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# The Verification of an optical system design for a low frequency MTF camera

Edwin B. Hoel

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THE VERIFICATION OF AN OPTICAL SYSTEM  
DESIGN FOR A LOW FREQUENCY MTF CAMERA

by

Edwin B. Hoel

A thesis submitted in partial fulfillment  
of the requirements for the degree of  
Bachelor of Science in the School of  
Photographic Arts and Sciences in the  
College of Graphic Arts and Photography  
of the Rochester Institute of Technology

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Signature of the Author.....  
Photographic Science  
and Instrumentation

Certified by.....  
Thesis Advisor

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Submitted to the  
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ABSTRACT

A proposed low frequency MTF camera system uses a cylinder lens to smear an area-modulated sinusoidal target into an irradiance-modulated sinusoidal image for the evaluation of a film's modulation transfer characteristics. The proposed system was constructed and evaluated. Resolution limits, field flatness, field sharpness, repeatability, defocus effects and system MTF were determined. The camera was tested with film and found to have an MTF value close to 1.0 for frequencies up to 10 cycles/mm at which point the function dropped off to a value of 0.2 at 30 cycles/mm. Off-axis images showed rapid degradation as a maximum MTF value of 0.05 for 30 cycles/mm was exhibited at the edges of the image field.

## ACKNOWLEDGMENTS

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## TABLE OF CONTENTS

	<u>PAGE</u>
INTRODUCTION	1
SYSTEM DESIGN	
A. Optical Considerations	5
B. Mechanical Considerations	12
SYSTEM TESTING	
A. Objective Lens	17
B. Repeatability	17
C. System MTF Determination	18
CONCLUSIONS	25
REFERENCES	26

LIST OF TABLES

	<u>PAGE</u>
TABLE 1 Ray Trace - XY Plane	10
TABLE 2 Ray Trace - XZ Plane	11

## LIST OF FIGURES

	<u>PAGE</u>	
FIGURE 1	Film Transport Mechanism	2
FIGURE 2	Variable Area Sinusoidal Target	4
FIGURE 3	Area-modulated Sinusoidal Target as oriented to the Cylinder Lens	6
FIGURE 4	Irradiance-modulated Sinusoidal Image	7
FIGURE 5	Pictorial View of the Optical System	8
FIGURE 6	Schematic View of the XY Plane of the Optical System	9
FIGURE 7	Schematic View of the XZ Plane of the Optical System	9
FIGURE 8	Schematic View of the XY Plane with the Beamsplitter	13
FIGURE 9	Mount for the Film Transport Mechanism and the Support System for the Optical Elements	15
FIGURE 10	Optical Element Carriers	16
FIGURE 11	Example of Microdensity Scan with Even Illumination	19
FIGURE 12	Example of Microdensity Scan with Uneven Illumination	20
FIGURE 13	Modulation Transfer Function for the Camera and Film	22
FIGURE 14	Effect of a Rotational Misalignment Between the Target and the Cylinder Lens	24

## INTRODUCTION

The modulation transfer function of a photographic emulsion is one of the most basic and useful characteristics that can be utilized when concerned with the film's ability to accurately record an image.

There are several different techniques that have been used for measuring the MTF of a photographic film. The method most commonly used at the Rochester Institute of Technology is the mathematical generation of the MTF from a microdensity scan of an edge that has been imaged on the test material. This method requires the imaging of a very high quality edge onto the film and extensive data manipulation. Another method of MTF determination uses a variable area sinusoidal target that is smeared by a cylinder lens resulting in an irradiance-modulated sinusoidal image. A range of frequencies are imaged onto the film and the images are then scanned on a microdensitometer for analysis. One of the main advantages of this method is that the random fluctuations arising from granularity are averaged out since the images cover an extended area of the film, thus increasing the accuracy of the measurement.<sup>1</sup>

There have been several attempts to design and construct an MTF camera at the Rochester Institute of Technology.<sup>2,3</sup> The most recent work done by Palum<sup>4</sup>, where a system was designed and a film transport mechanism built, was an integral part of this thesis. The film transport mechanism is illustrated in Figure 1. This system also incorporates a



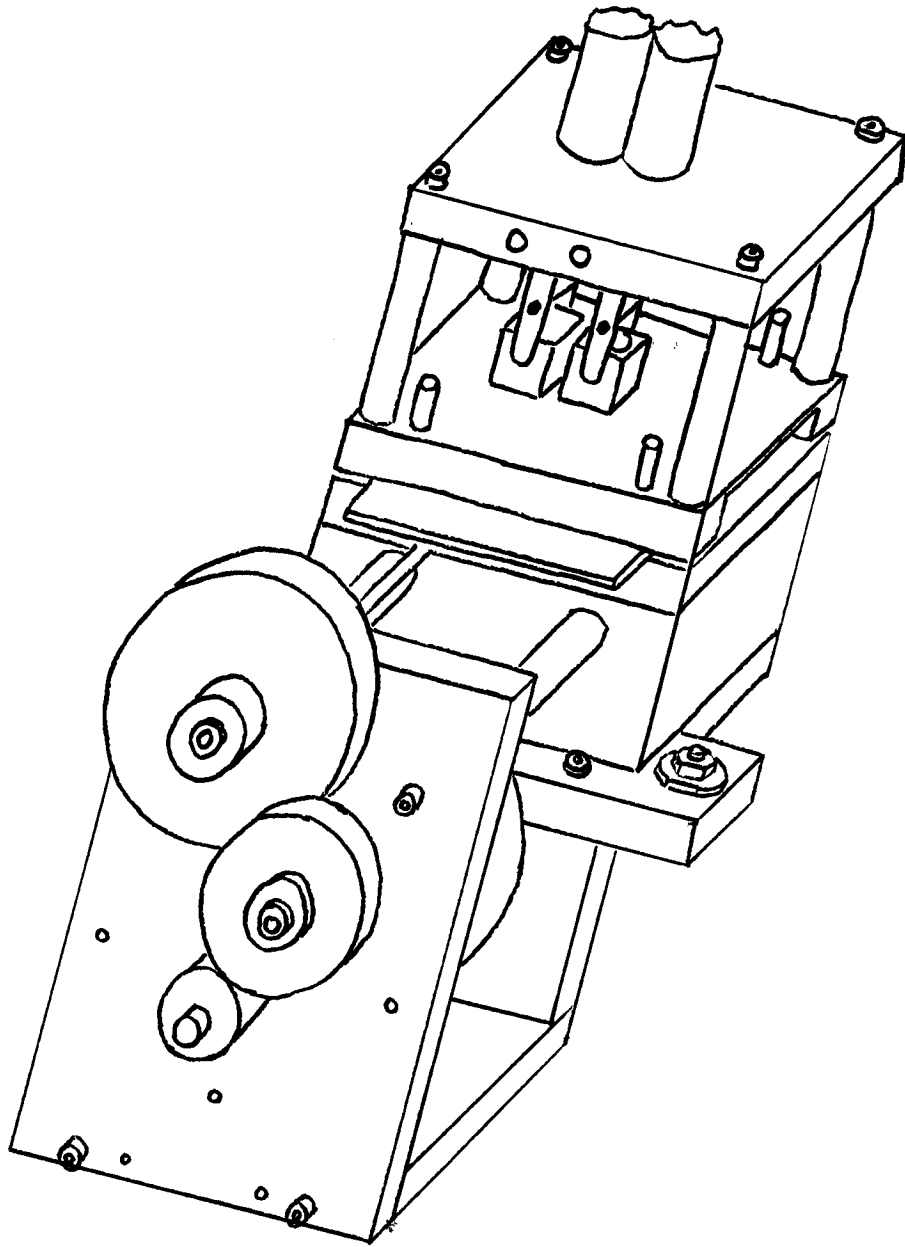


FIGURE 1 Film Transport Mechanism

set of variable area sinusoidal targets designed and constructed by Hertzmann.<sup>5</sup> (see Figure 2) These targets range in frequency from 0.1 to 10.0 cycles/mm and require a 3:1 reduction by the optical system so that the final images will range in frequency from 0.3 to 30 cycles/mm.

