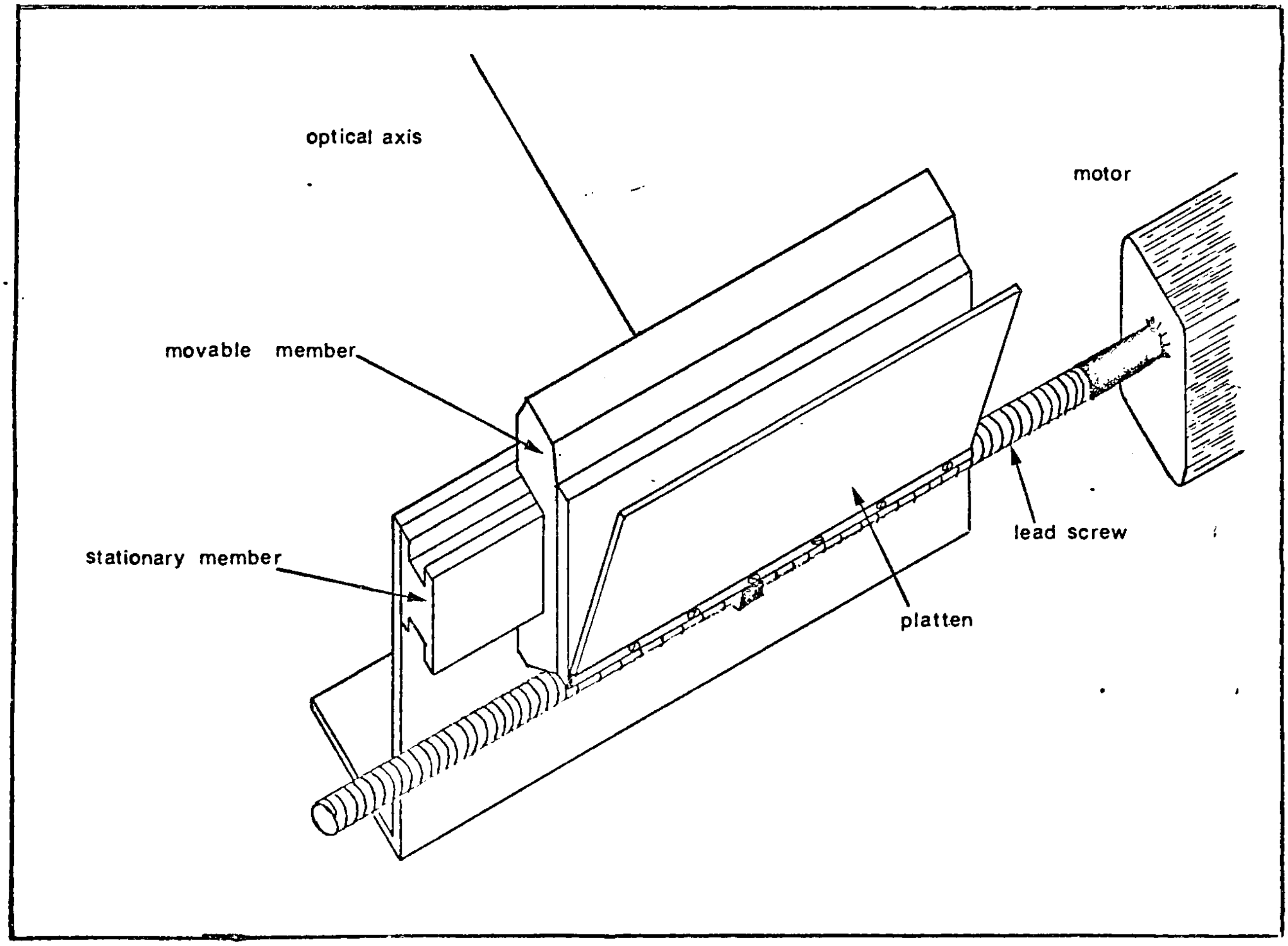

FIGURE 8

Base

The entire system is mounted on a standard size office desk. To obtain additional stability and to prevent vibrations, a concrete slab was prepared on the top surface of the desk. The system is mounted on a metal plate, and the plate is attached to the concrete slab via mounting bolts anchored in the concrete. The desk and concrete slab are illustrated in figure 9. The entire system will be enclosed in a light tight box for room light operation, but film will be loaded in the dark or under the appropriate safelight conditions.