The objectives of this thesis were to construct the optical system of the camera while utilizing Palum's film transport mechanism and Hertzmann's sine wave targets and to verify the system's performance characteristics. This would enable the Rochester Institute of Technology Photoscience Division to affect any design changes necessary and to construct a permanent model for its future use.

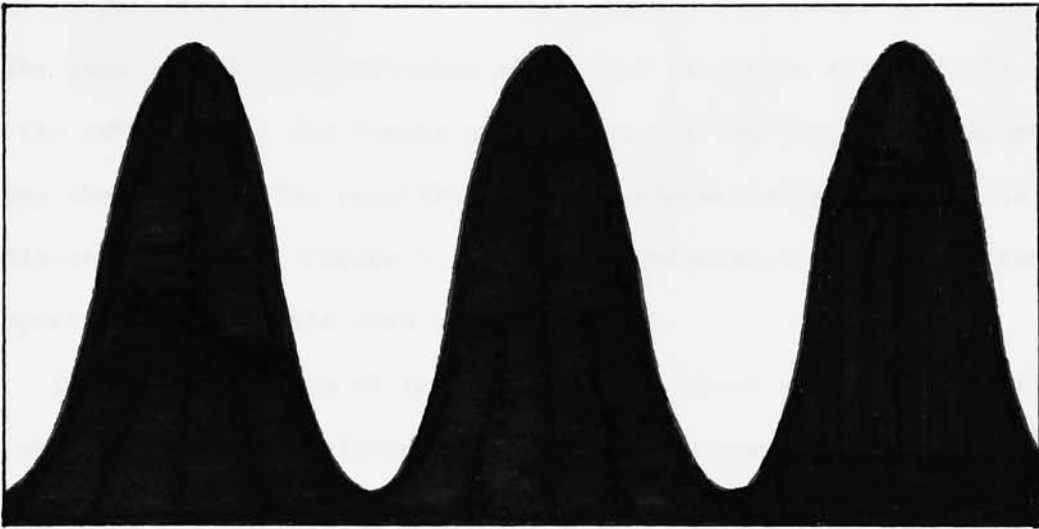


FIGURE 2 Variable Area Sinusoidal Target

## SYSTEM DESIGN

## A. Optical Considerations

An area-modulated sinusoidal target and a cylinder lens are shown in Figure 3. They are oriented so that the power-axis of the cylinder lens is parallel to the Y-axis of the target. The effect of the cylinder lens on the area-modulated sinusoidal target is to smear the image of the target along the Y-axis and to transmit the image, undeviated, along the Z-axis. The resulting image is sinusoidally modulated in irradiance as shown in Figure 4. The image irradiance varies in direct proportion to the white area of the target.

The optical system of the MTF camera designed by Palum consists of an objective lens, a cylinder lens and a field stop. A pictorial view of this optical system is shown in Figure 5.<sup>6</sup> A schematic view of the XY plane and the XZ plane of the optical system, represented as a thin lens system, are shown in Figures 6 and 7, respectively.<sup>7</sup> The ray trace results corresponding to these views are in Tables 1 and 2, respectively.<sup>8</sup>

In order to control the contrast of the image, unmodulated light is added to the modulated beam via a cube beamsplitter. The introduction of the cube beamsplitter into the optical path has the effect of displacing the image of the target back a distance that is related to the thickness and index of refraction of the beamsplitter. The displacement distance due to the beamsplitter is equal to:  $t(1 - 1/n)$ , where