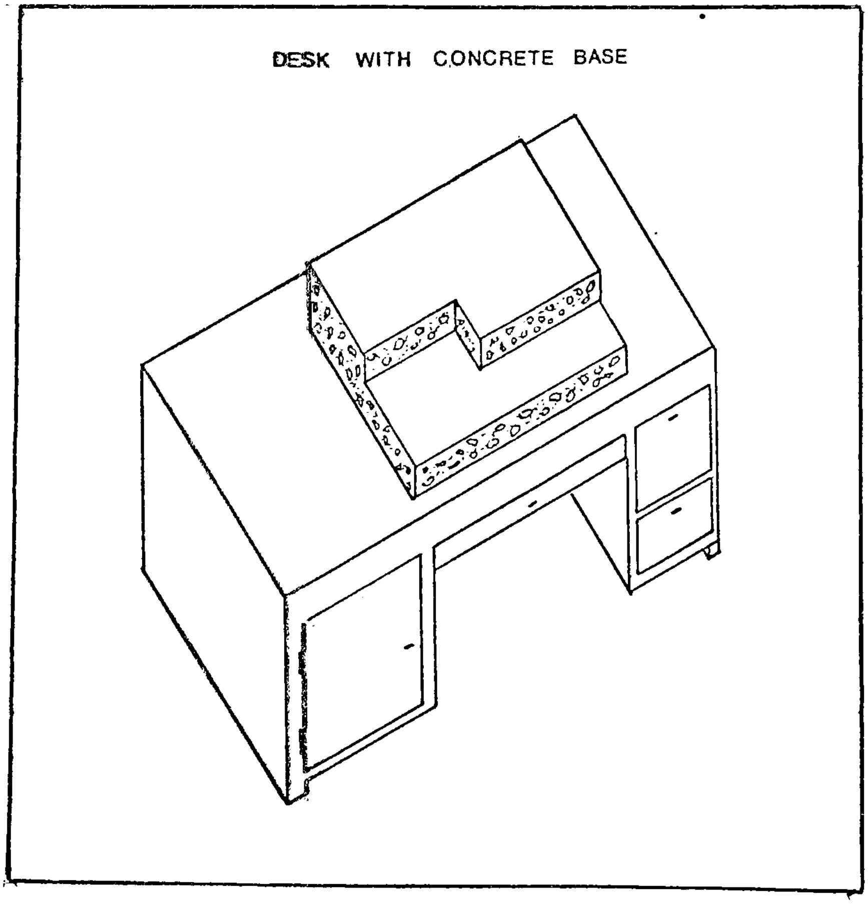

FIGURE 9

OPERATIONAL PROCEDURE

1) Load the film under appropriate safelight conditions.

2) Adjust the modulation by advancing to the proper slide in the background projector.

3) Set the desired shutter speed for the electronic shutter on the control panel.

4) Make the first exposure by depressing the exposure button.

5) Depress the advance button on the control panel. (This will automatically change the object slide and advance the film plane assembly)

6) Make the next exposure when the motor stops.

7) Repeat steps 5 and 6 until a total of 9 exposures have been made.

8) After making the last exposure, depress the advance button once more. This will reset the system for the next series of exposures.

9) The film can be removed before or after step 8.

FURTHER WORK

Due to time limitations, the total completion of the system was not accomplished. There are two projects which should be undertaken at the earliest possible time:

1 The system has not been calibrated for various ASA speeds of different film types, and the MTF's obtained with this system should be compared to published MTF data to ascertain the system's effectiveness.

2 A lighting system is needed to indicate to the operator which frequency is being imaged and at what modulation. This can be accomplished by using Light Emitting Diodes (LED) to light-up on the control panel for each individual position in the two slide trays, or some other convenient indicator system. It is emphasized that this lighting system would be a very nice convenience, but the camera system is still functional without it.