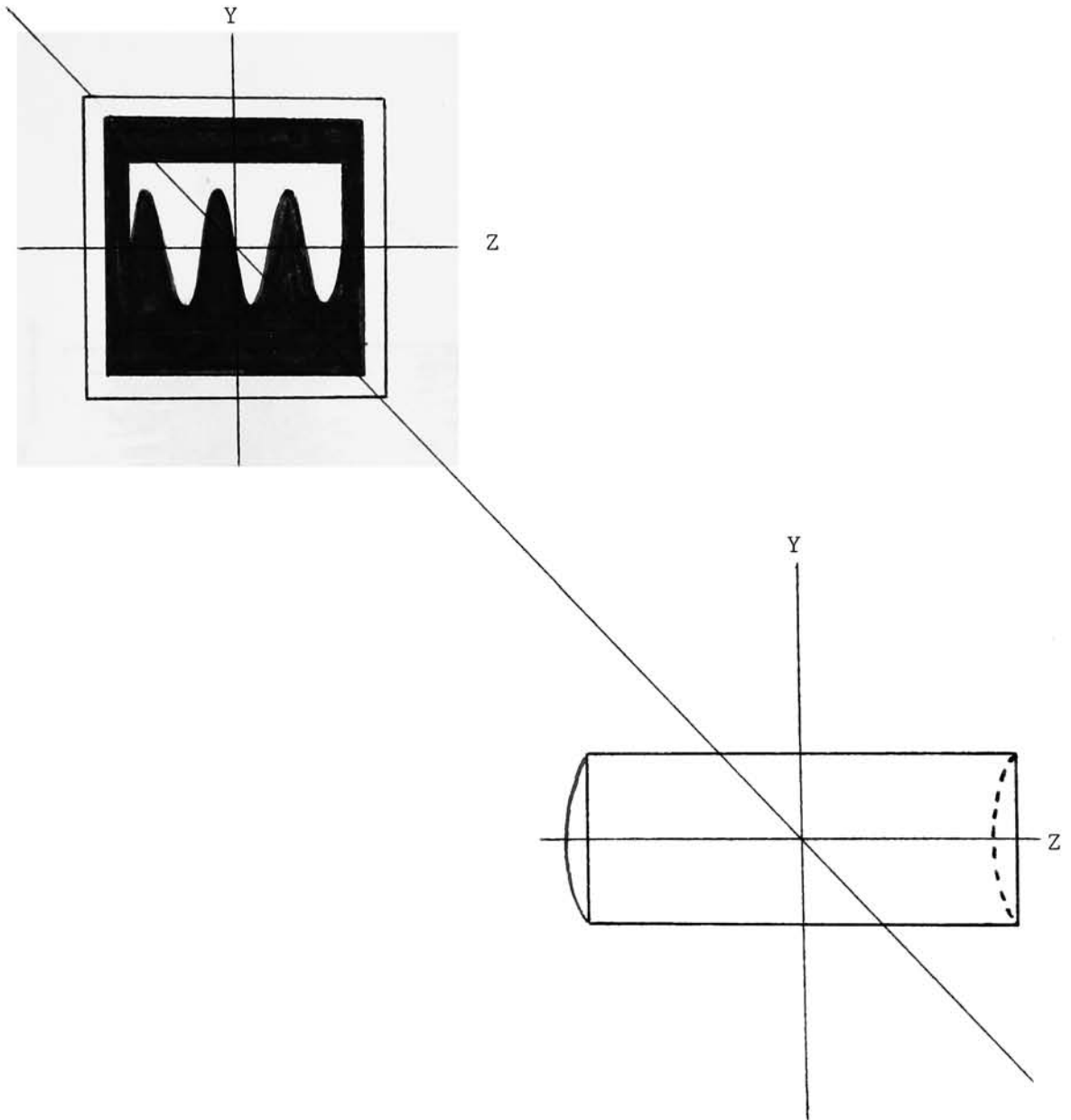


FIGURE 3 Area-modulated Sinusoidal Target  
as Oriented to the Cylinder Lens

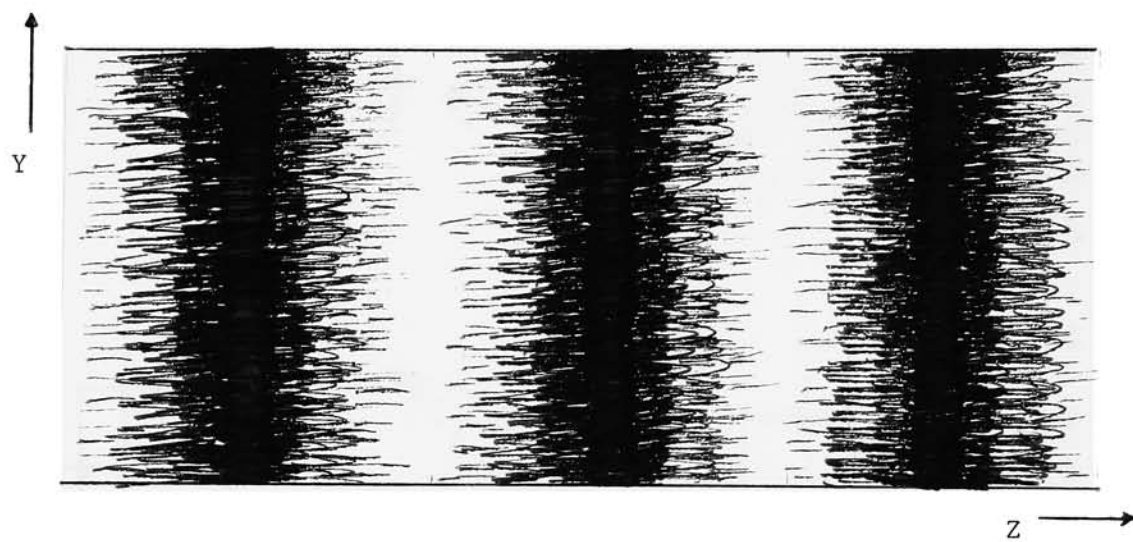


FIGURE 4 Irradiance-modulated Sinusoidal Image

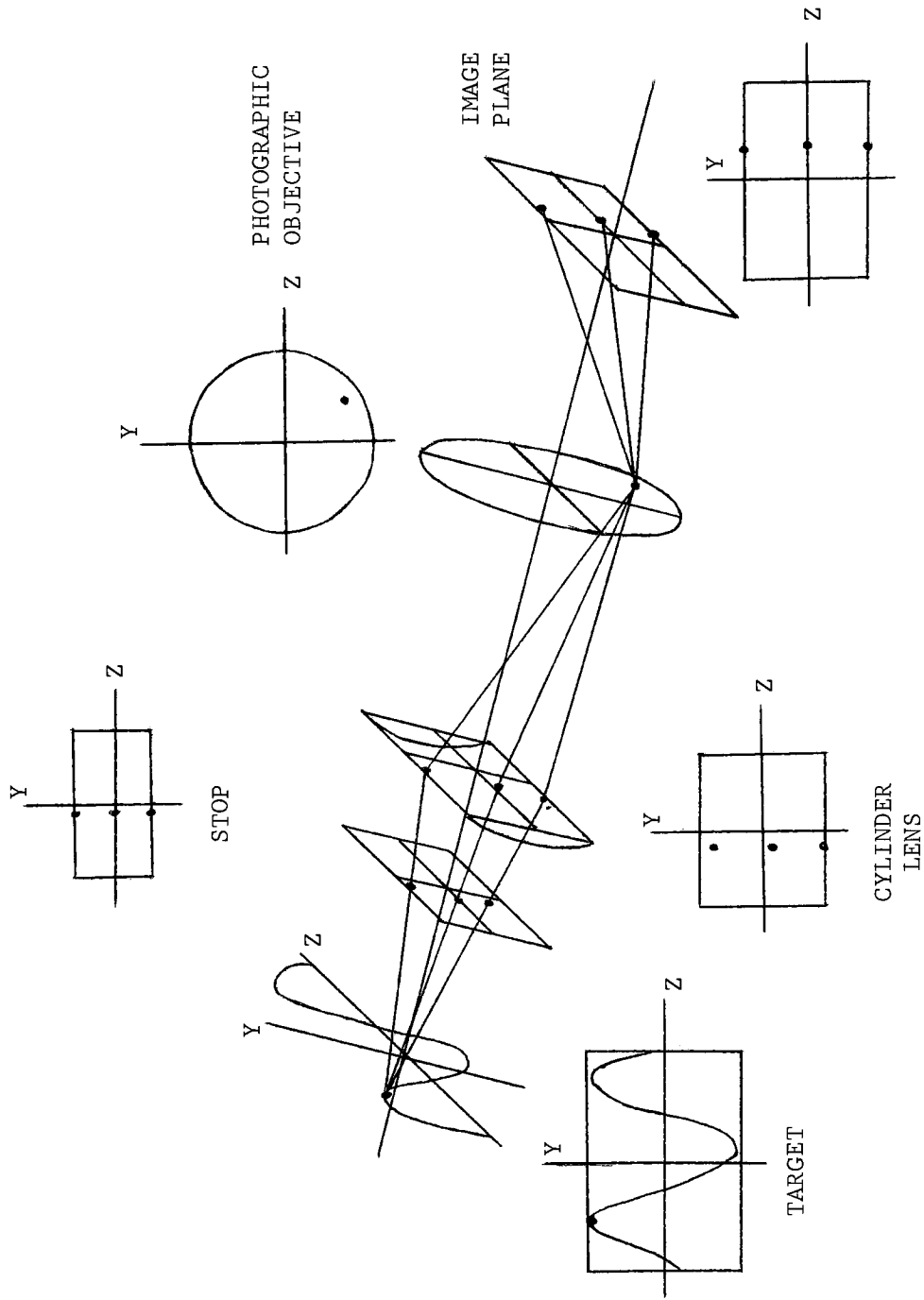


FIGURE 5 Pictorial View of the Optical System

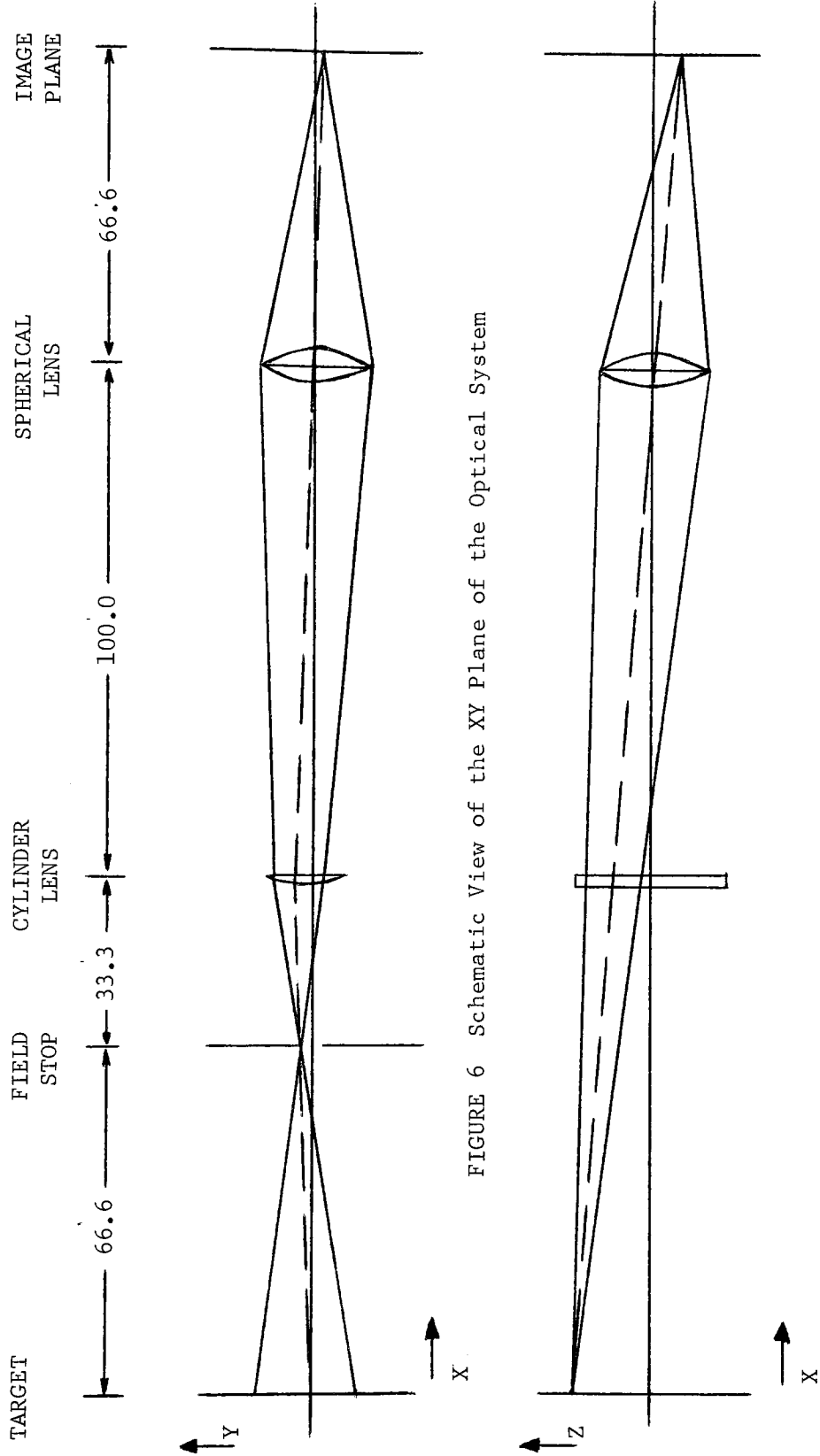


FIGURE 6 Schematic View of the XY Plane of the Optical System

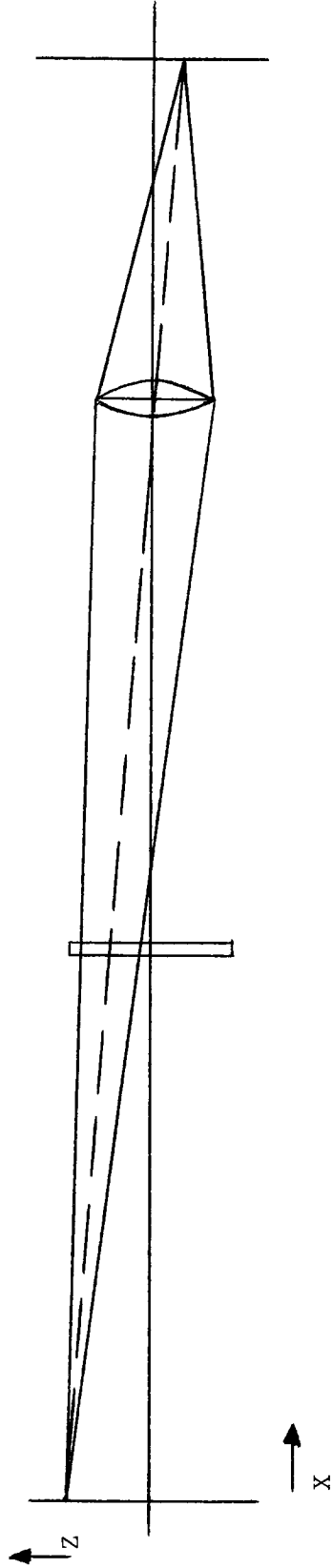


FIGURE 7 Schematic View of the XZ Plane of the Optical System



TABLE 1 Ray Trace - XY Plane

	0	1	2	3	4
$\phi$		0	(1/50)	(1/50)	
-t		-66.66	-33.33	-100.00	-66.66
y	9	0	-4.5	-9.0	0 ) Axial
u		+.135	.135	.045	) Ray
y	0	1	1.5	0	1.0 ) Principle
u		-.015	-.015	-.015	) Ray
y	-9	1	6	-9.0	-1.0 ) Upper
u		-.15	-.15	-.03	) Rim Ray
y	9	1	-3.0	-9.0	-1.0 ) Lower
u		.120	.120	.06	) Rim Ray

TABLE 2 Ray Trace - XZ Plane

	0	1	2	3	4
$\phi$		0	0	(1/50)	
-t		-66.66	-33.33	-100.00	-66.66
y	0	3.66	5.5	11	0 ) Axial
u		-.055	-.055	-.055	.165 ) Ray
y	15	10	7.5	0	-5 ) Principle
u		.075	.075	.075	.075 ) Ray
y	15	13.66	13	11	-5 ) Upper
u		.02	.02	.02	.240 ) Rim Ray
y	15	6.33	2	-11	-5 ) Lower
u		.130	.130	.130	-.09 ) Rim Ray

$t$  is the thickness of the beamsplitter and  $n$  is the index of refraction. In this case, where the beamsplitter is 40mm thick with  $n = 1.52$ ,

$$d = 40\text{mm} (1 - 1/1.52) = 13.68\text{mm}.$$

Figure 8 shows the distances between elements with the beamsplitter in the path.