ACKNOWLEDGEMENTS

The following people provided aid at various stages of this project, and with their advice, ideas, and work, the progress of this project was vastly accelerated:

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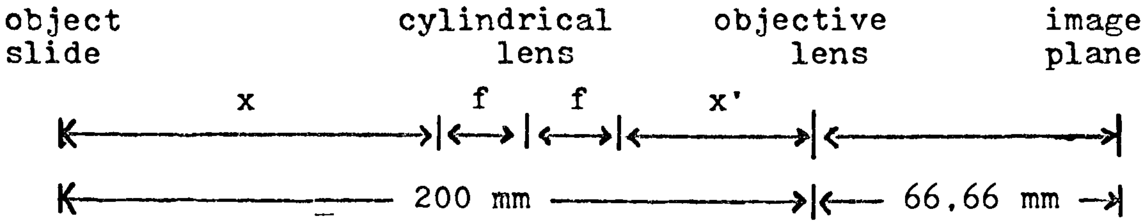
Calculation for the placement of the cylindrical lens:



$$x + x' + 2f = 200 \text{ mm} \qquad f = 25 \text{ mm}$$

$$\therefore x + x' = 150$$

$$\text{but, } xx' = f^2$$

$$x' = \frac{f^2}{x}$$

$$\therefore x + \frac{f^2}{x} = 150$$

$$x^2 - 150x + 625 = 0$$

$$\therefore x = 145,71 \text{ mm}$$

$$x' = 4,29 \text{ mm}$$

Calculation for the image shift due to the beam splitter

$$D = t - \frac{t}{n}$$

D = image shift

t = thickness of beam splitter

n = index of refraction of beam splitter

$$D = 40 \text{ mm} - \frac{40 \text{ mm}}{1,52}$$

$$D \Rightarrow 40 - 26,32$$

$$D = 13,68 \text{ mm}$$

RAY TRACE TABLE AND SAMPLE CALCULATIONS

	Surface								
	0		1		2		3		4
ϕ	0		0		.04		.02		0
$-t$		-148.89		-21.812		-29.29		-66.66	
y	-15.3286		0		2.2455		2.63		0
u		-.102947		-.102947		-.013126		.03947	
$\bar{y}$	0		1.92		2.197		0		-5
$\bar{u}$		-.01288		-.01288		.075		.075	

Surface

0	Object
1	Field Stop
2	Cylindrical Lens
3	Objective Lens
4	Image Plane

ϕ= power in (millimeters)$^{-1}$
t= distance between surfaces in millimeters
y= height of axial object ray at the surface in millimeters
$\bar{y}$= height of principle ray at the surface in millimeters
u= slope angle of axial object ray in radians
$\bar{u}$= slope angle of principle ray in radians

$$y_n = y_{n-1} - t_{n-1}\,u_{n-1}$$

example:

$$y_2 = y_1 - t_1\,u_1$$
$$y_2 = 0 - (21.812)(-.102947)$$
$$y_2 = 2.2455$$

$$u_n = u_{n-1} + \phi_n\,y_n$$

example:

$$u_3 = u_2 + \phi_3\,y_3$$
$$u_3 = -.013126 + (.02)(2.63)$$
$$u_3 = .03947$$

OPERATING PROCEDURES FOR THE SINUSOIDAL AREAL TARGETS

The illuminance levels due to the individual projectors, when measured at the film plane with all optics in position, should be such that the illuminance from the background projector is 3.15 times* the illuminance from the target projector if:

1) the system has been focused;
2) the 0.40 lines/mm slide is in position in the target projector;
3) the 25% modulation slide is in the background projector;
4) an area equivalent to 8 to 10 cycles is measured for both projectors.

Expose the film as per camera instructions.

When evaluating the processed film it will be necessary to know the relative exposures at various modulations and steps on the calibration patches. These values can be found in the following table.