The camera objective is a Kodak 50mm,  $f/1.9$  Ektar lens and was stopped down to  $f/2.3$  to provide a numerical aperture of 0.16 at a magnification of 0.333. The cylinder lens has a 50mm focal length, is of plano-convex bending and has dimensions of 63.5mm (length) x 25.4mm (height) x 3mm (center thickness).

#### B. Mechanical Considerations

The film transport mechanism which houses the objective lens was intended by Palum to be positioned vertically in his version of the MTF camera. Since the main frame of Palum's camera was never constructed, the optical design was tested horizontally on an optical bench. This required that a suitable mount be fabricated for the transport mechanism. Also required, since it was not feasible to use the standard mounts of the optical bench, was the design and construction of a support system for the beamsplitter, cylinder lens, field stop and target. The support system consists of an aluminum table onto which the elements are attached. Two slots were milled in the table, parallel to the optical-axis, so that when the beamsplitter, cylinder lens and field stop are mounted with thumbscrews through the table, their positions along the optical axis can easily be adjusted. The table was designed large enough to accommodate the exposing sources. This system, along with the film

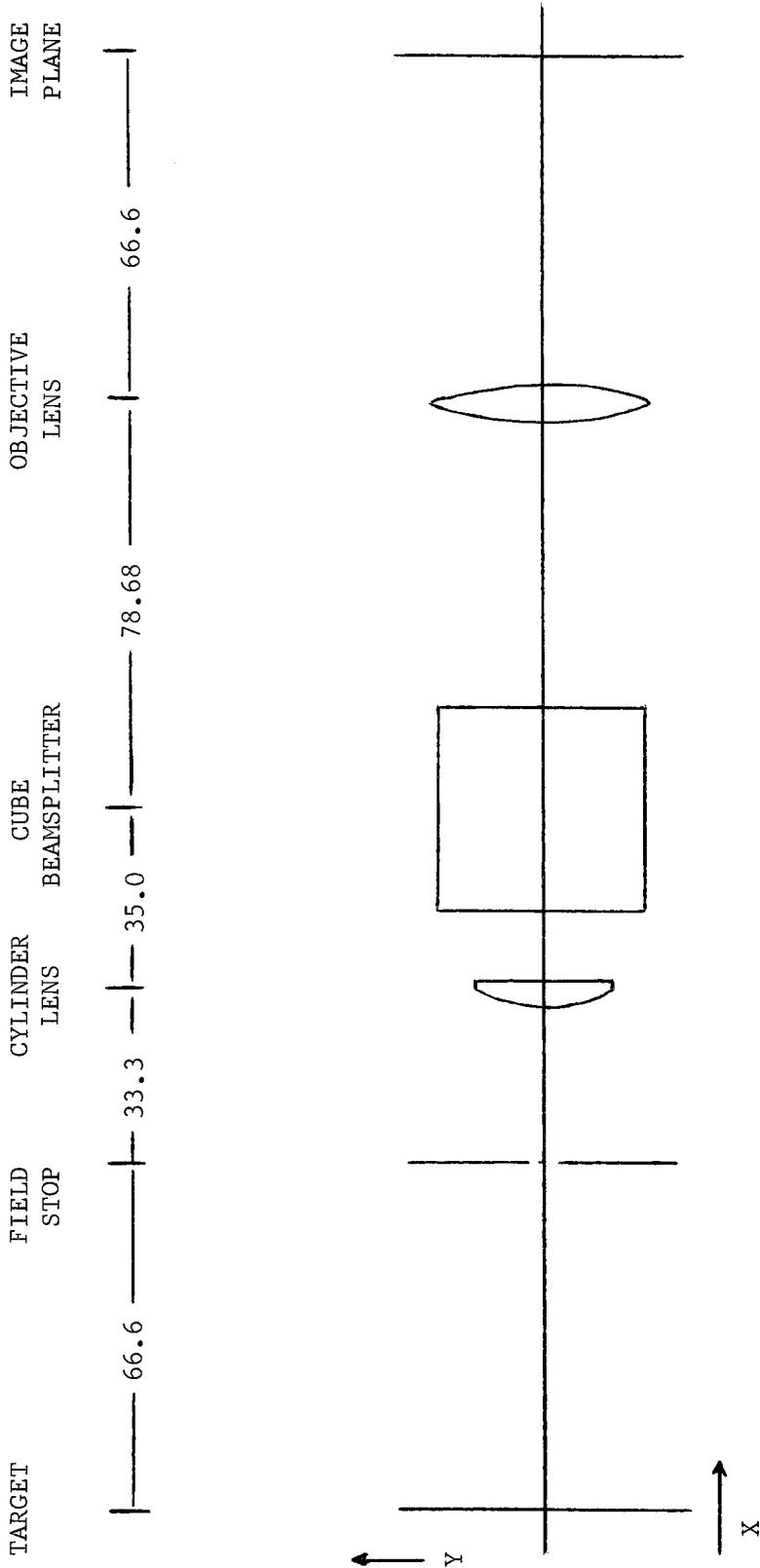


FIGURE 8 Schematic View of the XY Plane with the Beamsplitter

transport mount are illustrated in Figure 9, shown as they would normally be positioned together. The beamsplitter, cylinder lens and field stop were each mounted separately in carriers that were also fabricated. Details of these appear in Figure 10.

It was desirable to have the target mounted so that it could be easily and repeatably focused for testing purposes. This was accomplished by connecting a 2 x 2 inch slide holder to a micrometer slide. The slide holder protrudes up through a rectangular hole cut in the table.

All fabrication work was done by Mr. Richard Norman of the Rochester Institute of Technology.