---

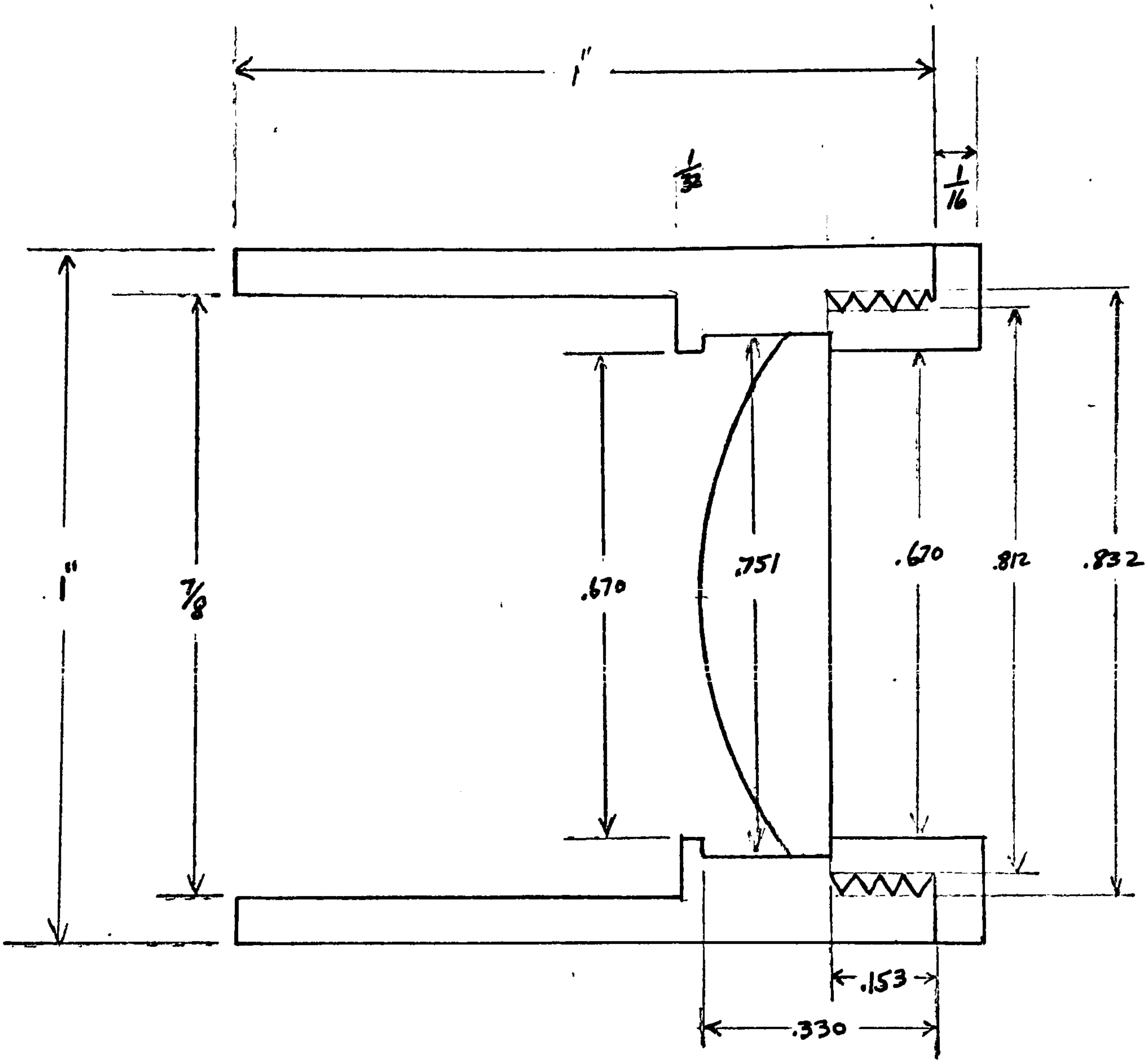
* The LATD of a target is 0.301, the base plus fog of the target is 0.04, and the illuminance at the film plane due to the background projector is 1.436 times the illuminance due to the target projector.

Relative Exposures of Calibration Patches

Step Number	Percent Modulation 25	33	44	55	64
1	1.000	1.000	1.000	1.000	1.000
2	0.845	0.834	0.813	0.802	0.795
3	0.723	0.701	0.665	0.645	0.633
4	0.625	0.596	0.547	0.521	0.503
5	0.547	0.513	0.453	0.422	0.401
6	0.486	0.446	0.379	0.343	0.319
7	0.437	0.394	0.320	0.281	0.255
8	0.398	0.352	0.273	0.231	0.203
9	0.367	0.319	0.236	0.192	0.162
10	0.343	0.292	0.206	0.160	0.130
11	0.323	0.271	0.183	0.135	0.104
12	0.308	0.255	0.164	0.116	0.084
Background	0.295	0.241	0.148	0.099	0.066