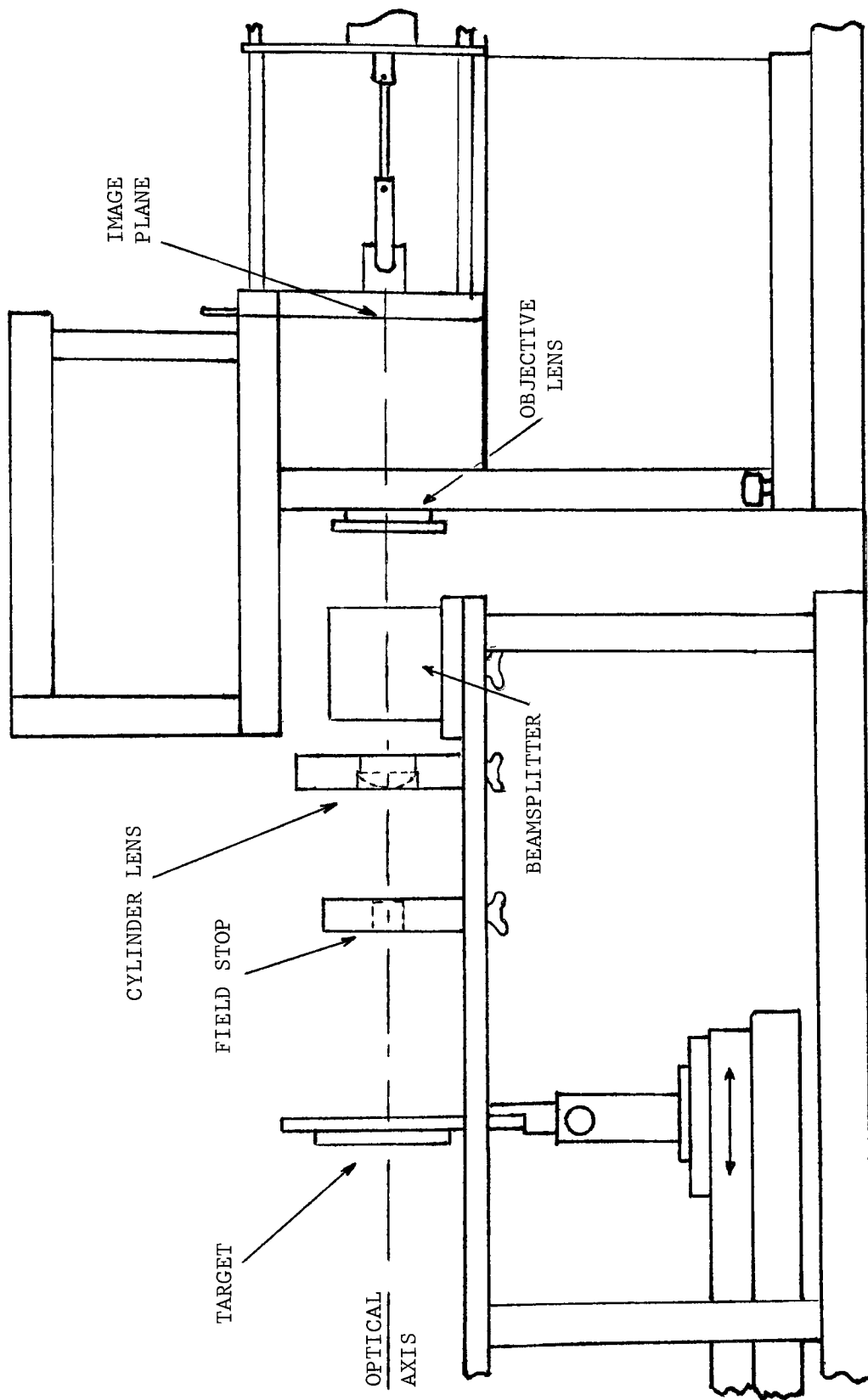
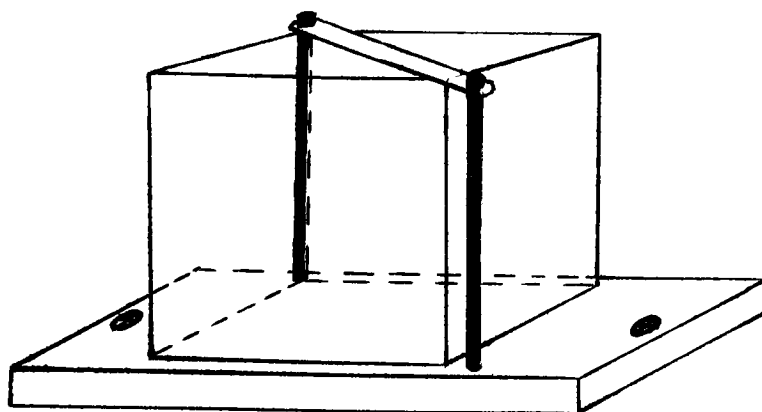
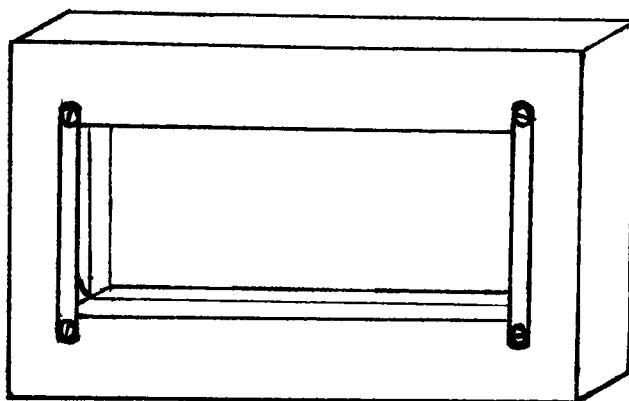


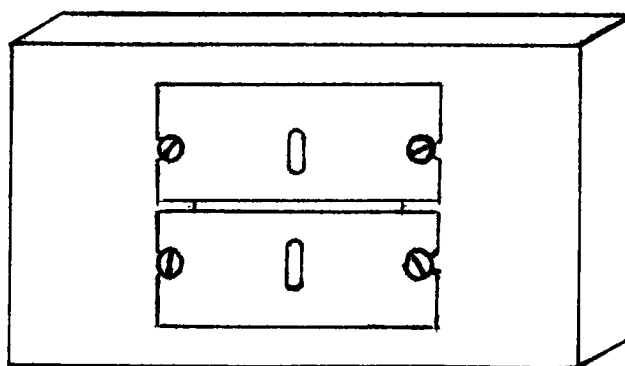
FIGURE 9 Mount for the Film Transport Mechanism and the Support System for the Optical Elements



CUBE BEAMSPLITTER



CYLINDER LENS



FIELD STOP

FIGURE 10 Optical Element Carriers

## SYSTEM TESTING

### A. Objective Lens

Several parameters of the objective lens were tested to insure that it would be of high enough quality for the MTF camera. The parameters tested were resolution limit, field sharpness and field flatness. A focus series of a fifteen bar resolution target imaged on and off axis was generated and then the images were viewed under a microscope and the maximum discernible frequencies were recorded. The results showed that the maximum resolution in the center of the field is about 130 cycles/mm. Off axis, the resolution drops to about 50 cycles/mm. The results also showed that the field is flat. Due to the decrease in image quality at the edges of the image field, it is apparent that only the central portion of the image field should be used for data collection. This is especially important at the higher frequencies.

### B. Repeatability

To insure the repeatability of exposure, several factors were considered. The first was illumination. The sources used in the camera are a small 25 watt tungsten lamp for the modulated beam and a small 7.5 watt tungsten lamp for the unmodulated beam. White plexiglass is used to diffuse both beams. In the modulated beam, one piece was placed directly behind the target. In the unmodulated beam, one piece was placed at the source and another was placed a few centimeters from the



beamsplitter. Each source was adjusted to give even illumination across the image plane. To minimize stray light and reflections, a hood was constructed to cover the optical elements and several surfaces were blackened. There was no significant difference in illumination between exposures. Figure 11 shows an example of a scan of an image produced by an evenly illuminated field and Figure 12 shows the effects of uneven illumination across the field.

Another possible source of variability was the film pressure plate. For repeatable exposures, the pressure plate must hold the film in the same plane for each exposure. The test involved comparing the micro-density scans of repeated images on the film. Analysis of the scans, however, showed a significant difference between some of the exposures. An adjustment was made to the amount of force applied to the pressure plate by a spring. The test was repeated and the results showed no significant difference between exposures.

Yet another factor, the focusing mechanism, was tested for variability. Several focus series of the same object were examined for differences in the microdensity scans at each focus position. Again, no significant changes occurred. It was therefore concluded that the MTF camera system is capable of producing repeatable exposures.

### C. System MTF Determination

In order to judge the performance of the system, a determination of the system's MTF was made. The film used was included within the system. Exposures at each frequency were made over a range of focus positions. The background source was adjusted to give an image modulation of about

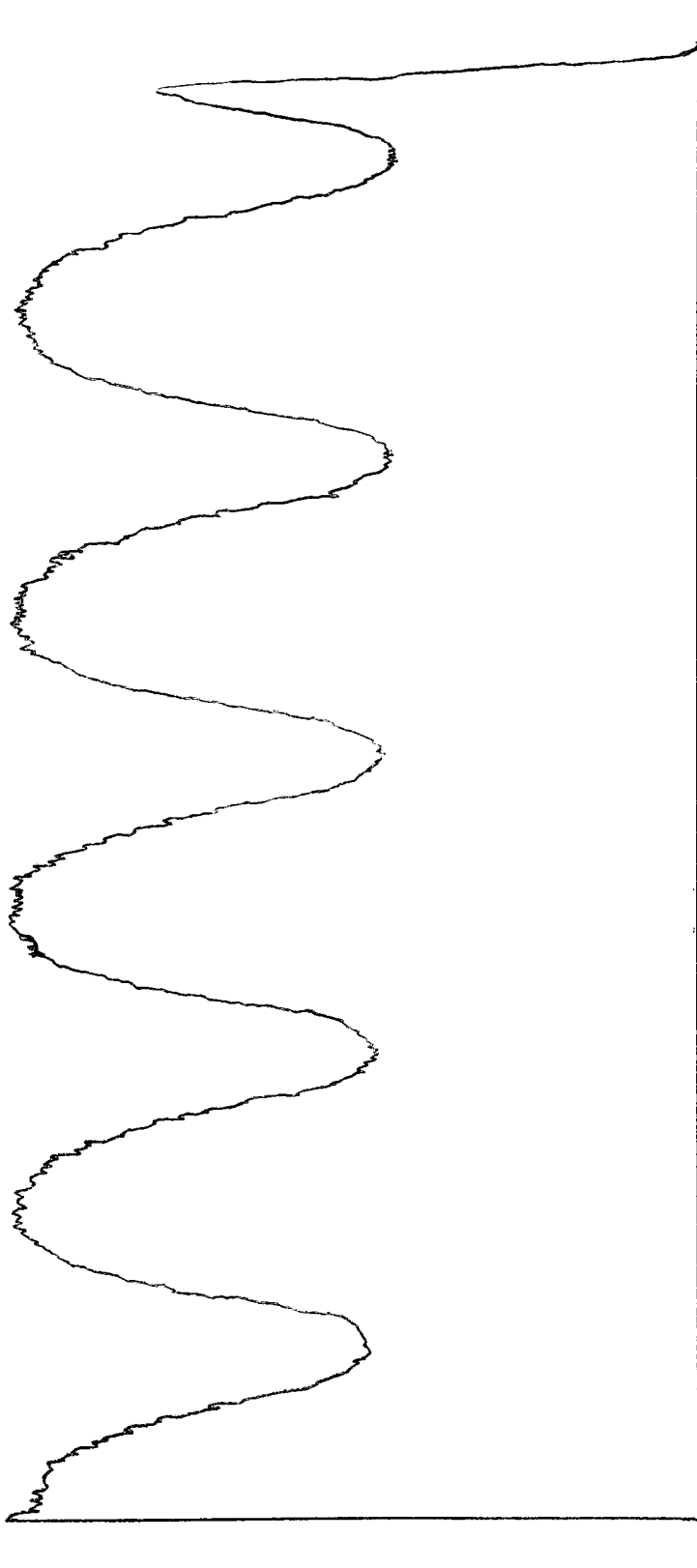


FIGURE 11 Example of a Microdensity Scan with Even Illumination

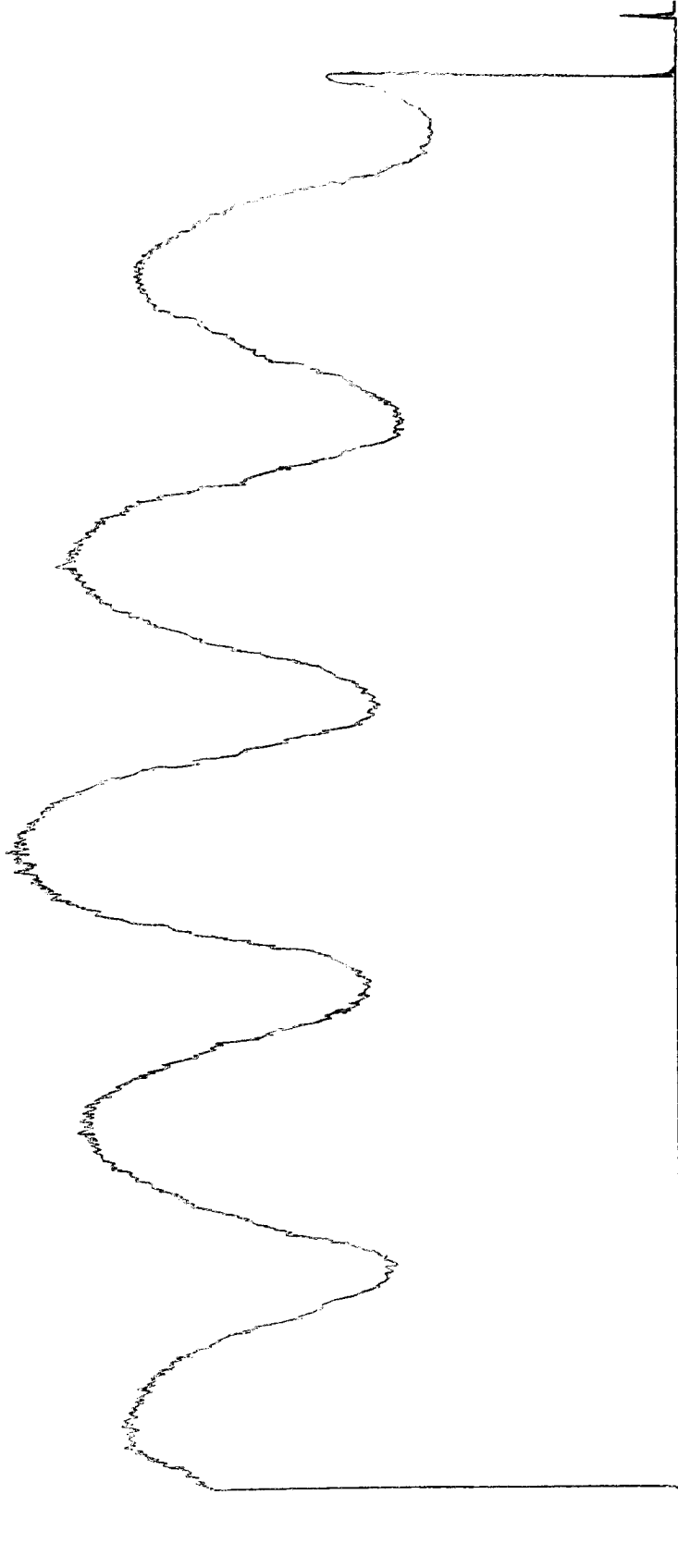


FIGURE 12 Example of a Microdensity Scan with Uneven Illumination

50 percent. Since the area-modulated sinusoidal targets are not all the same height, the distance from the main source to the target was adjusted so that the exposure for all targets remained constant. A stepped exposure was also put onto the film so that a D-logH curve could be drawn. The developed images were then scanned on a microdensitometer and their density vs. position plots were traced back through the characteristic curve of the film. From the plots of effective exposure vs. position, the values of modulation were computed, normalized and plotted as a function of spatial frequency to give the modulation transfer function for the camera and film. This technique of MTF determination is called the effective exposure method.<sup>9</sup> The MTF for the camera used with Kodak Panatomic-X film is shown in Figure 13.