CYLINDER LENS MOUNT
SCALE 4:1
QUANTITY 1
THREAD 40 TPI

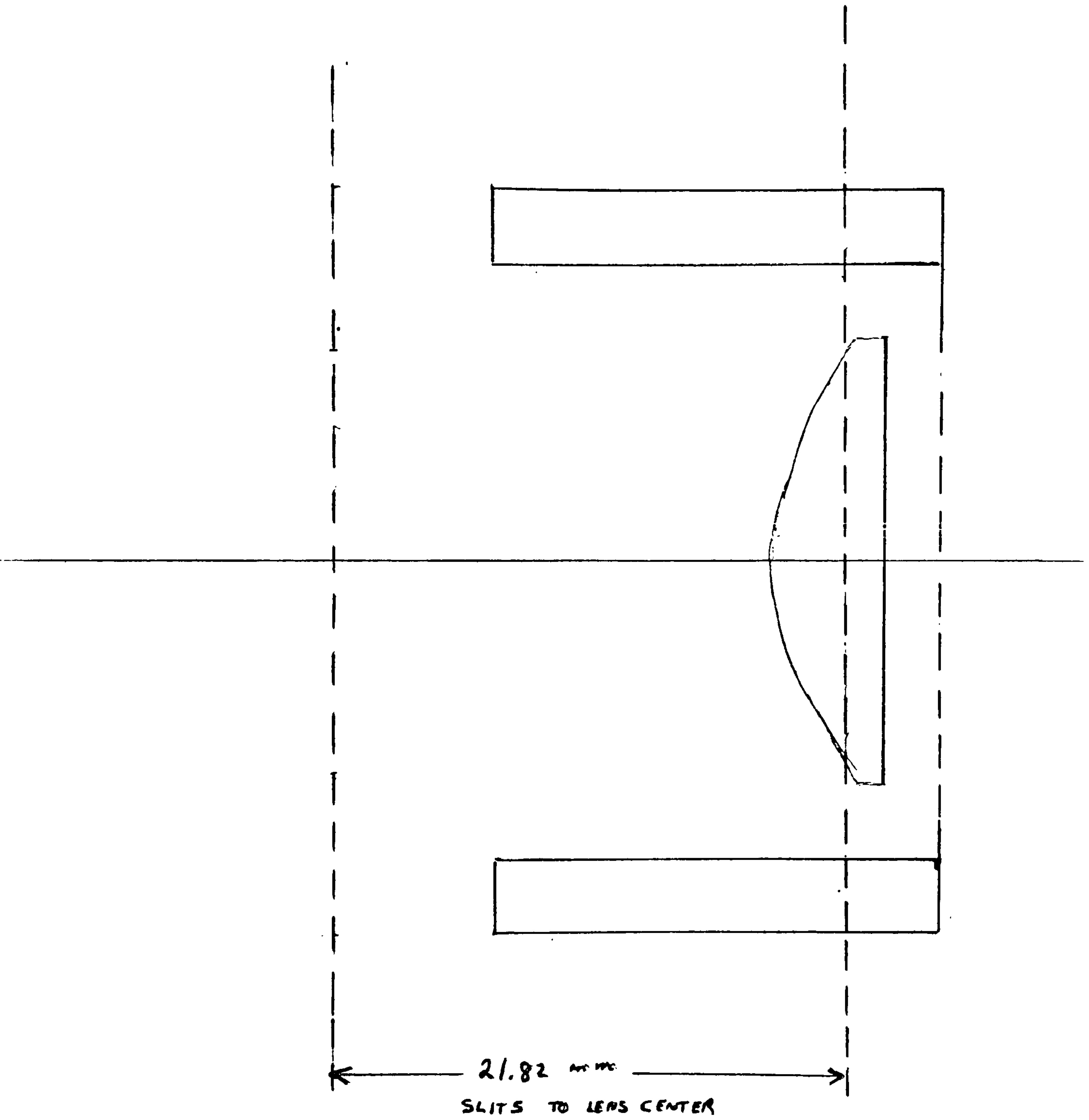
SHEET 1



RICHARD NORMAN 4 MAR 75

SHEET

SCALE 4:1



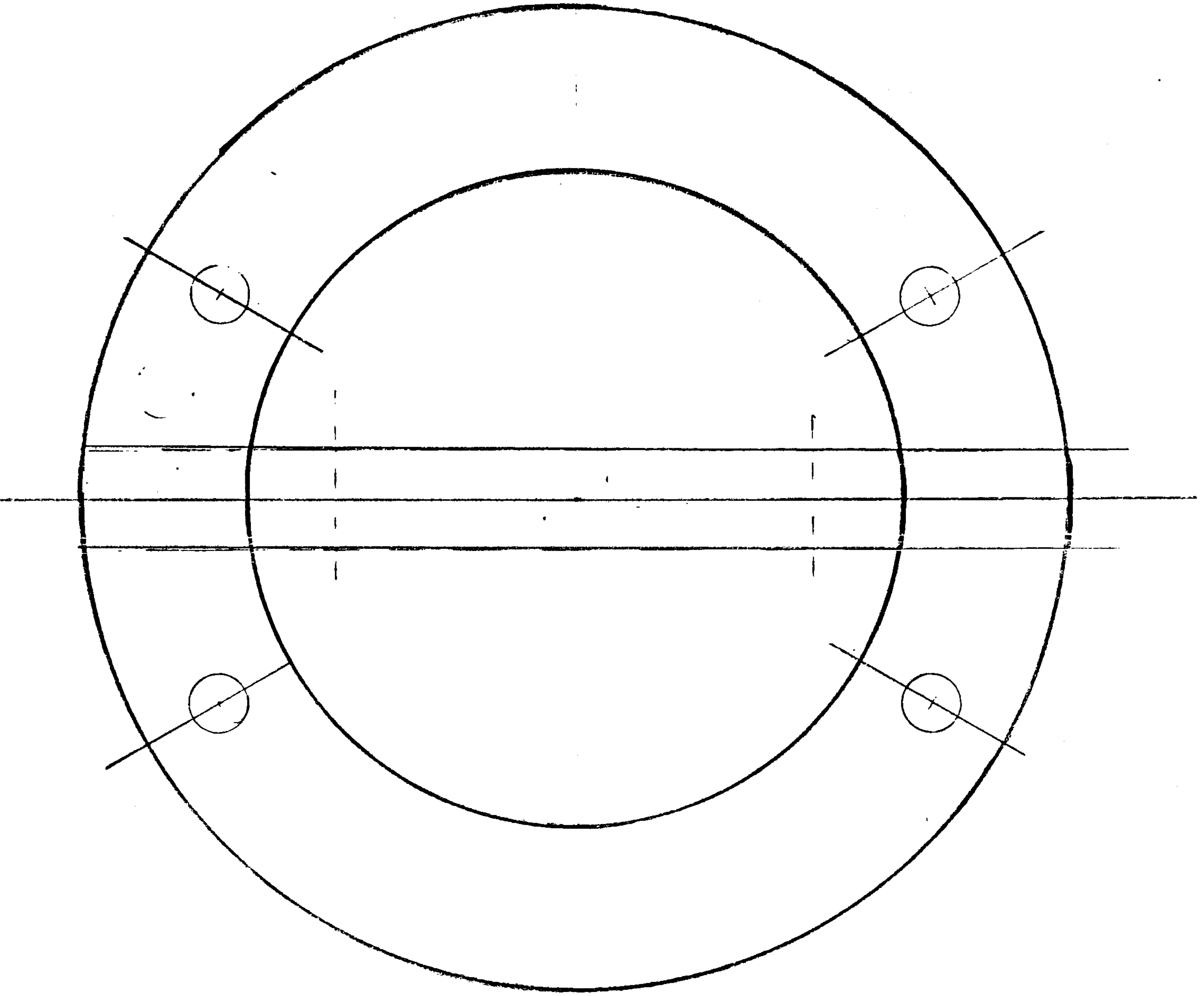
CYLINDER LENS IS $.182\overset{4}{5}$ THICK

FIGURE 5

RICHARD NORMAN 4 MAR 75

JOB ______
SHEET 3

SLIT HOLDER AND LENS TUBE HOLDER (Cylindrical Lens)
FROM $\frac{3}{8}$ PLATE 2024 ALUMINUM
SCALE 4:1
QUANTITY: 1