The effects due to focus position are negligible for the lower frequencies, but they begin to become significant at about 8 cycles/mm. The position for best focus, and thus highest modulation, remained constant for all frequencies and dropped off on each side of this position uniformly. This spread in modulation due to focus position which is evident in the higher frequencies is also shown in Figure 13.

Only the central portion of the image field was used to collect data for the MTF, but at the edges of the field, the maximum modulation value at 30 cycles/mm was found to be about 0.05. This is less than half the value taken in the center of the field.

It is important that the target be properly oriented with the cylinder lens to insure accurate sinusoidal images. If there is a rotational shift of the target, a skewed sine wave pattern will result.

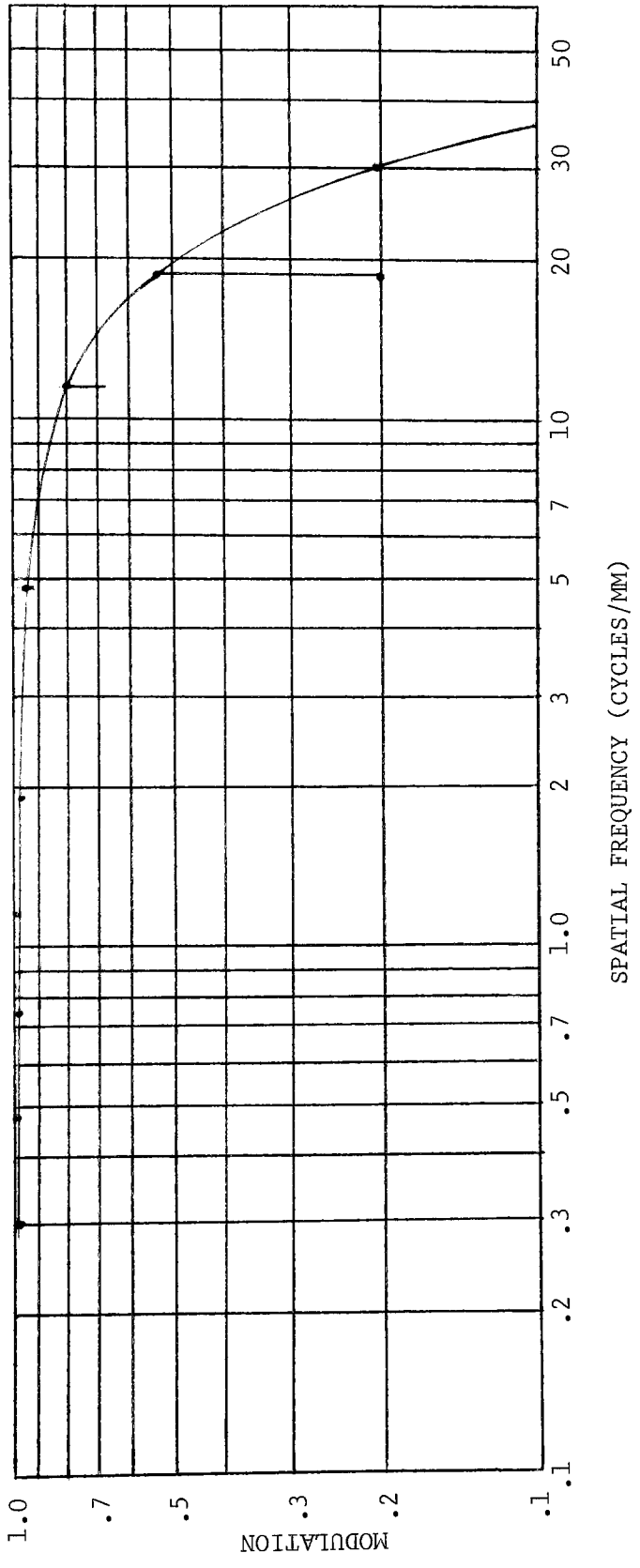
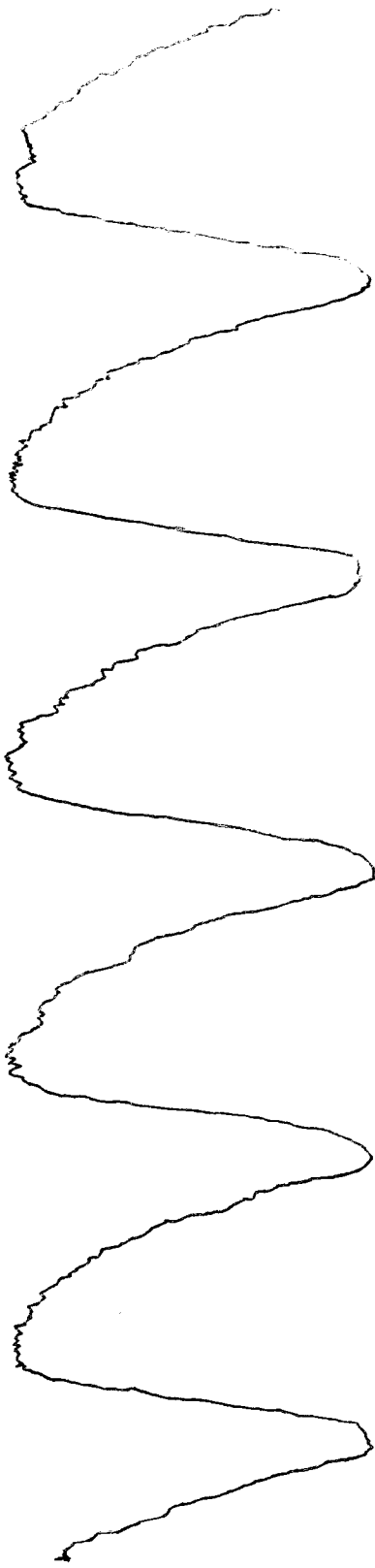


FIGURE 13 Modulation Transfer Function for the Camera and Film

This effect is shown in Figure 14.



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FIGURE 14 Effect of a Rotational Misalignment Between  
the Target and the Cylinder Lens

## CONCLUSIONS

The test results showed that the MTF camera is capable of imaging high quality sinusoidal images onto film. Due to the drop off in image quality at the edges of the image field, only the central portion of the image field should be used for data collection. The camera system with film was found to have an MTF value close to 1.0 for frequencies up to 10 cycles/mm at which point the function drops off to a value of 0.2 at 30 cycles/mm. Off axis, the maximum MTF value at 30 cycles/mm was about 0.05.



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