I.D. 1"
O.D. 1½"

2-56 HOLES 60° AND 120°
APART AS SHOWN,
$\frac{1}{8}$" in FROM edge (CENTERED)

SLIT 3.84 ± .01 MM X 18.5 $^{+.1}_{-0}$ MM

RICHARD NORMAN 4 MAR 75

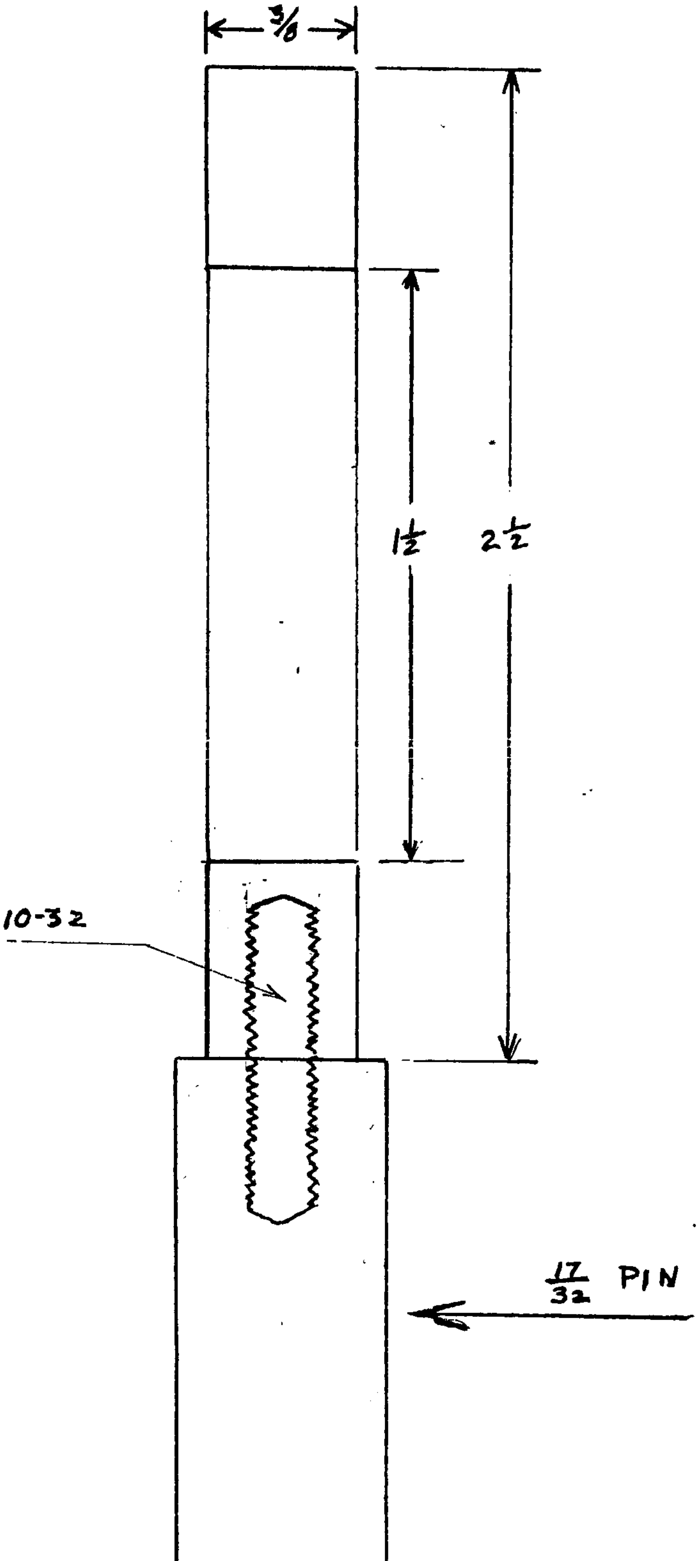
MOUNT TO HOLD SLIT AND LENS ASSEMBLY (cylindrical lens) SHEET 7

TYPE 2024 ALUMINUM PLATE 2½ × 2½ × 3/8

WITH 1½ HOLE CENTERED

SIDE VIEW

SCALE 2:1



RICHARD NORMAN 7 MAR 75